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Midwestern Regional Carbon Sequestration Partnership (MRCSP) Phase III (Development Phase)




# Life Cycle Analysis of Greenhouse Gas Emissions for the Niagaran Reef Complex $CO_2$-EOR Operations

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# Acronyms and Abbreviations

| | |
|---|---|
| CCS | Carbon capture and storage |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | $CO_2$ equivalent |
| DOE | U.S. Department of Energy |
| EOR | Enhanced oil recovery |
| EPA | U.S. Environmental Protection Agency |
| kg | Kilogram |
| kWh | Kilowatt-hour |
| LCA | Life cycle analysis |
| MCF | Thousand cubic foot |
| MMCF | Million cubic foot |
| MPa | Megapascal |
| MRCSP | Midwest Regional Carbon Sequestration Partnership |
| MT | Metric ton |
| NETL | National Energy Technology Laboratory |
| NNPRT | Northern Niagaran Pinnacle Reef Trend |
| PCOR | Plains $CO_2$ Reduction (Partnership) |
| psi | Pounds per square inch |

# 1.0 $CO_2$-EOR Life Cycle Analysis

## 1.1 Introduction

A greenhouse gas emissions life cycle analysis (LCA) was completed for 22 years of carbon dioxide-enhanced oil recovery ($CO_2$-EOR) operations at the Niagaran reef complex in the northern Michigan Basin based on research by the Midwest Regional Carbon Sequestration Partnership (MRCSP). The objective of the greenhouse gas LCA was to account for the total greenhouse gas emissions generated through the $CO_2$-EOR process. Methane produced from the 300- to 500-meter-deep Antrim shale has $CO_2$ content ranging from 5 percent to 30 percent. Therefore, the produced gas stream is gathered outside of Gaylord, Michigan, at the Chester 10 central gas processing plant, and run through an amine-based $CO_2$ separation process to remove the $CO_2$ so the methane can be sold to the market. The $CO_2$ is periodically dehydrated, compressed, and transported via pipeline for $CO_2$-EOR in nearby 5,000- to 6,500-foot (1500-2000 m) deep carbonate Niagaran reefs. The produced mixture of oil, water, and $CO_2$ is separated at the Dover 36 oil processing facility. The processed $CO_2$ is recycled to the reefs for $CO_2$-EOR in a closed loop system. During this process, a portion of the $CO_2$ remains permanently stored in the reefs (Figure 1).

This LCA was based on operations data for $CO_2$ injection, oil production, $CO_2$ recycling, compression, gas processing, dehydration, fugitive emissions, construction, produced water disposal, and well drilling. While MRCSP research on $CO_2$ storage in the Niagaran reefs started in 2013, the LCA is affected by $CO_2$ circulated through the system in previous years. Therefore, the analysis included the 22-year period of operations from 1996-2017, accounting for the expansion of the EOR complex from one reef to ten reefs. Analysis also reflects the long-term $CO_2$-EOR cycle, which may take years to pressurize a highly depleted reef before increased oil production. In addition, “45Q” incentives for $CO_2$ storage introduced by the U.S. Government in 2018 have encouraged operators to leave more $CO_2$ in the ground, which is reflected in the life-cycle $CO_2$ balance. The EOR operations were added to the existing Antrim shale gas processing facility, and the $CO_2$ separated from the methane is vented to the atmosphere when it is not used for $CO_2$-EOR. Consequently, upstream $CO_2$ capture emissions are not clearly differentiated in the LCA. Also, downstream emissions related to transport, processing, and consumption of oil products were not explicitly assessed in the LCA. Therefore, this analysis focuses on the gate-to-gate $CO_2$-EOR operations portion of the life cycle, where the initial gate is where $CO_2$ is transferred to the compression facility and the final gate is where oil is sold and transported offsite.

## 1.2 Background

$CO_2$-EOR involves injecting $CO_2$ into a depleted oil reservoir and producing the oil and $CO_2$ in nearby production wells (Norman, 1994; Melzer, 2012; IEA, 2015). The oil and $CO_2$ may then be separated and the $CO_2$ recycled back into the reservoir for additional EOR. At depths more than approximately 800 meters, the pressure-temperature conditions result in a miscible $CO_2$ flood, where the $CO_2$ is in a supercritical fluid phase. Therefore, the $CO_2$ must be compressed to supercritical pressures for subsurface injection, generally more than 7 megapascals (MPa) (approximately 1,000 pounds per square inch [psi]). The $CO_2$ can mobilize residual oil in the reservoir and facilitate additional incremental oil production.

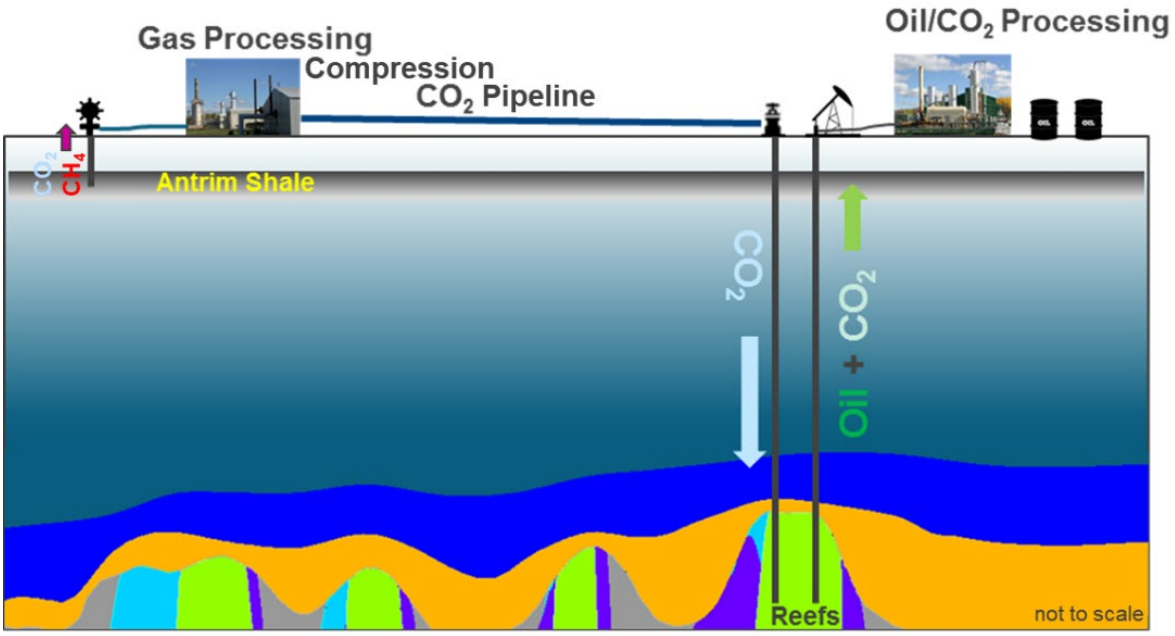



*Figure 1. Diagram illustrating the $CO_2$-EOR process at the Niagaran reef complex.*

Large-scale $CO_2$-EOR has been applied at many fields, such as in the Permian Basin in Texas, Louisiana, and in the west-central United States where $CO_2$ sourced from natural $CO_2$ fields is accessible via pipelines. While $CO_2$-EOR is not as common in the Midwest United States, where $CO_2$ is not as readily available, a $CO_2$-EOR system has been successfully operated since 1996 in Otsego County, Michigan, producing over 2 million barrels of oil.

In terms of life cycle analysis of greenhouse gas emissions, the $CO_2$-EOR system has several components that may produce emissions including upstream, gate-to-gate, and downstream items (Figure 2). Upstream items may include $CO_2$ capture/separation, primary gas production, construction, and $CO_2$ purification. Depending on the $CO_2$ source type, it may also include emissions from coal fired power plants, petro-chemical facilities, ethanol production, refineries, or other industrial sources of $CO_2$. Gate to gate items may include $CO_2$ compression, $CO_2$ purification/dehydration, pipeline transport, brine disposal, well drilling, oil processing, fugitive emissions, pipeline construction, facility construction, land use, artificial lift, venting/flaring, and gas separation. Downstream components may include crude oil pipeline transport, oil refining, point of sale transport, and combustion of fuel products.

There are many items to account for in greenhouse gas emissions analysis, but not all elements may be present at $CO_2$-EOR sites. For example, the Niagaran Reef $CO_2$-EOR system does not have pipeline booster pumps or $CO_2$ injection pumps, because the compression at the gas and oil processing facilities provides enough pressure for all $CO_2$ transport and injection. In addition, the $CO_2$ compressors run on natural gas, so the $CO_2$ emissions associated with compression are much less than electrical compressors running on electricity generated by coal-fired power plants. The oil-$CO_2$ separation method includes high- and low-pressure separators, which is less energy-intensive than other gas separation methods like cryogenic fractionation or refrigeration/fractionation.

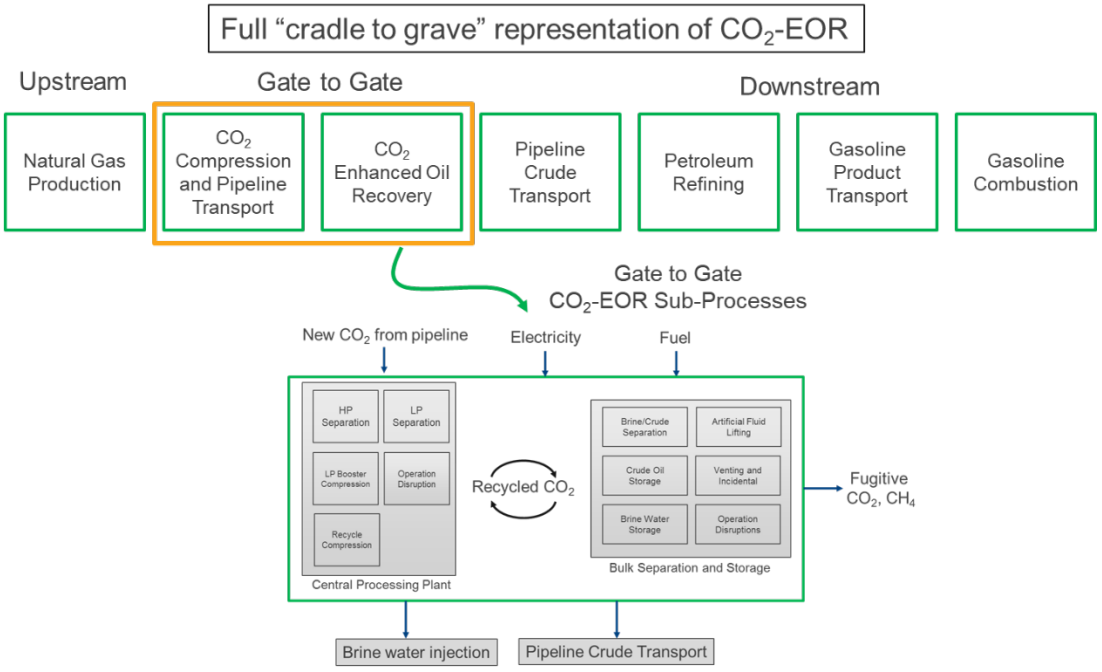



*Figure 2. Diagram illustrating "cradle to grave" upstream, gate to gate, and downstream life cycle components for the $CO_2$-EOR system.*

## 1.3 Previous Research

Several researchers have evaluated $CO_2$-EOR life cycle emissions factors to determine $CO_2$-EOR greenhouse gas emissions produced in relation to the amount of $CO_2$ permanently stored in the reservoir. Aycaguer (2001) examined life-cycle emissions for a 'Permian Basin of West Texas' $CO_2$-EOR scenario based on available emission unit factors from the petroleum industry and the U.S. Environmental Protection Agency (EPA). Suebsiri et al. (2006) analyzed life-cycle aspects of the Weyburn field based on economic optimization and sensitivity analysis. Khoo & Tan (2006) examined the life-cycle environmental effects of $CO_2$-EOR. Jaramillo et al. (2009) calculated emission factors for $CO_2$-EOR versus other conventional oil production and electricity generation. Manuilova et al. (2014) completed a LCA of post-combustion capture and $CO_2$-EOR for the Boundary Dam Project. The IEA examined the potential for industry to reduce net $CO_2$ emissions on large scales (Nagabhushan & Waltzer, 2015). The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) developed a parameterized model to evaluate different $CO_2$-EOR scenarios (Cooney et al., 2015; Skone, 2015). Nuñez-Lopez (2017) presented options for net carbon negative oil classification based on carbon LCA of $CO_2$-EOR. Azzolina et al. (2017) completed a LCA of incremental oil produced via $CO_2$-EOR.

This research differs from other LCA research in that it is based on site-specific facility operations for 22 years. Most other $CO_2$-EOR LCA's are based on unit process information rather than actual facility records over a long period of time. The input for this LCA included fundamental data like facility electricity bills, natural gas usage, $CO_2$ metering, and number of wells drilled for the EOR system.

There are some limitations to the analysis. The $CO_2$-EOR system operations started in 1996. Records on facility natural gas and electricity usage were not available for 1996-2010. Fugitive emissions were only recently tracked for EPA greenhouse gas program requirements. Consequently, fugitive emissions, facility electricity usage, and facility gas usage for the

1996-2010 time period were based on average trends in $CO_2$ processed in more recent years. Overall, system records showed a consistent usage rate for electricity and methane usage on unit a basis of $CO_2$ processed for the EOR operations.

## 1.4 Niagaran Reefs and Antrim Shale Exploration and Production Activity

In the study area, Antrim shale gas fields intersect with the Niagaran oil reef trend (Grammer et al., 2008; 2018). There are several thousand gas wells in the broad Antrim field, and several hundred wells along the Northern Niagaran Pinnacle Reef Trend (NNPRT). The Antrim shale is a Devonian-age organic shale play which has been developed since the 1960s in the region (Coburn et al., 2012). The shale is present at depths of approximately 1,000 to 1,600 ft (300 to 500 meters) in the study area. The formation can be up to 800 ft (240 meters) thick and composed of fractured shales; the formation is eroded toward the north by glacial activity. The Antrim shales produce methane gas with 5 percent to 30 percent $CO_2$ component; $CO_2$ content tends to increase with time (Goodman & Maness, 2008). Antrim production became increasingly active in the 1980s, when federal incentives were created to encourage production in unconventional shale and tight reservoirs (Coburn, 2011). Methane gas and $CO_2$ were produced. The $CO_2$ content in produced gas increased toward the end of an Antrim well life cycle as methane was depleted and more $CO_2$ desorbed from the organic shales. The greatest amount of $CO_2$ produced was also located in Otsego and Montmorency counties where there were both high gas production volumes and high $CO_2$ content. Production of methane gas was most successful in Otsego and Montmorency counties in Michigan.

The NNPRT is made up of several hundred discrete reefs at depths of approximately 4,000 to 7,000 feet (1,200 to 2,100 meters) (Burgess & Benson, 1969; Huh et al., 1977). Each individual reef may be up to several hundred hectares in size with a complex hydrocarbon and reservoir distribution. The NNPRT (or, Brown Niagaran reefs) was the largest oil and gas play in Michigan. The play became active in the late 1960s and continues to be a major play to date (Barnes et al., 2013). Many depleted reefs have also been converted into gas storage fields.

The EOR system takes advantage of the $CO_2$ available from the Chester 10 central gas processing facility located about 20 kilometers from the operator's Niagaran oil fields. In this gas processing facility, $CO_2$ is separated from the gas stream with an amine capture system. The captured $CO_2$ is transferred to Core Energy's main compression facility located at the Chester 10 facility, but the compressors are run only when new $CO_2$ is required for the EOR operations. Otherwise, $CO_2$ is vented to the atmosphere. The Dover 36 oil processing facility was constructed in 1992, and the $CO_2$-EOR operations began in 1996 at the Dover 33 reef, expanding to ten individual reefs through 2017. Reefs selected for $CO_2$-EOR were injected with $CO_2$ until the reefs met minimum miscibility pressure. Once pressurized, the reefs are put in regular EOR operation mode to recover more oil. Because the reefs are contained structures capable of maintaining pressure, each individual reef in the $CO_2$-EOR system generally includes only one or two injection wells and two to three production wells. Figure 3 illustrates the ten reefs in the Michigan Basin site and the associated production timeline.

## 1.0 $CO_2$-EOR Life Cycle Analysis

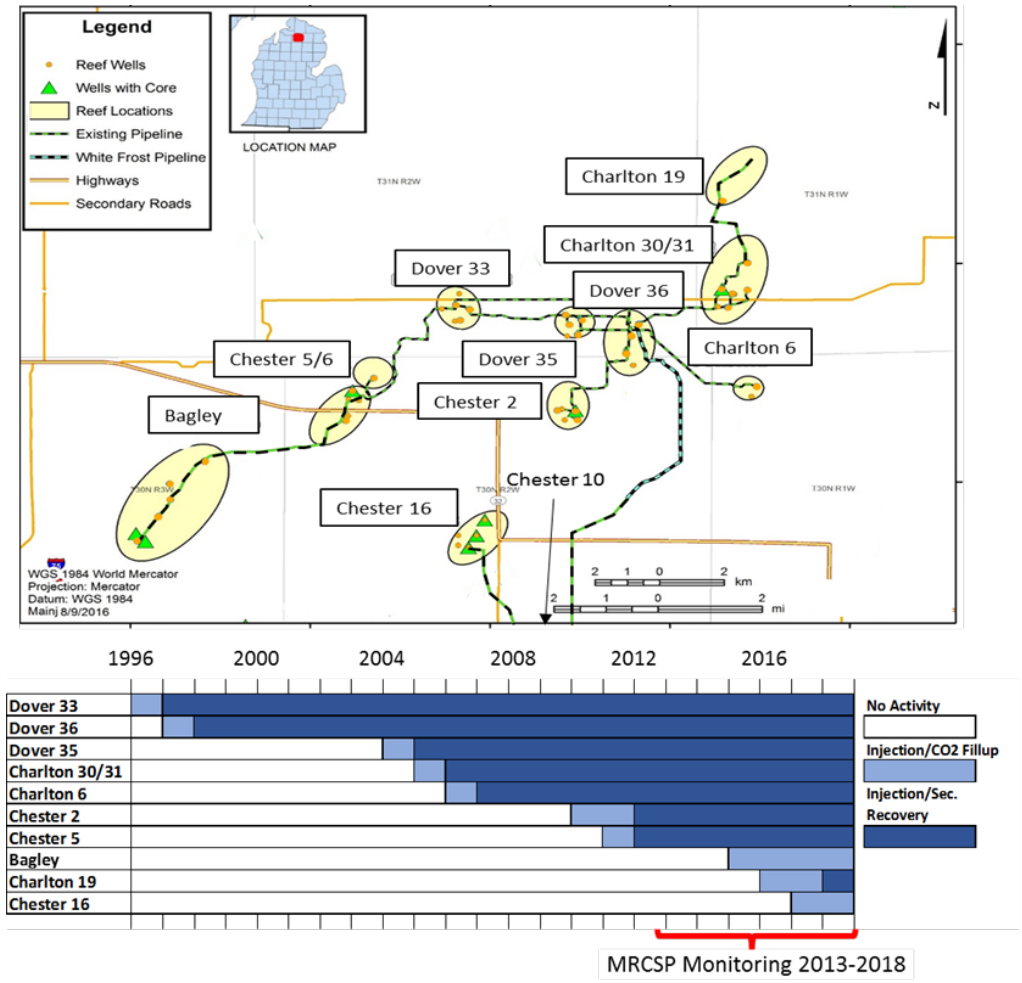



*Figure 3. Map showing the Niagaran reefs in the $CO_2$-EOR system and timeline of EOR operations.*

# 2.0 Methods

Information on gate-to-gate $CO_2$-EOR operations, $CO_2$ flow metering, and monitoring was integrated into an LCA framework to calculate greenhouse gas emission factors and net $CO_2$ balance. The methods emphasized including site-specific data where possible.

## 2.1 $CO_2$-EOR Operations, Metering, and Monitoring

The gate-to-gate $CO_2$-EOR system is set up with a series of flow meters to measure $CO_2$ flow, oil production, and recycled $CO_2$ gas. Coriolis mass flow meters installed on injection wells measure mass flow rate, daily injected quantities, temperature, and density of $CO_2$ (Figure 4). High-pressure and low-pressure oil-gas separators monitor the quantity of produced gas, which is recycled back into the reefs. A Coriolis flow meter also measures the quantity of pure $CO_2$ captured at the Chester 10 natural gas-processing facility. Once recycled gas is dehydrated and recompressed, the total quantity of recycled $CO_2$ is also measured by a Coriolis flow meter.

To track production flow rates, Coriolis flow meters are installed to record the quantity of gas produced at the high-pressure separators where the bulk recycle gas is captured. Vortex flow meters are installed at the low-pressure separators to measure gas produced prior to recycling. Occasional process outages result in forced venting of gas, and the dry and wet vents at the Dover 36 facility are metered to measure the quantity of gas being vented. A supervisory control and data acquisition system records production data from all flow meters is attached to the injection, production, and recycling operations.

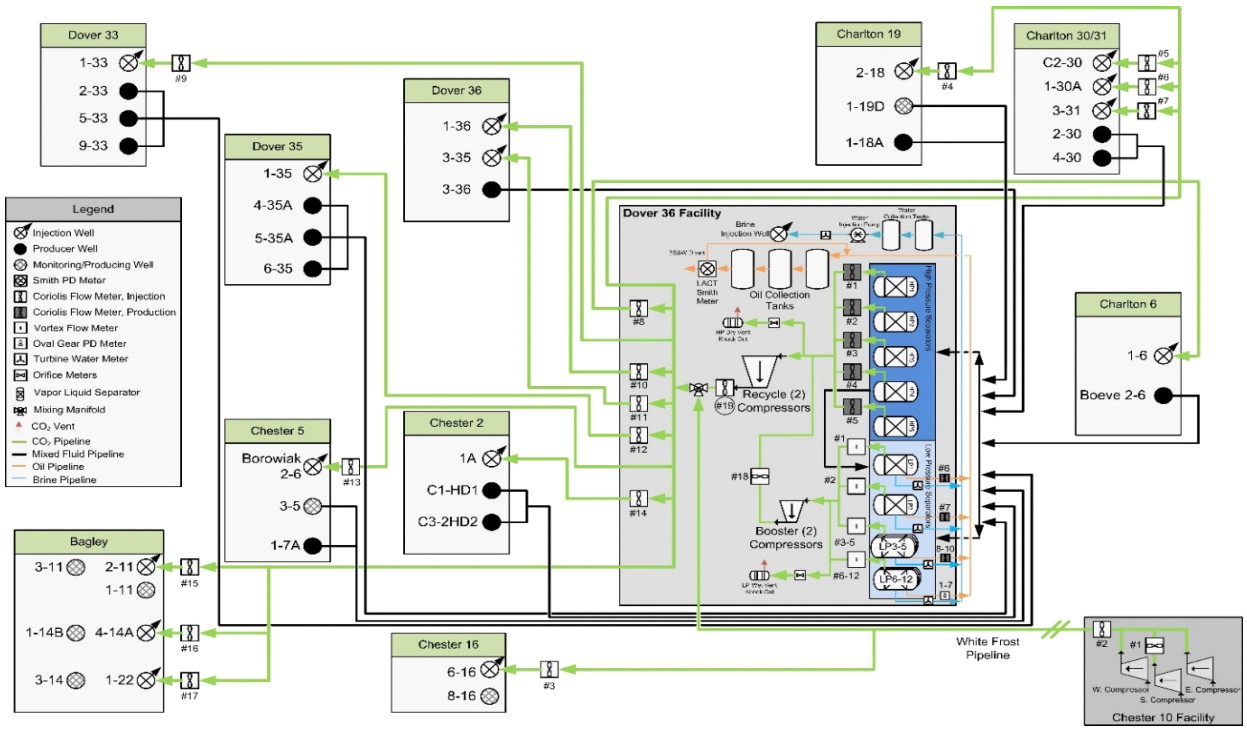



*Figure 4. System diagram illustrating $CO_2$ flow metering across the $CO_2$-EOR system.*

Together, these meters provide a comprehensive account of the $CO_2$ moving through EOR system operations (Pasumarti et al., 2016). Operational data were used to calculate the mass of $CO_2$ obtained from the gas processing facility, mass of $CO_2$ produced with oil, $CO_2$ recycled, and $CO_2$ injected into the reservoirs. Metering data were used to estimate cumulative net $CO_2$ stored associated with the EOR operations (Mawalkar et al., 2018). Methods for calculating the net $CO_2$ storage for the EOR system were based on work completed at DOE Carbon Storage partnership sites (Choi et al., 2013), NETL guidance (DOE-NETL, 2010a; 2011; 2012), EPA regulations (EPA, 2010), and other research (Hovorka, 2010; ARI, 2010). These calculations determine how much $CO_2$ remains in the reservoirs based on the net balance. With 22 years of operations across ten reefs, the $CO_2$-EOR accounting reflects changes in the system as reefs become highly depleted and $CO_2$ is transferred to new reefs to reach miscible pressures. $CO_2$ flow data were based on system metering as of August 2018.

In addition to system metering, various monitoring methods were applied at the $CO_2$-EOR reef complex to investigate the distribution of $CO_2$ in the reefs and assess the potential for leakage (Gupta et al., 2013; 2014). Reservoir zone monitoring included downhole pressure monitoring, distributed temperature sensors, distributed acoustic sensors, vertical seismic profiles, pulsed neutron capture wireline logging, geochemical fluid/gas sampling, borehole gravity surveys, and microseismic monitoring (Kelley, 2014). Near-surface monitoring included satellite monitoring. Overall, the monitoring program confirmed the storage capacity and security of the Niagaran reef reservoirs. While the internal geology of the reefs may be complex, the reefs are isolated structures that demonstrate the ability to contain pressure, fluids, and gases over geologic time periods. Therefore, there is minimal potential for leakage from the reservoirs.

## 2.2 LCA Framework

Many researchers have presented methodologies and frameworks for LCA of greenhouse gas emissions for $CO_2$-EOR operations and many of these studies focused on a general or unit-basis evaluation of the net $CO_2$ emission balance for the types of systems that produce oil and sequester $CO_2$ at the same time. The objective of this study was to complete a site-specific LCA of a $CO_2$-EOR system that has been operating for 22 years rather than develop an LCA methodology. Consequently, the $CO_2$-EOR greenhouse gas LCA model developed by the Plains $CO_2$ Reduction (PCOR) Partnership under the DOE-NETL carbon storage partnership program was employed to calculate greenhouse gas emissions factors and net $CO_2$ balance (Azzolina et al. (2016)). The model is spreadsheet-based and allows users to input their own site-specific values for analyzing $CO_2$-EOR applications.

The PCOR model includes segments for upstream, gate-to-gate, and downstream components of a $CO_2$-EOR system. The framework is a spreadsheet format with a list of over 200 items related to sources of greenhouse gas emissions from $CO_2$-EOR operations. Pre-assigned unit calculations are included for many emission factors based on other $CO_2$-EOR systems and research. The model addresses both operational and embodied emissions but does not differentiate between the types of emissions in the results. The PCOR model was designed to address $CO_2$ captured from a coal-fired power plant and processing of oil/gas/natural gas liquid mixtures in the $CO_2$-EOR system. Consequently, there were several significant differences in the Niagaran reef $CO_2$-EOR operations and the PCOR framework:

- Compression was modified to account for natural gas-fired compressors instead of electric compressors that source electricity from coal-fired power plant.

- Oil/gas processing was modified to account for the series of high- and low-pressure separators used at the site, instead of more resource-intensive Ryan-Holmes, fractionation, or membrane gas processing processes.
- Separate calculations were used for $CO_2$ capture from the gas processing plant, since the natural gas $CO_2$ stripping is a much different capture process compared to post-combustion capture from a coal-fired power plant. The PCOR model only has options for $CO_2$ captured from coal-fired power plants.

These three items resulted in the largest reductions in the greenhouse gas emissions calculations. In addition to these large changes, site-specific inputs were made in place of general unit emission factors. For example, the fugitive emissions related to venting of methane at the oil processing facility were based on EPA Greenhouse Gas Report, subpart W, calculations for petroleum and natural gas systems rather than a general unit value per barrel of oil. Many of the unit processes were included together in total facility electricity and natural gas usage records, similar to a utility bill for a home or business. Items like new wells drilled for $CO_2$-EOR operations were based on operator records and well permits.

Input was assigned for each year of operations from 1996-2017, for a total of 22 different yearly sheets in the model. Total emissions were then summed to evaluate the net emission factors and $CO_2$ balance. In the end, most of the model is simple multiplication and addition of the $CO_2$-equivalent emissions for the various items. Much of the challenge in the LCA is ensuring that accurate values are assigned to the model. As discussed in Section 3.0 through Section 5.0, the analysis revealed how the life-cycle greenhouse gas emissions factors can vary over time as $CO_2$-EOR operations expand to additional oil fields. Figure 5 summarizes the $CO_2$ flow distribution over the 22 years of operations with 2.2 million metric tonnes net $CO_2$ storage in the reef complex. As shown, EOR was expanded from one reef to a total of ten reefs.

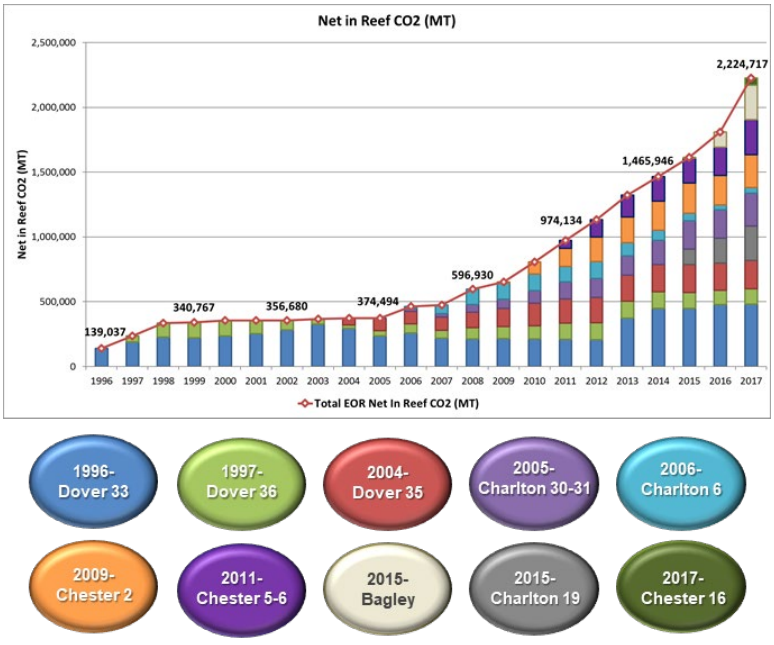



*Figure 5. Graph showing timeline of $CO_2$ flow and oil production for the Niagaran reef EOR complex (net $CO_2$ as of 2018).*

# 3.0 Input Data

This analysis focused on inputting a robust input data set from site-specific operations at the Niagaran reef $CO_2$-EOR complex. $CO_2$ flow rates and oil production were key input data for the analysis. However, many other aspects factor into the total greenhouse gas footprint of the operations.

## 3.1 LCA Boundaries

An important part of the $CO_2$-EOR greenhouse gas LCA is definition of system boundaries. Figure 6 summarizes the operational boundaries designated for the Niagaran reef $CO_2$-EOR greenhouse gas LCA. The analysis was divided into upstream, gate-to-gate, and downstream operations and related components.

### 3.1.1 Upstream

The upstream component was assigned as gas processing of the Antrim shale gas stream at the Chester 10 central gas processing facility. This facility collects natural gas from several hundred Antrim shale gas wells and strips out the $CO_2$ from the gas stream. The upstream component included an amine capture process with a multi-stage stripper tower and steam regenerator tower. The capture process is powered by a portion of the natural gas stream collected at the facility in a complex gathering, processing, and accounting system that collects gas from more than 500 wells. Input was based on facility records for energy usage associated with the capture towers. Only the gas directed to the $CO_2$-EOR system was included in the upstream analysis. The Antrim shale gas wells were not included in the upstream component, because they were not drilled for $CO_2$ production; the $CO_2$ is more of an impurity in the Antrim gas production. If the $CO_2$ is not used for EOR, it is vented to the atmosphere from the Chester 10 capture towers.

### 3.1.2 Gate to Gate

The gate to gate component was defined as all of the individual operations from $CO_2$ dehydration and compression at the Chester 10 facility to the oil tanks located at the Dover 36 facility. $CO_2$ is supplied at 0.14 MPa (20 psi) to the compression facility and managed solely by the operator for EOR operations from that point. Major processes and related components include $CO_2$ dehydration and compression, pipeline transport, injection wells, producer wells, return product/fluid pipelines, oil/$CO_2$ processing at low-pressure/high-pressure separators, dehydration, recycle gas compression, wastewater disposal in an injection well, facility/well construction, and land use.

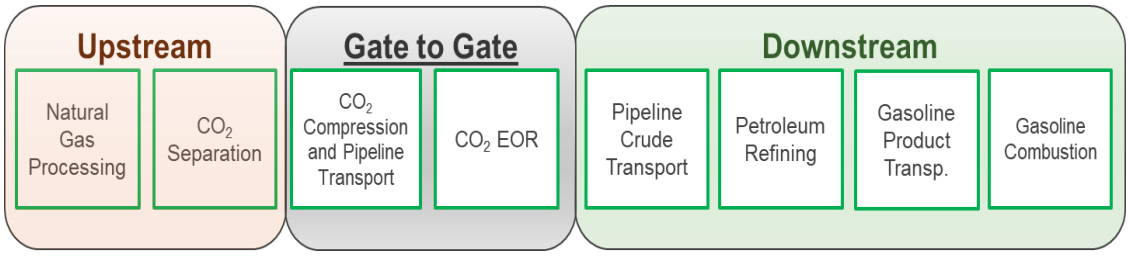



*Figure 6. Diagram illustrating upstream, gate-to-gate, and downstream boundaries of the $CO_2$-EOR system.*

### 3.1.3 Downstream

The downstream component included oil transport, refining, transport to point of sale, and combustion. Input metrics for the downstream items were retained from the PCOR $CO_2$-EOR model. In general, the oil produced from the site is transported to refineries in the state for production of fuel products.

## 3.2 Input Data

The life cycle model includes a list of over 200 items to account for the various processes in $CO_2$-EOR operations that may contribute to greenhouse gas emissions. The 22 years of operations resulted in a considerable amount of data input into the model. Figure 7 shows gate-to-gate input data for 2017, illustrating the amount of data input into the model. Natural gas usage is a major component of the operations for $CO_2$ compression, $CO_2$ capture, and oil processing. Electricity usage, fugitive emissions, and land-use/construction also have a significant impact on greenhouse gas emission factors. A large amount of natural gas is combusted to run the Chester 10 compressors to pressurize the $CO_2$ to approximately 7 to 8 MPa (approximately 1,000 to 1,200 psi), and these compressors are run continuously when new $CO_2$ is supplied to the EOR system. Additional compression is supplied at the Dover 36 facility. However, this compression is adequate for pipeline transport and injection, so no additional pipeline booster or injection pumps are necessary.

Table 1 lists the 2017 data input into the $CO_2$-EOR LCA model. The model provides both emission factors and total $CO_2$ equivalent ($CO_2e$) emission mass for the various activities, where $CO_2e$ is the carbon dioxide unit equivalent for all contributions to greenhouse gas emissions. Data for the full 1996-2017 time period are provided in Appendix A.

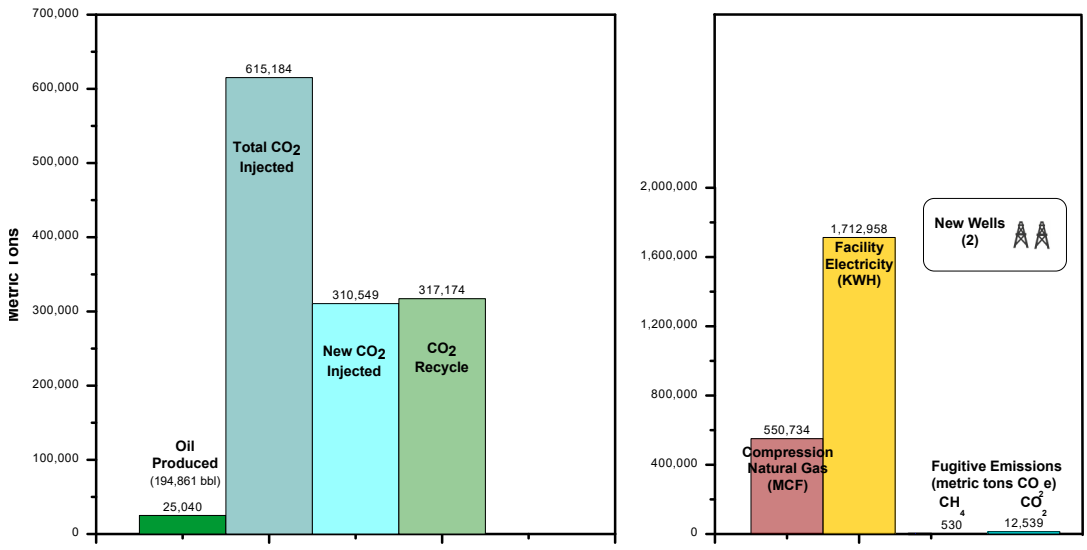



*Figure 7. Chart illustrating 2017 gate-to-gate inputs for the Niagaran reef $CO_2$-EOR operations.*

## 3.0 Input Data

**Table 1. Summary of 2017 LCA input data for Niagaran reef $CO_2$-EOR operations.**

| Parameter Description | Source | Basis | | Units |
|---|---|---|---|---|
| $CO_2$-EOR project duration | 2017 data | Monthly operating data | 1 | yr |
| **Upstream $CO_2$ Capture at Gas Processing Facility** | | | | |
| $CO_2$ provided for EOR operations | System Data | Based on Pure $CO_2$ from Gas Processing Plant | 310,549,000 | kg $CO_2$ |
| $CO_2$ MEA capture energy & NG steam boiler regeneration | Luis, 2016 | Capture energy and steam boiler regeneration | 4,000 | kJ/kg $CO_2$ |
| MCF nat. gas combusted per metric tonne $CO_2$ captured | Derived | Based on operational data from gas proc. facility | 4 | MCF |
| Emissions from capture | Derived | Pure $CO_2$ * 4 MCF NG/metric ton $CO_2$ captured * 2.73 kg $CO_2$/kg NG combusted * 0.019 kg NG/SCF | 64,433,000 | kg $CO_2$ |
| **Pipeline Transport of $CO_2$** | | | | |
| Pipeline distance | System Data | GIS maps of $CO_2$ pipeline network | 90 | km |
| Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | Based on 75 kg $CO_2$/km-yr | Derived from the fugitive emissions factor for pipeline transport of $CO_2$ (leaks) & km of pipeline after API (2009); Lamb et al. (2015) | 6,750 | kg $CO_2$ / yr |
| Emissions from pipeline transport of $CO_2$ | Derived | Derived | 6,750 | kg $CO_2$ |
| **$CO_2$ EOR Operations** | | | | |
| Crude oil produced | System Data | Based on Oil Production | 194,861 | bbl crude oil |
| Crude oil density | Field oil samples | Dover 33 Oil API 43.6 | 128.5 | kg crude / bbl |
| Crude oil produced | Derived | Crude oil produced and oil density | 25,039,639 | kg crude oil |
| New $CO_2$ from Gas Processing Facility | System Data | Based on Pure $CO_2$ from Gas Processing Plant | 310,549,000 | kg $CO_2$ |
| $CO_2$ produced (recycled) | System Data | Based on System Metering | 317,174,000 | kg $CO_2$ |
| Total $CO_2$ injected | System Data | Based on Injection Metering | 615,184,000 | kg $CO_2$ |
| $CO_2$ stored | System Data | Based on Injection Metering | 298,010,000 | kg $CO_2$ |
| Facility electricity | System Data | Chester 10 and Dover 36 Facility electricity data | 1,712,958 | kWh |
| $CH_4$ flared | System Data | Gas Processing data from EPA GHGRR Subpart W | 530,000 | kg $CH_4$ |
| $CH_4$ flaring $CO_2$ emissions rate | Literature | NETL (2015) Oilfield Gas-Water-Oil Separation | 2.75 | $CH_4$ Emissions Factor |
| Flaring Combustion efficiency | Literature | Cooney et al. (2015) | 99% | % |
| $CO_2$ leakage rate from storage over 100-year time period | System Data | Based on reef MVA | 0.001% | % $CO_2$ stored |
| Number of New Wells for $CO_2$ EOR system | System Data | Chester 8-16, El Mac Hills 1-18A | 2 | count |
| Well footprint | Derived | Based on typical wellpad in the area (2 acres) | 10,117 | $m^2$ |
| Total footprint of all wells | Derived | Derived from the well footprint and total # of wells | 20,234 | $m^2$ |
| Land area of gas processing facility | System Data | Dover 36 and Chester 10 facility area (10 acres), distributed across 20 yrs | 40469 | $m^2$ |
| Emissions per sq. meter of repurposed land | Literature | Derived from Cooney et al. (2015) | 7.5 | kg $CO_2e$ / $m^2$ |
| EOR gas processing facility construction | Literature | From Cooney et al. (2015), distributed over 20 years | 0.0125 | kg $CO_2e$ / bbl |
| Compression direct combustion $CO_2$ emissions | System Data | Combustion data from EPA GHGRR Subpart C | 29,136,000 | kg $CO_2e$ |
| Gas/Oil processing fugitive $CO_2$ emissions | System Data | Gas Processing data from EPA GHGRR Subpart W | 6,591,500 | kg $CO_2e$ |

## 3.0 Input Data

| Parameter Description | Source | Basis | | Units |
|---|---|---|---|---|
| $CO_2$ emissions from $CH_4$ flaring | Derived | Derived from the kg VOC & the $CO_2$ emissions rate | 1,442,925 | kg $CO_2e$ |
| $CO_2$ emissions from gas proc. facility electricity | System Data | Derived from the MWh and the life-cycle delivered electricity emissions factor | 1,130,552 | kg $CO_2e$ |
| $CO_2$ emissions for repurposed land | Derived | Derived from the land area repurposed and the emissions per sq. meter of repurposed land | 166,100 | kg $CO_2e$ |
| $CO_2$ leakage from storage over time period | Derived | Derived from the $CO_2$ stored and the $CO_2$ leakage rate from storage | 2,980 | kg $CO_2e$ |
| Facility and well construction | Derived | Derived from the $CO_2$ emissions factor and the barrels of crude produced | 2,436 | kg $CO_2e$ |
| Compressor $CO_2$ emissions (direct to atmosphere) | System Data | EPA GHGRR Subpart C Core forms | 549 | kg $CO_2e$ |
| Emissions from $CO_2$ EOR operations | Derived | Derived | 38,473,042 | kg $CO_2e$ |
| **Downstream crude oil transport, refining, and combustion (after Azzolina et al., 2016)** | | | | |
| $CO_2$ emissions factor for crude oil transport by pipeline | Derived | Derived from $CO_2$ emissions for crude oil transport by pipeline & barrels oil produced | 4 | kg $CO_2e$/ bbl |
| Crude oil Refining | Derived | Product-weighted average emissions factor | 46 | kg $CO_2e$ / bbl |
| Fuel transport to point of sale | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | kg $CO_2e$ / bbl |
| Fuel combustion emissions factor | Derived | Jaramillo et al. (2009); EPA (2015a) | 415 | kg $CO_2e$ / bbl |
| Emissions from Downstream | Derived | Derived | 91,614,000 | kg $CO_2e$ |

MCF – Thousand cubic foot

Facility records on natural gas usage and electricity usage were not available from 1996-2010. Consequently, average values were used to estimate these input data during this time period (Table 2). Trends in energy usage suggest that these parameters follow a consistent trend based on the amount of $CO_2$ processed in the Chester 10 and Dover 36 facilities. For example, the Chester 10 compression facility used an average of 1.13 million cubic feet (MMCF) of natural gas per metric ton $CO_2$ compressed. Fugitive emissions data were available only for 2016-2017, because the EPA has required reporting greenhouse gas emissions for 'subpart C' and 'subpart W' fixed sources since 2016. Consequently, the fugitive emission data input into the model was also based on 2016-2017 data for other years. Fugitive emissions were also based on total new $CO_2$ supplied to the EOR complex. Records on $CO_2$ flow rates were provided by the operator for the full 1996-2017 time period; however, some of the older records appear less accurate than more recent system metering.

The various items contributing to the greenhouse gas emissions varied over the 22 years of EOR operations. The chart in Figure 8 shows these fields for the 22-year analysis period. As shown, much of the natural gas usage was directly proportional to the new $CO_2$ volume obtained from the Chester 10 gas processing facility when the main $CO_2$ compression is active. During periods with mainly $CO_2$ recycle (1998-2004), there was less natural gas usage because the $CO_2$ pressure is maintained, and a lesser amount of compression is required from the Dover 36 facility. From 2004-2017, more $CO_2$ was acquired from the Chester 10 gas plant as the $CO_2$-EOR operations expanded to other reefs and research on $CO_2$ storage was completed for the MRCSP.

**Table 2. Summary of estimated input data for natural gas fuel and electricity usage.**

| Year | Fuel Used Chester 10 (MCF) | Fuel Used Dover 36 Facility (MCF) | Electricity Chester 10 (KWH) | Electricity Dover 36 Facility (KWH) | Pure $CO_2$ (MT) | Recycle Gas Produced (MT) | Chester 10 Fuel/New $CO_2$ | Chester 10 Elec/New $CO_2$ | Dover36 Fuel/Recycle | Dover36 Elec/Recycle |
|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 124,631 | 0 | 502,682 | 0 | 110,238 | 0 | NA | NA | NA | NA |
| 1997 | 77,061 | 59,016 | 310,817 | 59,730 | 68,162 | 88,388 | NA | NA | NA | NA |
| 1998 | 111,658 | 135,848 | 450,356 | 137,492 | 98,763 | 203,459 | NA | NA | NA | NA |
| 1999 | 6,717 | 125,470 | 27,091 | 126,988 | 5,941 | 187,916 | NA | NA | NA | NA |
| 2000 | 17,251 | 95,955 | 69,580 | 97,116 | 15,259 | 143,711 | NA | NA | NA | NA |
| 2001 | 0 | 95,207 | 0 | 96,359 | 0 | 142,591 | NA | NA | NA | NA |
| 2002 | 752 | 90,102 | 3,032 | 91,192 | 665 | 134,945 | NA | NA | NA | NA |
| 2003 | 13,097 | 95,154 | 52,827 | 96,306 | 11,585 | 142,512 | NA | NA | NA | NA |
| 2004 | 5,345 | 101,752 | 21,559 | 102,984 | 4,728 | 152,394 | NA | NA | NA | NA |
| 2005 | 1,696 | 25,893 | 6,840 | 87,454 | 1,500 | 129,414 | NA | NA | 0.20 | NA |
| 2006 | 108,524 | 75,659 | 437,716 | 76,867 | 95,992 | 113,747 | NA | NA | 0.67 | NA |
| 2007 | 30,375 | 82,249 | 122,512 | 90,182 | 26,867 | 133,450 | NA | NA | 0.62 | NA |
| 2008 | 168,844 | 81,203 | 681,008 | 98,094 | 149,346 | 145,159 | NA | NA | 0.56 | NA |
| 2009 | 138,902 | 90,640 | 560,245 | 116,178 | 122,862 | 171,918 | NA | NA | 0.53 | NA |
| 2010 | 126,316 | 130,913 | 718,282 | 109,231 | 157,520 | 161,638 | 0.80 | NA | 0.81 | NA |
| 2011 | 219,108 | 133,995 | 633,600 | 136,969 | 174,449 | 181,942 | 1.26 | 3.63 | 0.74 | 0.75 |
| 2012 | 215,069 | 153,944 | 854,400 | 161,793 | 172,926 | 218,298 | 1.24 | 4.94 | 0.71 | 0.74 |
| 2013 | 237,297 | 184,828 | 890,400 | 177,494 | 200,802 | 276,068 | 1.18 | 4.43 | 0.67 | 0.64 |
| 2014 | 182,378 | 178,263 | 772,800 | 174,349 | 157,796 | 264,215 | 1.16 | 4.90 | 0.67 | 0.66 |
| 2015 | 193,650 | 182,738 | 813,600 | 174,029 | 165,223 | 253,278 | 1.17 | 4.92 | 0.72 | 0.69 |
| 2016 | 221,397 | 143,402 | 811,200 | 149,796 | 196,448 | 212,858 | 1.13 | 4.13 | 0.67 | 0.70 |
| 2017 | 343,547 | 207,187 | 1,540,800 | 172,158 | 310,549 | 317,174 | 1.11 | 4.96 | 0.65 | 0.54 |
| | Estimated | Estimated | Estimated | Estimated | | | | | | |
| | | | | | | Average | 1.13 | 4.56 | 0.67 | 0.68 |

MT- metric ton

## 3.0 Input Data

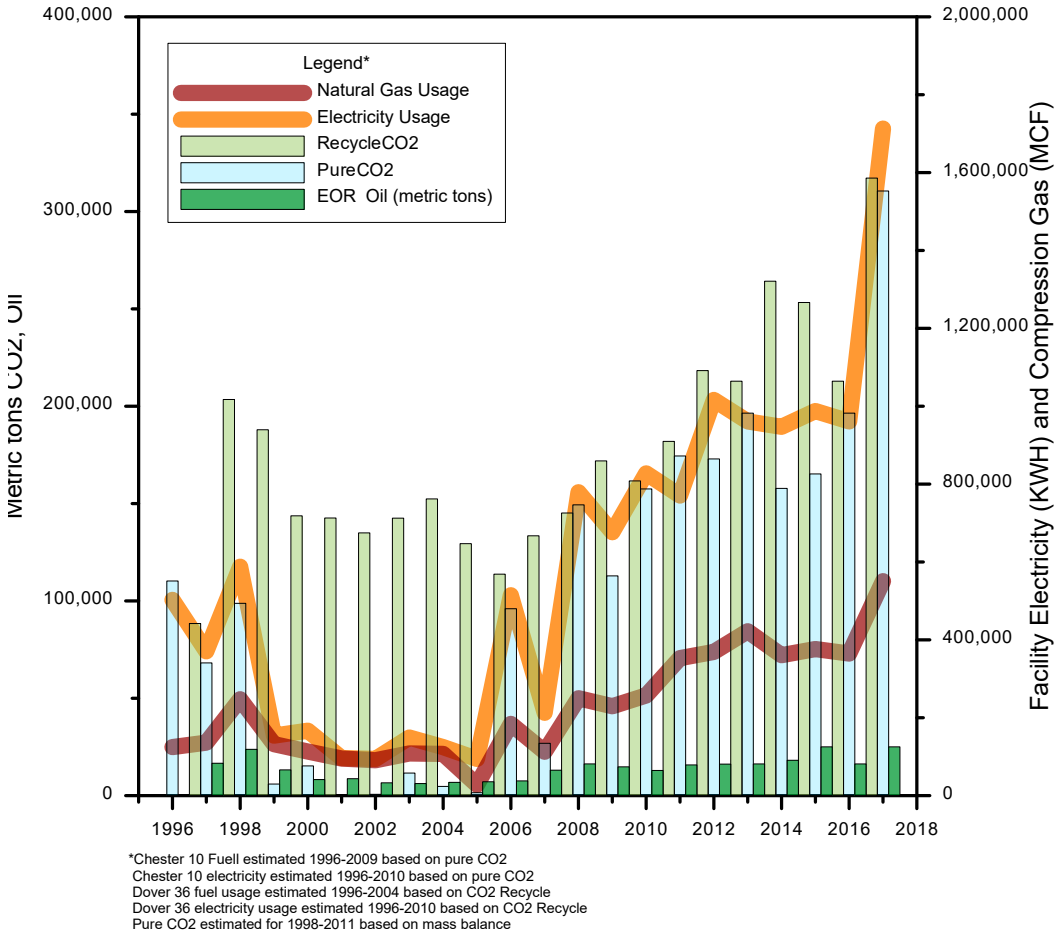



*Figure 8. Chart showing variations in greenhouse gas LCA input data for 1996-2017 for the Niagaran reef $CO_2$-EOR complex.*

The upstream capture portion of the system was limited to Chester 10 gas processing for only the new $CO_2$ supplied for EOR operations. Exploration and production activities for Antrim shale gas production were not included in the upstream component since the central gas processing facility gathers gas from several hundred Antrim wells. These wells were drilled for the purpose of natural gas production, most of the wells were drilled in the 1970s, and the wells produce various amounts of natural gas and $CO_2$. The $CO_2$ capture equipment includes a five-train $CO_2$ shrinkage system that reduces $CO_2$ content in the natural gas stream from 15% to less than 2% by volume. The system uses a portion of the natural gas stream to generate steam for the regenerator towers and power other capture processes. Capture-related combustion equates to approximately 0.2 metric ton $CO_2$ emitted per metric ton $CO_2$ captured based on 0.4 MCF natural gas combusted per metric ton $CO_2$ captured and 2.73 kilograms (kg) $CO_2$ emitted per kilogram of natural gas combusted which compares to $CO_2$ capture emission analysis by Luis (2016) and DOE-NETL (2010b, 2010c, 2013). The upstream capture calculations were generalized because the $CO_2$ capture plant links to a complicated gathering system of several hundred wells. The $CO_2$ levels vary in these wells over time and location, and detailed information was not available for the time period evaluated.

# 4.0 Analysis Results

The LCA results account for cumulative greenhouse gas emissions over 22 years of $CO_2$-EOR operations at the Niagaran reef complex. Thus, the results reflect long-term trends and net $CO_2$ balance of the system. Gate-to-gate emission factors were the focus of this study and have the most accurate input fields. The upstream $CO_2$ capture emissions are directly related to the volume of $CO_2$ provided from the Antrim gas plant to the Chester 10 facility for EOR. The downstream emissions are a function of the oil produced in the EOR.

Figure 9 provides a snapshot of 2017 emission factors associated with the $CO_2$-EOR operations. The model suggests a gate-to-gate emission factor for 2017 of 198 kg $CO_2$e per barrel of oil, which is similar to other $CO_2$-EOR greenhouse gas life cycle studies (Marriott, 2013; Azzolina et al., 2016). As shown, the emissions from compression had the largest emission factors in the gate-to-gate EOR operations. Gate-to-gate emission factors for other operations represented less than 10 percent of the total gate-to-gate emissions. The emission factor was calculated as 330.7 kg $CO_2$e per barrel for upstream capture and 470 kg $CO_2$e per barrel for downstream processes. A total of 615,184 metric tons of $CO_2$ were stored in 2017, which equates to -1,570 kg $CO_2$e per barrel emission factor. Thus, the net emission factor for 2017 are calculated as -999 kg $CO_2$e per barrel, which suggests much more $CO_2$ was stored than emitted.

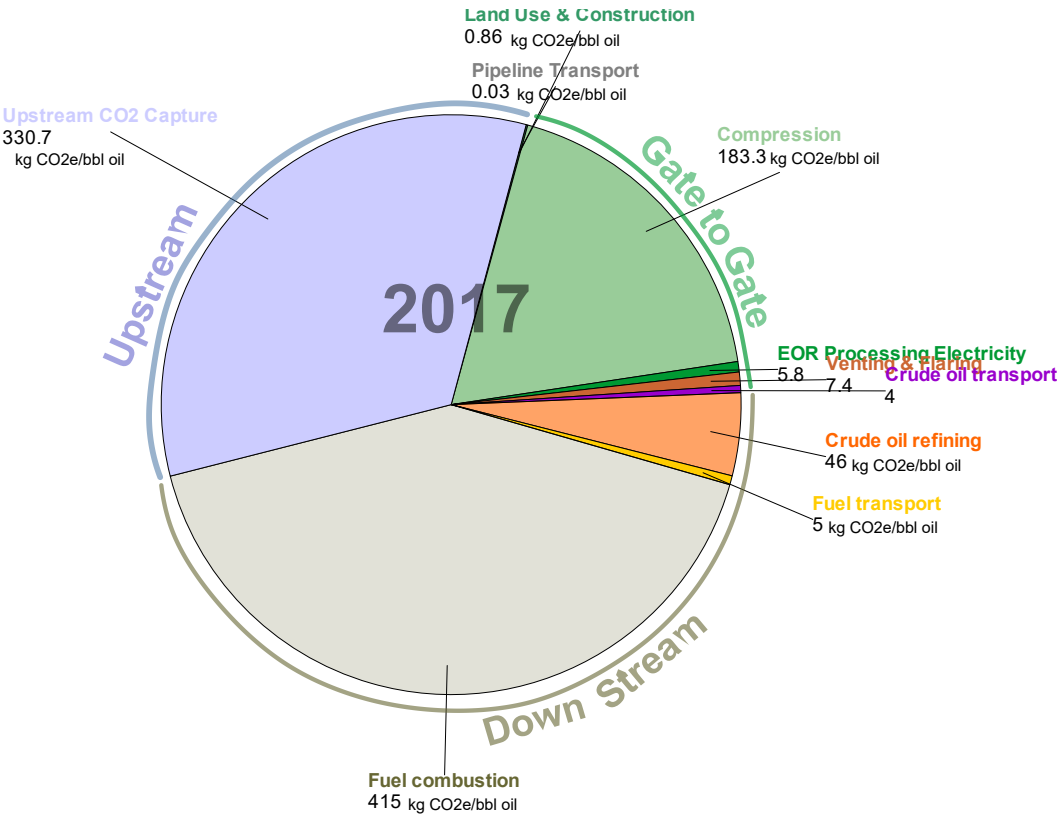



*Figure 9. Chart illustrating 2017 LCA greenhouse gas emission factors for 2017 $CO_2$-EOR operations at Niagaran reefs.*

## 4.0 Analysis Results

Table 3 summarizes net LCA calculations on total mass basis. In 2017, oil production was moderate compared to the amount of new $CO_2$ injected in the reef complex. Based on 2017 operations, the LCA shows the system produced 64,443 metric tons of $CO_2e$ for upstream capture, 38,495 metric tons of $CO_2e$ for gate-to-gate EOR operations, and 91,614 metric tons of $CO_2e$ for downstream oil transport, refining, and combustion. System metering for 2017 measured 298,010 metric tons associated storage. Thus, net $CO_2e$ emissions in 2017 totaled -103,468 metric tons.

Oil production and total $CO_2$ injection vary substantially based on the stage of the EOR operations (Figure 10). Consequently, the year-to-year emission factors expressed as kilograms of $CO_2e$ per barrel of oil produced may be a misleading measure of emission intensity. In the early years of operations, there was very little oil production and a large amount of $CO_2$ injection as the reefs were filled with $CO_2$ to reach minimum miscibility pressures. Once the reefs were pressured with $CO_2$, much of the $CO_2$ was recycled to reduce costs associated with compression of $CO_2$, resulting in lower emission factors. In recent years, more reefs were added to the EOR complex, and more $CO_2$ was obtained from the Antrim gas processing facility. In addition, "45Q" incentives introduced by the U.S. Government have encouraged retaining $CO_2$ in depleted reefs.

**Table 3. Summary of $CO_2$-EOR greenhouse gas LCA results, 1996-2017.**

| Year | Oil Produced | | $CO_2$ Flows (metric tonnes) | | | Emission Factors (kg CO2e/bbl) | | | Total Emissions (metric tonnes) | | | Associated Storage (metric tonnes) | Net CO2e Emissions (metric tonnes) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oil (barrels) | Oil (metric tonnes) | Total $CO_2$ Injected | New $CO_2$ from Gas Processing Facility | Recycle $CO_2$ | Upstream $CO_2$ Capture | Gate to Gate | Down-stream | Upstream $CO_2$ Capture | Gate to Gate | Down-stream | | |
| 1996 | 100 | 13 | 139,037 | 110,238 | 0 | NA | NA | NA | 22,872 | 7166 | 0 | 139,037 | -108,999 |
| 1997 | 129,250 | 16,609 | 185,415 | 68,162 | 88,388 | 109 | 81 | 470 | 14,142 | 10511 | 60,767 | 97,026 | -11,606 |
| 1998 | 184,885 | 23,758 | 302,222 | 98,763 | 203,459 | 208 | 106 | 470 | 38,543 | 19554 | 86,924 | 98,763 | 46,257 |
| 1999 | 102,758 | 13,204 | 193,857 | 5,941 | 187,916 | 13 | 117 | 470 | 1,289 | 12025 | 48,312 | 5,941 | 55,684 |
| 2000 | 63,989 | 8,223 | 158,970 | 15,259 | 143,711 | 32 | 153 | 470 | 2,061 | 9786 | 30,084 | 15,259 | 26,673 |
| 2001 | 67,547 | 8,680 | 142,579 | 0 | 142,591 | 0 | 130 | 470 | 0 | 8759 | 31,757 | 0 | 40,529 |
| 2002 | 51,059 | 6,561 | 135,610 | 665 | 134,945 | 1 | 161 | 470 | 72 | 8237 | 24,005 | 665 | 31,649 |
| 2003 | 48,027 | 6,171 | 154,097 | 11,585 | 142,512 | 24 | 196 | 470 | 1,174 | 9397 | 22,580 | 11,585 | 21,566 |
| 2004 | 52,875 | 6,794 | 157,122 | 4,728 | 152,394 | 10 | 180 | 470 | 528 | 9521 | 24,859 | 4,728 | 30,180 |
| 2005 | 55,325 | 7,109 | 130,914 | 1,500 | 129,414 | 3 | 85 | 470 | 175 | 4697 | 26,011 | 1,500 | 29,383 |
| 2006 | 58,747 | 7,549 | 201,510 | 95,992 | 113,747 | 339 | 227 | 470 | 19,916 | 13308 | 27,620 | 87,763 | -26,918 |
| 2007 | 101,525 | 13,046 | 147,529 | 26,867 | 133,450 | 55 | 99 | 470 | 5,574 | 10042 | 47,732 | 14,079 | 49,269 |
| 2008 | 126,646 | 16,274 | 265,753 | 149,346 | 145,159 | 245 | 146 | 470 | 30,986 | 18472 | 59,543 | 120,595 | -11,594 |
| 2009 | 114,943 | 14,770 | 228,423 | 112,862 | 171,918 | 204 | 152 | 470 | 23,417 | 17449 | 54,040 | 56,505 | 38,402 |
| 2010 | 100,448 | 12,908 | 315,875 | 157,520 | 161,638 | 325 | 187 | 470 | 32,682 | 18740 | 47,226 | 154,237 | -55,589 |
| 2011 | 122,594 | 15,753 | 348,405 | 174,449 | 181,942 | 295 | 200 | 470 | 36,195 | 24530 | 57,638 | 166,463 | -48,100 |
| 2012 | 125,805 | 16,166 | 378,155 | 172,926 | 218,298 | 285 | 209 | 470 | 35,879 | 26342 | 59,147 | 159,857 | -38,489 |
| 2013 | 126,544 | 16,261 | 395,275 | 196,448 | 212,858 | 322 | 206 | 470 | 40,759 | 26118 | 59,495 | 182,417 | -56,045 |
| 2014 | 141,140 | 18,136 | 408,528 | 157,796 | 264,215 | 232 | 191 | 470 | 32,740 | 26908 | 66,357 | 144,313 | -18,309 |
| 2015 | 194,861 | 25,040 | 401,480 | 165,223 | 253,278 | 176 | 144 | 470 | 34,280 | 27971 | 91,614 | 148,202 | 5,664 |
| 2016 | 126,544 | 16,261 | 395,275 | 196,448 | 212,858 | 322 | 206 | 470 | 40,759 | 26118 | 59,495 | 182,417 | -56,045 |
| 2017 | 194,861 | 25,040 | 615,184 | 310,549 | 317,174 | 331 | 198 | 470 | 64,433 | 38495 | 91,614 | 298,010 | -103,468 |
| | | | | | | | | | | | | | |
| Total | 2,290,473 | 294,326 | 5,801,215 | 2,233,269 | 3,711,865 | 209 | 163 | 470 | 478,476 | 374,147 | 1,076,820 | 2,089,350 | -159,907 |

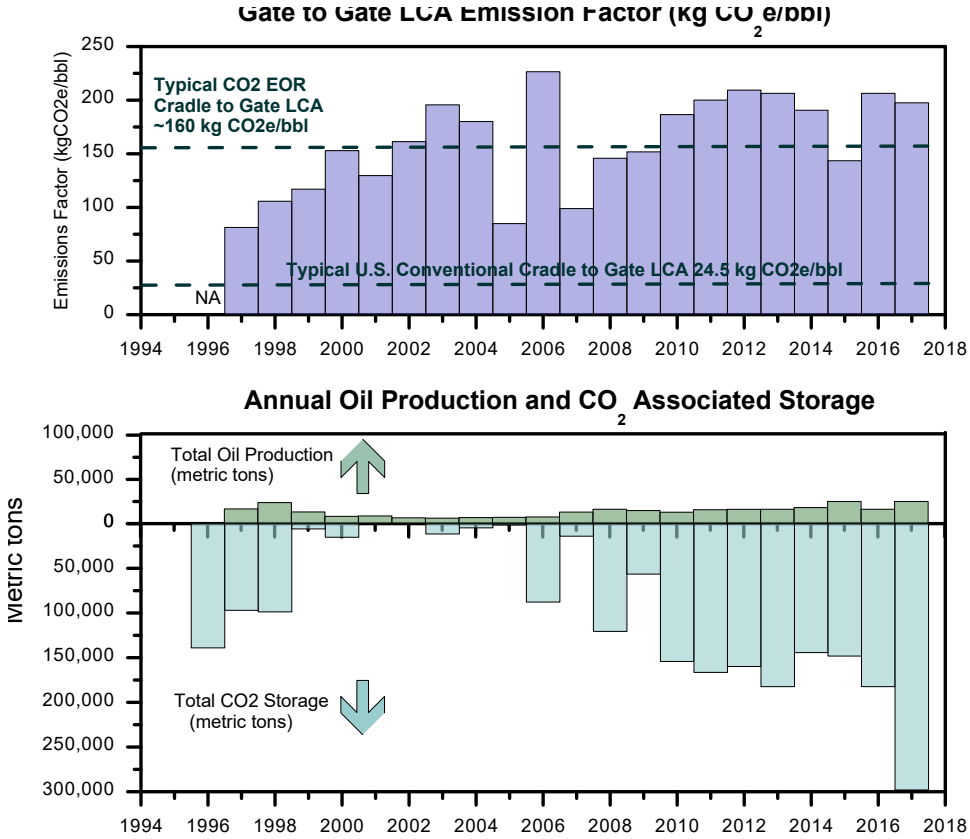



*Figure 10. Graph of annual oil production, $CO_2$ associated storage, and gate-to-gate emission factors illustrating the variations in Niagaran reef $CO_2$-EOR operations over time.*

## 4.1 Options to Optimize Carbon Storage and Minimize $CO_2$-EOR Emission Factors

One of the advantages of the greenhouse gas emission LCA is the ability to ascertain where greenhouse gas emissions may be reduced. Overall, the Niagaran reef EOR operations have low net greenhouse gas emissions due to the large amount of $CO_2$ being retained in the reservoirs. The greenhouse gas emission factors are an unclear metric on a kilograms-of-$CO_2$e per barrel-of-oil unit basis for operations because the system has highly variable oil production, energy usage, and new $CO_2$ supplied from the Chester 10 gas processing plant. Therefore, net $CO_2$e emissions from each process are a better metric to evaluate system performance.

The greenhouse gas emissions LCA suggests that the Niagaran reef $CO_2$-EOR system benefits from the gas processing $CO_2$ source, natural gas-fired compression, small pipeline network, and contained geology of the reef structures. Since $CO_2$ compression represents a large contribution to emissions, improvements on compression technology may provide the largest reduction in life cycle emissions. The well understood physics related to compressing gas streams suggest that increases in compressor efficiency are a difficult technical challenge. Analysis suggest that fugitive emissions related to $CO_2$ venting and methane flaring may be sources that could be reduced. However, these components would have a less than 5% effect on overall greenhouse gas emissions from gate-to-gate operations. As with any $CO_2$-EOR operation, increases in the volume of $CO_2$ permanently stored has the largest direct impact on life cycle greenhouse gas emissions. U.S. Federal "45Q" credits would encourage operators to retain $CO_2$ underground.

# 5.0 Conclusions

This greenhouse gas LCA provides a site-specific examination of 22 years of $CO_2$-EOR operations in a group of Niagaran reefs in the Michigan Basin. The results show variations in net greenhouse emissions over time, reflecting the stages of EOR, addition of new reefs, and progress in $CO_2$ storage practices. This research focused on the gate-to-gate portion of EOR operations, where the most accurate information was available. The PCOR greenhouse gas LCA model was utilized for the calculations, and the model provided a useful framework because specific values could be entered for emission calculations. Many of the EOR operations items like natural gas usage and electricity usage were tracked on a facility basis rather than by individual components, because that approach was the best option for obtaining records.

## 5.1 Gate-to-Gate Operations

For the cumulative 1996-2017 time period, the LCA suggests that the $CO_2$-EOR gate-to-gate operations had an emission factor of 163 kg $CO_2$e per barrel of oil, which is comparable to other LCAs on $CO_2$-EOR systems (Figure 11). $CO_2$ compression was the largest contributor to the gate-to-gate EOR greenhouse gas emissions. When $CO_2$ is supplied to the EOR operations, the multi-stage compressors are run continuously, resulting a large amount of emissions from methane combustion. However, the compressors operate on natural gas, $CO_2$ is frequently recycled, and the compressors provide enough pressure for pipeline transport and injection, so the emissions from $CO_2$ compression are less than emissions from other EOR operations. The highly contained nature of the Niagaran reef complex also helps to maintain pressure in the EOR system.

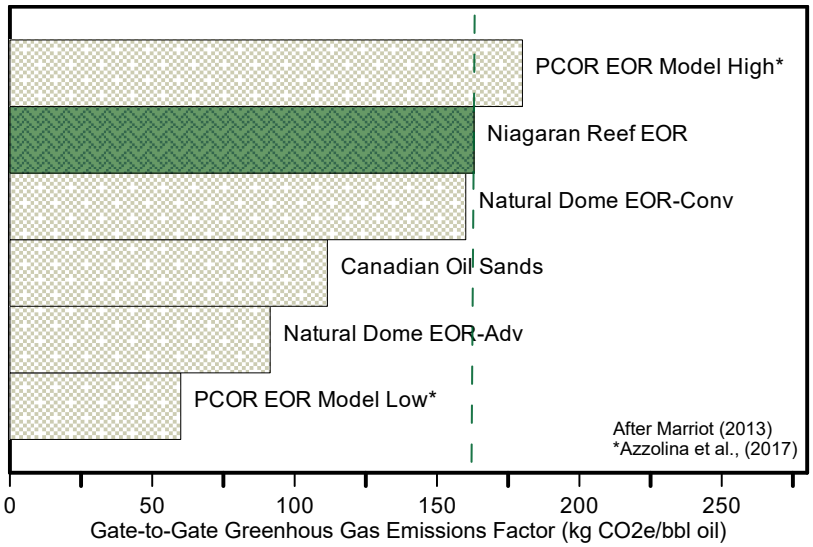



*Figure 11. Graph illustrating Niagaran reef $CO_2$-EOR life cycle emission factor in comparison to other $CO_2$-EOR gate-to-gate greenhouse gas emission factors.*

## 5.2 Upstream Operations

The upstream component was based on the $CO_2$ capture system operating data for the central gas processing facility and volume of $CO_2$ routed to the EOR system. The central gas processing facility strips $CO_2$ from gas produced in Antrim shale wells, which results in approximately 2.73 kg $CO_2$ emitted per kilogram of natural gas combusted, or 0.2 metric ton of $CO_2$ emitted per metric ton of $CO_2$ captured. The $CO_2$ is vented to the atmosphere when it is not utilized for $CO_2$-EOR. Consequently, it is not clear whether the upstream component should be included in the greenhouse gas LCA calculations. Regardless, the EOR system takes $CO_2$ from an anthropogenic source that would otherwise be released to the atmosphere. Many other $CO_2$-EOR operations obtain $CO_2$ from natural, underground $CO_2$ fields or domes, which has no impact to man-made greenhouse gas emissions.

## 5.3 Downstream Operations

The downstream component was based on the default PCOR greenhouse gas LCA model. These calculations estimate an emission factor of 470 kg $CO_2e$ per barrel for downstream oil transport, refining, transport to the point of sale, and fuel combustion.

## 5.4 Net Emissions

Figure 12 illustrates the net greenhouse gas emissions for the 22 years of $CO_2$-EOR operations. The LCA suggests that a total of 1,929,000 metric tons of $CO_2e$ were generated from the upstream, gate-to-gate, and downstream components of the $CO_2$-EOR system. Monitoring and metering of the net $CO_2$ balance shows 2,089,000 metric tons of $CO_2$ storage for the system through 2017. Thus, the system has net greenhouse gas emissions of -160,000 metric tons of $CO_2e$. If the upstream capture is discounted, net emissions would be -630,000 metric tons of $CO_2e$. The $CO_2$-EOR system has resulted in 2,089,000 metric tons of $CO_2$ storage and 2,290,473 barrels of oil production. This equates to a high ratio of 0.91 metric ton of $CO_2$ stored per barrel of oil produced.

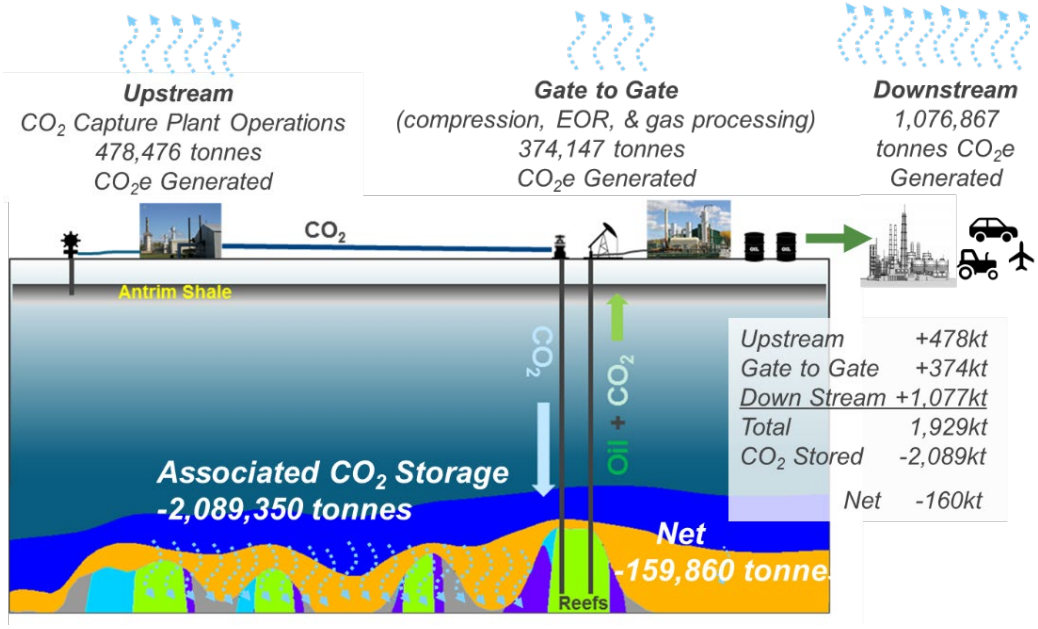



*Figure 12. Diagram illustrating net $CO_2$ balance for the 1996-2017 greenhouse gas LCA.*

Other greenhouse gas LCAs suggest that there are usually net positive emissions from the $CO_2$-EOR process. However, the net emissions from $CO_2$-EOR are significantly less than emissions from conventional oil production when accounting for $CO_2$ storage. The system benefits from a ready source of $CO_2$, a short pipeline system, natural-gas-fueled compression, a highly contained reservoir, and closed loop oil processing system. In addition, the operations were part of the MRCSP, which increased efforts for $CO_2$ storage. Recent incentives for $CO_2$ storage would suggest that much of the $CO_2$ will be ultimately retained in the reefs.

Overall, the greenhouse gas LCA highlights the value of examining a long period of $CO_2$-EOR operations. Year to year, the EOR operations exhibit large variations in net $CO_2$ emissions (Figure 13). Examining a snapshot in time to determine unit emission factors may provide misleading results. Most $CO_2$-EOR operations follow a similar process: initial pressuring of highly depleted oil reservoirs, expanding to additional areas over time. As such, it is necessary to consider the evolution of $CO_2$-EOR operations in greenhouse gas LCA.

Some areas that may be improved in the life cycle model include better accounting for embodied emissions associated with construction of the compression and oil processing facilities. In the Niagaran reefs $CO_2$-EOR system, the compression facility is the largest factor for gate-to-gate emissions. There are several multi-stage compressors, which require a fair amount of capital investment, fuel, and maintenance by the operator. Similarly, the oil processing facility has significant equipment and construction. While these components are one-time capital investments, they may be better represented in LCA. Similarly, compression is often overlooked in other carbon capture and storage (CCS) applications because of the focus on capture and storage.

Other factors may affect the $CO_2$-EOR system life cycle. The Antrim shale play is becoming depleted, and the supply of $CO_2$ will decline along with gas production in future years. Once gas production declines in the Antrim, the wells will be plugged and abandoned, eliminating the source of $CO_2$. Therefore, there is value to developing new sources of $CO_2$. Recent “45Q” incentives introduced by the U.S. Government have generated interest in CCS by nearby sources. In addition, there are opportunities to integrate carbon capture with new industrial sources, establish regional $CO_2$ pipelines, and connect to the Niagaran reef trend.

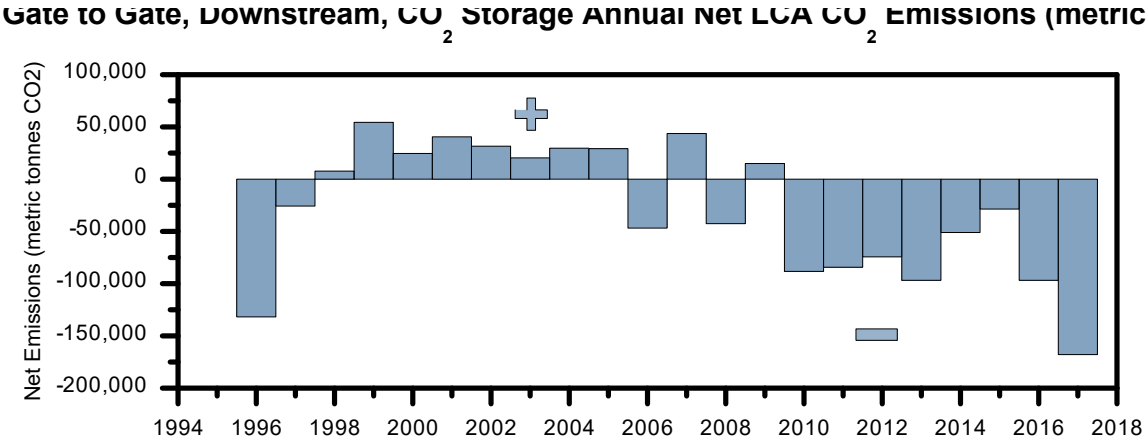



*Figure 13. Graph illustrating annual trends considering gate-to-gate, downstream, and $CO_2$ storage net emissions.*

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# APPENDIX A

**$CO_2$ ENHANCED OIL RECOVERY LIFE CYCLE ANALYSIS MODEL**

**DESCRIPTION**

This workbook calculates the life cycle greenhouse gas (GHG) emissions associated with incremental oil produced via carbon dioxide enhanced oil recovery ($CO_2$ EOR) where the $CO_2$ is sourced from a coal-fired power plant.

**EXCEL WORKBOOK ORGANIZATION**

This Excel workbook is organized into eight tabs (worksheets) as follows:

**1. Base Model –** The Base Model worksheet goes from upstream to downstream segments using line-by-line calculations in an accounting-style ledger to derive the component $CO_2$ emission factors expressed as both mass of $CO_2$ equivalents (kg $CO_2$e) and mass of $CO_2$ equivalents per barrel of crude oil produced (kg $CO_2$e/bbl). In the base model, inputs where the source is "Literature" are unlocked and may be modified by users to meet their site-specific needs. Other rows where the source is "Derived" are locked and may not be modified. These locked cells contain calculations, and the cells are locked to prevent the accidental overwriting of these calculations.

**2. Dashboard Summary –** The Dashboard Summary worksheet captures key Base Model outputs into a table. The Dashboard Summary presents emission factors in kg $CO_2$e/bbl for upstream, gate-to-gate, and downstream segments. It also presents the kg $CO_2$e/bbl stored in the reservoir and the MWh of electricity coproduct generated as part of the electricity–oil system. The Dashboard Summary worksheet is locked and cannot be modified.

**3. Coproduct Displacement –** The Coproduct Displacement worksheet allocates the electricity coproduct via displacement and assumes 100% displacement of electricity, meaning that each new MWh produced displaces an existing MWh (i.e., a one-to-one replacement). The source of the existing MWh that is displaced is the average 2010 U.S. electricity grid mix, which has an emission factor of 660 kg CO2e/MWh. The user may modify this grid electricity GHG emission factor in the Base Model. The coproduct Displacement worksheet is locked and cannot be modified.

**4. Gasoline and Diesel –** The Gasoline and Diesel worksheet tabulates the emissions specific to gasoline and diesel combustion to allow for direct comparison with conventional sources of these two fuels. We compare the $CO_2$ EOR life cycle GHG emissions per MJ of gasoline or diesel combusted against DOE NETL's baseline for conventional gasoline and diesel (DOE NETL, 2008). Gasoline and diesel represent approximately 45% and 23%, respectively, of the total refinery production in our model, so these liquid fuels make up the majority (68%) of refinery production in the United States. These tabulated emissions are summarized in a stacked bar graph located to the right of the table. The Gasoline and Diesel worksheet is locked and cannot be modified.

**5. Unit Conversions –** The Unit Conversions worksheet is used to convert units in the Base Model. It is locked and cannot be modified with the exception of two cells: D15 and D16, which convert the kg of $CH_4$ and $N_2O$, respectively, to kg $CO_2$e using the IPCC (2013) 100-year global warming potentials of 34 and 298, respectively.

**6. Coal-Type Lookup Table –** The Coal-Type Lookup Table worksheet is a lookup table of as-fired properties of four U.S. coals from Rubin et al. (2007). The cells specific to coal type, HHV in kJ/kg, and kg C/kg coal are unlocked, and users may modify these inputs to meet their site-specific needs. All other cells are locked and cannot be modified.

**7. Brine and Gas Correlations –** The Brine and Gas Correlations worksheet calculates the correlations between brine production and injection rates and crude oil recovery ratios using inputs from DOE NETL (2013a). These correlations are used to estimate emissions from the electrical use of pumps for brine injection associated with the WAG flood and injection of excess brine into disposal wells. The worksheet is locked and cannot be modified.

**8. References** - The References worksheet lists the literature references that are cited in the Base Model.

**HOW TO CITE THIS DOCUMENT**

This document should be cited as: Azzolina, N.A., Peck, W.D., Hamling, J.A., Gorecki, C.D., Ayash, S.C., Doll, T.E., Nakles, D.V., and Melzer, L.S., 2016, How green is my oil? A detailed look at greenhouse gas accounting for $CO_2$-enhanced oil recovery ($CO_2$-EOR) sites: International Journal of Greenhouse Gas Control, v. 51,p. 369–379: last updated July 2016 (version 01).

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**APPENDIX A**

| | Input Parameters | | | | | | | | | Output | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Oil Produced (bbl) | Oil Produced (metric tonnes) | Total CO2 Injected (metric tonnes) | Pure CO2 (metric tonnes) | Recycle CO2 (metric tonnes) | Associated Storage (metric tonnes) | Facility Gas Combustion (MCF) | Facility Electricity (KWH) | New Wells | Gate to Gate EF (kgCO2e/bbl) | Gate to Gate total Emissions (metric tons) | Downstream EF (kgCO2e/bbl) | Downstream Total Emissions (Metric tons) | Total CO2 Associated Storage (metric tonnes) | Est. Capture EF (kgCo2e/bbl) | Total Capture Emissions* (metric tonnes) | Net CO2e Emissions (metric tonnes) | DOE-NETL Capture** (metric tons) | |
| 1996 | 100 | 13 | 139,037 | 110,238 | 0 | 139,037 | 124,631 | 502,682 | 0 | 71658 | 7166 | 470 | 0 | 139,037 | NA | 22872 | -108,999 | 20367 | * 4000 kJ/kg CO2 MEA capture energy and NG steam boiler for regeneration 4000 kJ/kg CO2 * 0.95BTU/kJ*1MCF/1.037E+6 BTU * 1000kgCo2/1metric tonne CO2 = 4 MCF/metric tonne CO2 captured Total capture emissions = Pure CO2 * 4 MCF NG/metric ton CO2 captured * 2.73 kg CO2/kg NG combusted * 0.019 kg NG/SCF NG Patricia Luis. 2016. Use of monoethanolamine (MEA) for CO2 capture in a global scenario: Consequences and alternatives, Desalination, V. 380, p 93-99 |
| 1997 | 129,250 | 16,609 | 185,415 | 68,162 | 88,388 | 97,026 | 136,078 | 370,548 | 0 | 81 | 10511 | 470 | 60,767 | 97,026 | 109.4 | 14142 | -11,606 | 12593 | |
| 1998 | 184,885 | 23,758 | 302,222 | 98,763 | 203,459 | 98,763 | 247,505 | 587,848 | 0 | 106 | 19554 | 470 | 86,924 | 98,763 | 208.5 | 38543 | 46,257 | 18247 | |
| 1999 | 102,758 | 13,204 | 193,857 | 5,941 | 187,916 | 5,941 | 132,187 | 154,079 | 0 | 117 | 12025 | 470 | 48,312 | 5,941 | 12.5 | 1289 | 55,684 | 1098 | |
| 2000 | 63,989 | 8,223 | 158,970 | 15,259 | 143,711 | 15,259 | 113,206 | 166,698 | 0 | 153 | 9786 | 470 | 30,084 | 15,259 | 32.2 | 2061 | 26,673 | 2819 | |
| 2001 | 67,547 | 8,680 | 142,579 | 0 | 142,591 | -12 | 95,207 | 96,359 | 0 | 130 | 8759 | 470 | 31,757 | -12 | 0.0 | 0 | 40,529 | 0 | |
| 2002 | 51,059 | 6,561 | 135,610 | 665 | 134,945 | 665 | 90,853 | 94,225 | 0 | 161 | 8237 | 470 | 24,005 | 665 | 1.4 | 72 | 31,649 | 123 | **2.86 kg of CO2 per kg of NG combusted for amine reboiler |
| 2003 | 48,027 | 6,171 | 154,097 | 11,585 | 142,512 | 11,585 | 108,252 | 149,134 | 1 | 196 | 9397 | 470 | 22,580 | 11,585 | 24.5 | 1174 | 21,566 | 2140 | 0.000973 kg CH4/kg CH3 processed = 3.4 MC NG/ton CO2 captured Total Capture Emissions = Pure CO2 * 3.4 MCF NG/metric ton CO2 * 2.86 kg CO2/kg NG Comb * 0.019 kg NG/SCF NG |
| 2004 | 52,875 | 6,794 | 157,122 | 4,728 | 152,394 | 4,728 | 107,098 | 124,544 | 0 | 180 | 9521 | 470 | 24,859 | 4,728 | 10.0 | 528 | 30,180 | 874 | |

Input Parameters

Output

NETL (2010). NETL Life Cycle Inventory Data – Unit Process: Natural Gas Sweetening. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: April 2011 (version 02). www.netl.doe.gov/energy-analyses (http://www.netl.doe.gov/energy-analyses)

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 55,325 | 7,109 | 130,914 | 1,500 | 129,414 | 1,500 | 27,589 | 94,295 | 0 | 85 | 4697 | 470 | 26,011 | 1,500 | 3.2 | 175 | 29,383 | | 277 |
| 2006 | 58,747 | 7,549 | 201,510 | 95,992 | 113,747 | 87,763 | 184,183 | 514,584 | 1 | 227 | 13308 | 470 | 27,620 | 87,763 | 339.0 | 19916 | -26,918 | | 17735 |
| 2007 | 101,525 | 13,046 | 147,529 | 26,867 | 133,450 | 14,079 | 112,624 | 212,694 | 3 | 99 | 10042 | 470 | 47,732 | 14,079 | 54.9 | 5574 | 49,269 | | 4964 |
| 2008 | 126,646 | 16,274 | 265,753 | 149,346 | 145,159 | 120,595 | 250,047 | 779,103 | 4 | 146 | 18472 | 470 | 59,543 | 120,595 | 244.7 | 30986 | -11,594 | | 27593 |
| 2009 | 114,943 | 14,770 | 228,423 | 112,862 | 171,918 | 56,505 | 229,542 | 676,422 | 0 | 152 | 17449 | 470 | 54,040 | 56,505 | 203.7 | 23417 | 38,402 | | 20852 |
| 2010 | 100,448 | 12,908 | 315,875 | 157,520 | 161,638 | 154,237 | 257,229 | 827,513 | 0 | 187 | 18740 | 470 | 47,226 | 154,237 | 325.4 | 32682 | -55,589 | | 29103 |
| 2011 | 122,594 | 15,753 | 348,405 | 174,449 | 181,942 | 166,463 | 353,103 | 770,569 | 0 | 200 | 24530 | 470 | 57,638 | 166,463 | 295.2 | 36195 | -48,100 | | 32230 |
| 2012 | 125,805 | 16,166 | 378,155 | 172,926 | 218,298 | 159,857 | 369,013 | 1,016,193 | 0 | 209 | 26342 | 470 | 59,147 | 159,857 | 285.2 | 35879 | -38,489 | | 31949 |
| 2013 | 126,544 | 16,261 | 395,275 | 196,448 | 212,858 | 182,417 | 422,125 | 960,996 | 2 | 206 | 26118 | 470 | 59,495 | 182,417 | 322.1 | 40759 | -56,045 | | 36295 |
| 2014 | 141,140 | 18,136 | 408,528 | 157,796 | 264,215 | 144,313 | 360,641 | 947,149 | 0 | 191 | 26908 | 470 | 66,357 | 144,313 | 232.0 | 32740 | -18,309 | | 29154 |
| 2015 | 194,861 | 25,040 | 401,480 | 165,223 | 253,278 | 148,202 | 376,388 | 987,629 | 0 | 144 | 27971 | 470 | 91,614 | 148,202 | 175.9 | 34280 | 5,664 | | 30526 |
| 2016 | 126,544 | 16,261 | 395,275 | 196,448 | 212,858 | 182,417 | 364,799 | 960,996 | 2 | 206 | 26118 | 470 | 59,495 | 182,417 | 322.1 | 40759 | -56,045 | | 36295 |
| 2017 | 194,861 | 25,040 | 615,184 | 310,549 | 317,174 | 298,010 | 550,734 | 1,712,958 | 2 | 198 | 38495 | 470 | 91,614 | 298,010 | 330.7 | 64433 | -103,468 | | 57376 |
| Total | 2,290,473 | 294,326 | 5,801,215 | 2,233,269 | 3,711,865 | 2,089,350 | 5,013,034 | 12,707,218 | 14 | 163 | 374,147 | 470 | zah | 2,089,350 | 209 | 478,476 | -159,907 | | 412,610 |
| | | | | | | | | | | | | | | | check | | #VALUE! | | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | nining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | nining, processing, and tra | l mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining, processing, and transport and the net plant efficiency | 60 | 36 | 90 | |
| Upstream | nining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate and HHV of the coal with unit conversion from kWh to MWh | 389 | 324 | 403 | |
| Upstream | nining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the purchased $CO_2$ quantity and $CO_2$ capture rate of the coal plant | 134,997,142 | 127,497,301 | 143,434,463 | |
| Upstream | nining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to Mt | 0.1 | 0.1 | 0.1 | |
| Upstream | nining, processing, and tra | $O_2$ emissions associated with coal mining, processing, and transpo | kg $CO_2$e | | | | Derived | Derived from the adjusted emissions factor and the MWh of electricity required to deliver the purchased $CO_2$ quantity | 20,816,576 | 14,198,961 | 31,947,662 | |
| Upstream | nining, processing, and tra | emissions factor associated with coal mining, processing, and tran | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 107 | 73 | 164 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007); and DOE NETL (2013b) | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of electricity (kWh = 3600 kJ/hr) and the net plant efficiency | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on user selection above | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg to kJ/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on user selection above | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the HHV, carbon fraction, and net plant efficiency | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as published in IPCC (2005) | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emissions (adjusted for net plant efficiency) and the $CO_2$ capture efficiency | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emissions (adjusted for net plant efficiency) and the $CO_2$ capture efficiency | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased $CO_2$ mass and the captured $CO_2$ rate | 346,943 | 393,202 | 356,339 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy needs of the coal plant and the emitted $CO_2$ from the coal plant | 54,802,765 | 34,505,444 | 77,637,250 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 281 | 177 | 398 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tonne to MWh/kg | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil recovery and net $CO_2$ utilization | 310,549,000 | 310,549,000 | 310,549,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity needed per kg of $CO_2$ and the kg of $CO_2$ | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | ycle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle emission factor and the electricity needed to pipeline the tonnes of $CO_2$ | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline network | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015) | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive emissions factor for pipeline transport of $CO_2$ (leaks) and the km of pipeline | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015) | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive emissions factor for pipeline transport of $CO_2$ (services) and the number of services per year | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2017 | 2017 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive emissions for pipeline transport of $CO_2$, emissions from services, and the project duration in years | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.03 | 0.003 | 0.13 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **388** | **250** | **563** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil produced | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 194,861 | 194,861 | 194,861 | System Data | Based on Oil Production | 194,861 | 194,861 | 194,861 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil recovery and the oil density | 25,039,639 | 24,747,347 | 25,331,930 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 61 | 61 | 61 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,157 | 3,157 | 3,157 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ utilization with unit conversion from kg to tonne | 0.32 | 0.32 | 0.32 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement | kg $CO_2$ | 310,549,000 | 310,549,000 | 310,549,000 | System Data | Based on Pure CO2 from Gas Processing Plant | 310,549,000 | 310,549,000 | 310,549,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to kg/bbl | 31.3 | 31.3 | 31.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,628 | 1,628 | 1,628 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/total CO2 inj | 6.0% | 6.0% | 6.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss rate of purchased $CO_2$ and the purchased $CO_2$ requirement | 18,763,710 | 18,763,710 | 18,763,710 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss of purchased $CO_2$ and the barrels of crude oil produced | 96.3 | 96.3 | 96.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 317,174,000 | 317,174,000 | 317,174,000 | System Data | Based on System Metering | 317,174,000 | 317,174,000 | 317,174,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversion from kg to tonnes and the days of operation | 869.0 | 869.0 | 869.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 615,184,000 | 615,184,000 | 615,184,000 | System Data | Based on Injection Metering | 615,184,000 | 615,184,000 | 615,184,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversion from kg to tonnes and the days of operation | 1,685.4 | 1,685.4 | 1,685.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, $CO_2$ produced, and fugitive losses of purchased $CO_2$ | 48.4% | 48.4% | 48.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 298,010,000 | 298,010,000 | 298,010,000 | System Data | Based on Injection Metering | 298,010,000 | 298,010,000 | 298,010,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored and barrels of crude oil produced | 1,529 | 1,529 | 1,529 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored and the $CO_2$ leakage rate from storage | 2,980 | 0 | 14,901 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, $CO_2$ leakage rate from storage, and barrels of oil produced | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected and $CO_2$ produced | 48.4% | 48.4% | 48.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering Gas Vented/oil production | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 3.42 | 3.42 | 3.42 | System Data | Based on System Metering Brine Disposal/oil production | 3.4 | 3.4 | 3.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE NETL (2013a) | 3.4 | 3.4 | 3.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbon gas production rate and the crude oil produced | 4,257 | 4,207 | 4,306 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine production rate and the crude oil produced | 85,635,564 | 84,635,927 | 86,635,201 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine injection rate and the crude oil produced | 85,635,564 | 84,635,927 | 86,635,201 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2017 | 2017 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to days | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to hours | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours to minutes | 525,600 | 525,600 | 525,600 | |
| **GATE-TO-GATE: LAND USE** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed across 20 yrs | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion from acres to $m^2$ | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion from acres to $m^2$ | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 2 | | System Data | Chester 8-16,<br>El Mac Hills 1-18A | 2 | 2 | 2 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footprint and total number of wells | 20,234 | 20,234 | 20,234 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the gas processing facility and total wells | 22,258 | 22,258 | 22,258 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2015) | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area repurposed and the emissions per sq meter of repurposed land | 166,100 | 166,100 | 166,100 | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.85 | 0.9 | 0.9 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (2015), distributed over 20 years | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissions factor and the barrels of crude produced | 2,436 | 2,436 | 2,436 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.01 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, production from repressuring reefs | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift pump electricity rate and the kg of crude produced | 25,040 | 24,747 | 25,332 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to MWh | 25 | 25 | 25 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 16,526 | 16,333 | 16,719 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.08 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compressor power factor and the daily $CO_2$ production rate | 2.35E+00 | 2.35E+00 | 2.35E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MWh | | | | Derived | NA, Derived from the compressor power and the hours of operation | 20,553 | 20,553 | 20,553 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | 29136000 | 29136000 | 29136000 | System Data | Combustion data from Core EPA GHGRR Subpart C | 29,136,000 | 29,136,000 | 29,136,000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 149.5 | 149.5 | 149.5 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | 0.00E+00 | 0.00E+00 | 0.00E+00 | System Data | No CO2 pump | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump power factor and the daily $CO_2$ injection rate | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump power and the hours of operation | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | 6591500 | 6591500 | 6591500 | System Data | Gas Processing data from Core EPA GHGRR Subpart W | 6,591,500 | 6,591,500 | 6,591,500 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 33.82668 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of compressor and pump emissions | 35,727,500 | 35,727,500 | 35,727,500 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 183.3 | 183.3 | 183.3 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | erations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | erations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | 549 | 549 | 549 | System Data | Subpart C Core forms | 549 | 549 | 549 | |
| Gate-to-Gate | erations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 1712958 | 1712958 | 1712958 | System Data | Chester 10 and Dover 36 Facility electricity data | 1,712,958 | 1,712,958 | 1,712,958 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to MWh | 1,713 | 1,713 | 1,713 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 1,130,552 | 1,130,552 | 1,130,552 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 5.8 | 5.8 | 5.8 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Gas, Water, and Oil Separation" | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Gas, Water, and Oil Separation" | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | 530,000 | 530,000 | 530,000 | System Data | Gas Processing data from Core EPA GHGRR Subpart W | 530,000 | 530,000 | 530,000 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Gas, Water, and Oil Separation" | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and the $CO_2$ emissions rate | 1,442,925 | 1,442,925 | 1,442,925 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare rate) | 5% | 5% | 5% | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncontrolled emissions rate, vent rate, and kg of crude oil produced | 10,892 | 5,383 | 22,039 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Gas, Water, and Oil Separation" | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas usage rate and the kg of crude oil produced | 250 | 247 | 253 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas delivered $CO_2$ emissions factor and the natural gas usage | 42 | 42 | 43 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas delivered $CH_4$ emissions factor and the natural gas usage | 5 | 4 | 5 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas delivered $N_2O$ emissions factor and the natural gas usage | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 154 | 152 | 156 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 197 | 194 | 199 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | aration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | aration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.03E-05 | 5.03E-05 | 5.03E-05 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas combustion $CO_2$ emissions factor and the natural gas usage | 688 | 680 | 696 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas combustion $CH_4$ emissions factor and the natural gas usage | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas combustion $N_2O$ emissions factor and the natural gas usage | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 0.4 | 0.4 | 0.5 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 4 | 4 | 4 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2e$ | 692 | 684 | 700 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Venting and Flaring, DOE NETL (2015) "Crude Oil Storage Tank" | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate and kg crude produced | 250 | 247 | 253 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE NETL (2015) "Venting and Flaring of Gas from Vapor Recovery Unit" | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and the flare rate | 238 | 235 | 241 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE NETL (2015) "Venting and Flaring of Gas from Vapor Recovery Unit" | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentanes ($C_5H_{12}$) and uses the stated combustion efficiency (DOE-NETL, 2013a) | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flared and the $CO_2$ emissions rate | 712 | 704 | 721 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Venting and Flaring, Derived from the difference between produced brine and injected brine | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlation of Rogers and Pitzer (1982) and the mg/L of total dissolved solids (TDS) | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion from kg/$m^3$ to kg/bbl | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fla | Produced water volume | bbl | | | | Derived | Derived from the produced water for disposal and the produced water density | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fla | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fla | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced water methane content, barrels of produced water, and percent released to the atmosphere | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fla | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fla | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Disposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity (on site disposal well) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Disposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produced water for disposal and the pump electricity rate | 0 | 0 | 0 | |
| Gate-to-Gate | Disposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to MWh | 0 | 0 | 0 | |
| Gate-to-Gate | Disposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 0 | 0 | 0 | |
| Gate-to-Gate | Disposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES)** | | | | | | | | | | | | |
| Gate-to-Gate | (Ryan-Holmes) – $CO_2$ Ready | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produced (recycled) | 317,174,000 | 317,174,000 | 317,174,000 | |
| Gate-to-Gate | ssing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy rate for backup power generato | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | ssing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal energy rate and the kg of recycled $CO_2$ | 3,012,149 | 3,012,149 | 3,012,149 | |
| Gate-to-Gate | ssing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | ssing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | ssing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diesel required and the diesel use per MJ | 77,195 | 77,195 | 77,195 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel required and the diesel density | 65,086 | 65,086 | 65,086 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Production, Transport, and Refining" | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Production, Transport, and Refining" | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Production, Transport, and Refining" | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas combustion $CO_2$ emissions factor and the natural gas usage | 4.08E+04 | 4.08E+04 | 4.08E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas combustion $CH_4$ emissions factor and the natural gas usage | 2.72E+02 | 2.72E+02 | 2.72E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas combustion $N_2O$ emissions factor and the natural gas usage | 7.91E-01 | 7.91E-01 | 7.91E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 9,261 | 9,261 | 9,261 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 236 | 236 | 236 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2e$ | 50,268 | 50,268 | 50,268 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fired Construction Equipment, Variable Horsepower" | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel combustion $CO_2$ emissions factor and the diesel usage | 204,888 | 204,888 | 204,888 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel combustion $CH_4$ emissions factor and the diesel usage | 29.4 | 29.4 | 29.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel combustion $N_2O$ emissions factor and the diesel usage | 5.3 | 5.3 | 5.3 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 998 | 998 | 998 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 1,580 | 1,580 | 1,580 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 207,466 | 207,466 | 207,466 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 1.1 | 1.1 | 1.1 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produced (recycled) | 317,174,000 | 317,174,000 | 317,174,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas use rate and the kg of $CO_2$ for reinjection | 5,626,382 | 5,626,382 | 5,626,382 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy content of natural gas and the kg of natural gas | 302,717,556,266 | 302,717,556,266 | 302,717,556,266 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions factor for natural gas and the Btu of natural gas | 35,417,954 | 35,417,954 | 35,417,954 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 16,065,301 | 16,065,301 | 16,065,301 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 82.4 | 82.4 | 82.4 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 7.29E-03 | 7.29E-03 | 7.29E-03 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased natural gas rate and the kg of $CO_2$ for reinjection | 2,311,956 | 2,311,956 | 2,311,956 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas delivered $CO_2$ emissions factor and the natural gas usage | 388,722 | 388,722 | 388,722 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas delivered $CH_4$ emissions factor and the natural gas usage | 41,838 | 41,838 | 41,838 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas delivered $N_2O$ emissions factor and the natural gas usage | 10.6 | 10.6 | 10.6 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1,422,495 | 1,422,495 | 1,422,495 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 3,166 | 3,166 | 3,166 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 1,814,383 | 1,814,383 | 1,814,383 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 9.3 | 9.3 | 9.3 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holmes Gas Separation" | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ production rate and the kg of $CO_2$ ready for reinjection | 1,236,981 | 1,236,981 | 1,236,981 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ production rate and the kg of $CO_2$ ready for reinjection | 2,307,717 | 2,307,717 | 2,307,717 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ production rate and the kg of $CO_2$ ready for reinjection | 1,954,738 | 1,954,738 | 1,954,738 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ production rate and the kg of $CO_2$ ready for reinjection | 2,241,096 | 2,241,096 | 2,241,096 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the individual NGL productions | 7,740,531 | 7,740,531 | 7,740,531 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (2015) | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (2015) | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (2015) | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (2015) | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy content and the kg of NGL produced | 377,737,936 | 377,737,936 | 377,737,936 | |
| **GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION)** | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of hydrocarbon gas and $CO_2$ produced (recycled) | 317,178,257 | 317,178,207 | 317,178,306 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity rate per unit of EOR reinjection gas and the kg of EOR reinjection gas ($CO_2$ injected) | 4,375 | 4,375 | 4,375 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 2,887,433 | 2,887,432 | 2,887,433 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 14.8 | 14.8 | 14.8 | RF |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extraction from EOR Gas - Refrigeration" with "refine_NGLs" equal to 1. | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas usage rate and the kg of EOR reinjection gas | 607 | 607 | 607 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas delivered $CO_2$ emissions factor and the natural gas usage | 102 | 102 | 102 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas delivered $CH_4$ emissions factor and the natural gas usage | 11 | 11 | 11 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas delivered $N_2O$ emissions factor and the natural gas usage | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 374 | 374 | 374 | |
| Gate-to-Gate | geration/Fractionation) – N | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 1 | 1 | 1 | |
| Gate-to-Gate | geration/Fractionation) – N | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 477 | 477 | 477 | |
| Gate-to-Gate | geration/Fractionation) – N | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas combustion $CO_2$ emissions factor and the natural gas usage | 1,668 | 1,668 | 1,668 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas combustion $CH_4$ emissions factor and the natural gas usage | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas combustion $N_2O$ emissions factor and the natural gas usage | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.1 | 1.1 | 1.1 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 9.1 | 9.1 | 9.1 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 1,678 | 1,678 | 1,678 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.009 | 0.009 | 0.009 | RF |
| Gate-to-Gate | eration/Fractionation) – C3 | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extraction from EOR Gas - Refrigeration" | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C4 | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extraction from EOR Gas - Refrigeration" | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C5 | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extraction from EOR Gas - Refrigeration" | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C3 | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery rate and the kg of EOR reinjection gas | 420,067 | 420,067 | 420,067 | |
| Gate-to-Gate | eration/Fractionation) – C4 | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery rate and the kg of EOR reinjection gas | 1,142,200 | 1,142,199 | 1,142,200 | |
| Gate-to-Gate | eration/Fractionation) – C5 | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery rate and the kg of EOR reinjection gas | 1,996,551 | 1,996,550 | 1,996,551 | |
| Gate-to-Gate | eration/Fractionation) – C3 | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C4 | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C5 | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C3 | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy content and the kg of propane | 21,129,374 | 21,129,371 | 21,129,377 | |
| Gate-to-Gate | eration/Fractionation) – C4 | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy content and the kg of butane | 55,510,900 | 55,510,892 | 55,510,909 | |
| Gate-to-Gate | eration/Fractionation) – C5 | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy content and the kg of pentane | 100,226,849 | 100,226,834 | 100,226,865 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | ng (Membrane) – Fluid for | Mass of fluid for compression | fluid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of hydrocarbon gas and $CO_2$ produced (recycled) | 317,178,257 | 317,178,207 | 317,178,306 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compressor, Single-Stage Centrifugal, Operation" | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of fluid for compression and the energy usage rate | 6,316 | 6,316 | 6,316 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 4,168,511 | 4,168,510 | 4,168,512 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 21.4 | 21.4 | 21.4 | M |
| Gate-to-Gate | Membrane) – Compressor F | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compressor, Single-Stage Centrifugal, Operation" | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor F | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor fugitive emissions rate and the kg of fluid compressed | 10,451 | 10,450 | 10,451 | |
| Gate-to-Gate | Membrane) – Compressor F | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.05 | 0.05 | 0.05 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dioxide Dehydration" | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usage rate and the kg of $CO_2$ produced (recycled) | 61,099 | 61,099 | 61,099 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to MWh | 61.1 | 61.1 | 61.1 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 40,325 | 40,325 | 40,325 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 0.21 | 0.21 | 0.21 | M |
| Gate-to-Gate | (Membrane) – Chiller Elect | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Stream Chilling" | 1.67E-06 | 1.67E-06 | 1.67E-06 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | (Membrane) – Chiller Elect | Electricity used | MWh | | | | Derived | Derived from the electricity rate per unit of gas and the kg of gas (recycled $CO_2$ + hydrocarbon gas) | 530 | 530 | 530 | |
| Gate-to-Gate | (Membrane) – Chiller Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and the life-cycle delivered electricity emissions factor | 349,594 | 349,594 | 349,594 | |
| Gate-to-Gate | (Membrane) – Chiller Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 1.79 | 1.79 | 1.79 | M |
| Gate-to-Gate | ng (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (2015) "Membrane Separation of CO2 and Hydrocarbons" | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | ng (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of fluid for compression and the kg of fluid sent through the membrane | 111,407,083 | 111,407,065 | 111,407,100 | |
| Gate-to-Gate | ane) – Post-Membrane Am | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane Separation of CO2 and Hydrocarbons" | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas for the amine system and the ratio of inflow/kg $CO_2$ recovered | 102,275,967 | 102,275,951 | 102,275,983 | |
| Gate-to-Gate | - Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solvent makeup rate and the kg of $CO_2$ recovered | 10,247 | 10,247 | 10,247 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas usage rate and the kg of EOR reinjection gas | 6,794,053 | 6,477,586 | 7,110,521 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas, U.S. Mix 2010, Extraction and Transport" | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas delivered $CO_2$ emissions factor and the natural gas usage | 1,142,322 | 1,089,113 | 1,195,532 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas delivered $CH_4$ emissions factor and the natural gas usage | 122,948 | 117,221 | 128,675 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas delivered $N_2O$ emissions factor and the natural gas usage | 31 | 30 | 33 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 4,180,228 | 3,985,512 | 4,374,943 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 9,305 | 8,872 | 9,739 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 5,331,855 | 5,083,497 | 5,580,214 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 27.4 | 26.1 | 28.6 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial Boiler, Natural Gas Fired, Over 100 Million BTU/hr" | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas combustion $CO_2$ emissions factor and the natural gas usage | 18,656,622 | 17,787,595 | 19,525,649 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas combustion $CH_4$ emissions factor and the natural gas usage | 358 | 341 | 374 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas combustion $N_2O$ emissions factor and the natural gas usage | 342 | 326 | 358 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 12,158 | 11,592 | 12,724 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 101,927 | 97,180 | 106,675 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, $CH_4$, and $N_2O$ in kg $CO_2$e | 18,770,707 | 17,896,366 | 19,645,049 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ C | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissions and the barrels of oil produced | 96.3 | 91.8 | 100.8 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow gas and the kg of $CO_2$ recovered | 9,131,116 | 9,131,115 | 9,131,118 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Membrane CO2 Recovery" | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 758,664 | 758,664 | 758,664 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 1,253,413 | 1,253,413 | 1,253,413 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 2,147,108 | 2,147,108 | 2,147,108 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 505,333 | 505,333 | 505,333 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 1,289,645 | 1,289,645 | 1,289,645 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Membrane CO2 Recovery" | 1,811,048 | 1,811,048 | 1,811,048 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy content and the kg of NGL produced | 445,598,469 | 445,598,399 | 445,598,539 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **197.6** | **197.5** | **197.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **93.1** | **93.1** | **93.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **14.8** | **14.8** | **14.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **147.1** | **141.4** | **152.9** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,529.3** | **1,529.3** | **1,529.3** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **96.3** | **96.3** | **96.3** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (2008) | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/ton-mile to kWh/kg-km | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances from Midland, TX, to either Cushion, Oklahoma or Houston, Texas. | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degrees API to kg/$m^3$ | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ to kg/bbl | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of oil produced and the oil density per barrel | 194,961,324 | 194,961,324 | 194,961,324 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way energy intensity, pipeline distance, and mass of crude oil transported | 9,157,850 | 8,140,311 | 10,175,388 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to MWh | 9,158 | 8,140 | 10,175 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way energy use and the $CO_2$ emissions factor for electricity | 6,044,181 | 5,372,605 | 6,715,756 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissions for crude oil transport by pipeline and the barrels of oil produced | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | ion of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fraction of total refinery production | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average emissions factor | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP factor for $CH_4$ | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP factor for $N_2O$ | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2015a) | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | Coal mining, processing, and transport | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | Coal mining, processing, and transport | l mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining, | 60 | 36 | 90 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate ar | 389 | 324 | 403 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the pu | 85,396,889 | 80,652,617 | 90,734,195 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to Mt | 0.1 | 0.1 | 0.1 | |
| Upstream | Coal mining, processing, and transport | $O_2$ emissions associated with coal mining, processing, and transpo | kg $CO_2$e | | | | Derived | Derived from the adjusted em | 13,168,211 | 8,982,020 | 20,209,546 | |
| Upstream | Coal mining, processing, and transport | emissions factor associated with coal mining, processing, and tran | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 104 | 71 | 160 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007) | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elect | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on use | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on use | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the HI | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publishe | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emiss | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emiss | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased C | 219,470 | 248,733 | 225,414 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy need | 34,667,294 | 21,827,556 | 49,112,000 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 274 | 172 | 388 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per tonne of $CO_2$ transported (100 to 1000 km) | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/to | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil r | 196,448,000 | 196,448,000 | 196,448,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | ycle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle em | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netwo | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015) | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive emi | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (services) | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015) | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (services) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive emi | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2016 | 2016 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive emi | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.05 | 0.005 | 0.20 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **378** | **243** | **548** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pro | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil produced | bbl crude | 126,544 | 126,544 | 126,544 | System Data | Based on Oil Production | 126,544 | 126,544 | 126,544 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 16,260,904 | 16,071,088 | 16,450,720 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 60 | 60 | 60 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,124 | 3,124 | 3,124 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ utili | 0.32 | 0.32 | 0.32 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 196,448,000 | 196,448,000 | 196,448,000 | System Data | Based on Pure CO2 from Gas | 196,448,000 | 196,448,000 | 196,448,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 32.4 | 32.4 | 32.4 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,682 | 1,682 | 1,682 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/to | 14.3% | 14.3% | 14.3% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 28,094,192 | 28,094,192 | 28,094,192 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 222.0 | 222.0 | 222.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ produced (recycled) | kg $CO_2$ | 212,858,000 | 212,858,000 | 212,858,000 | System Data | Based on System Metering | 212,858,000 | 212,858,000 | 212,858,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 583.2 | 583.2 | 583.2 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ injected | kg $CO_2$ | 395,275,000 | 395,275,000 | 395,275,000 | System Data | Based on Injection Metering | 395,275,000 | 395,275,000 | 395,275,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 1,082.9 | 1,082.9 | 1,082.9 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, CO | 46.1% | 46.1% | 46.1% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ stored | kg $CO_2$ | 182,417,000 | 182,417,000 | 182,417,000 | System Data | Based on Injection Metering | 182,417,000 | 182,417,000 | 182,417,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored a | 1,442 | 1,442 | 1,442 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored a | 1,824 | 0 | 9,121 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected and | 46.1% | 46.1% | 46.1% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering Ga | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine production rate | kg brine / kg crude | 6.08 | 6.08 | 6.08 | System Data | Based on System Metering Br | 6.1 | 6.1 | 6.1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 6.1 | 6.1 | 6.1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbon | 2,764 | 2,732 | 2,797 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine production | kg brine | | | | Derived | Derived from the brine produ | 98,866,296 | 97,712,215 | 100,020,378 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine injection | kg brine | | | | Derived | Derived from the brine injecti | 98,866,296 | 97,712,215 | 100,020,378 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2016 | 2016 | 1 | 1 | 1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours to | 525,600 | 525,600 | 525,600 | |
| **GATE-TO-GATE: LAND USE** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 2 | | System Data | Lawnichak 9-33, Chester 6-16 | 2 | 2 | 2 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footprir | 20,234 | 20,234 | 20,234 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 22,258 | 22,258 | 22,258 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (20 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 166,100 | 166,100 | 166,100 | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.3 | 1.3 | 1.3 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (201 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissio | 1,582 | 1,582 | 1,582 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, pr | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 16,261 | 16,071 | 16,451 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 16 | 16 | 16 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and th | 10,732 | 10,607 | 10,857 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | Compressor power | MW | | | | Derived | NA,Derived from the compres | 1.57E+00 | 1.57E+00 | 1.57E+00 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | Compressor energy | MCF | 364,799 | 364,799 | 364,799 | System Data | System Data | 364,799 | 364,799 | 364,799 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 combustion | 19,936,922 | 19,936,922 | 19,936,922 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 157.5 | 157.5 | 157.5 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 11 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycled | 4,423,609 | 4,423,609 | 4,423,609 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 35.0 | 35.0 | 35.0 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of comp | 24,360,531 | 24,360,531 | 24,360,531 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and Injection Electricity | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 192.5 | 192.5 | 192.5 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 353 | 353 | 353 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity | kWh | 960996 | 960996 | 960996 | System Data | Chester 10 and Dover 36 Facil | 960,996 | 960,996 | 960,996 | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 961 | 961 | 961 | |
| Gate-to-Gate | Well Operations – Facility Electricity | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and th | 634,257 | 634,257 | 634,257 | |
| Gate-to-Gate | Well Operations – Facility Electricity | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 5.0 | 5.0 | 5.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Gas | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Gas | 95% | 95% | 95% | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Core | 344,186 | 344,186 | 344,186 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Gas | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 937,046 | 937,046 | 937,046 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting and Flaring | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncont | 7,073 | 3,495 | 14,312 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Gas | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas u | 163 | 161 | 165 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas | 1.81E-02 | 1.81E-02 | 1.81E-02 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas ( | 27 | 27 | 28 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas ( | 3 | 3 | 3 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas ( | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 100 | 99 | 101 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 0 | 0 | 0 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$, | 128 | 126 | 129 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Upstream (Industrial Boiler) | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (201 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas ( | 447 | 441 | 452 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas ( | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas ( | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 2 | 2 | 2 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$, | 449 | 444 | 455 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas Combustion (Industrial Boiler) | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 163 | 161 | 165 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 154 | 153 | 156 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentane | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 463 | 457 | 468 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlatio | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produc | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and th | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES)** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – $CO_2$ Ready for Reinjection | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 212,858,000 | 212,858,000 | 212,858,000 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Demand | iesel (purchased) thermal energy rate for backup power generato | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Demand | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal ene | 2,021,477 | 2,021,477 | 2,021,477 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Demand | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fired | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Demand | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fired | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Demand | Diesel use | L diesel | | | | Derived | Derived from the MJ of diesel | 51,806 | 51,806 | 51,806 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fired | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel re | 43,680 | 43,680 | 43,680 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Proc | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Proc | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Proc | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.74E+04 | 2.74E+04 | 2.74E+04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.83E+02 | 1.83E+02 | 1.83E+02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.31E-01 | 5.31E-01 | 5.31E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 6,215 | 6,215 | 6,215 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 158 | 158 | 158 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 33,736 | 33,736 | 33,736 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Upstream | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fired | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fired | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fired | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 137,502 | 137,502 | 137,502 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 19.7 | 19.7 | 19.7 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 3.6 | 3.6 | 3.6 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 670 | 670 | 670 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 1,060 | 1,060 | 1,060 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 139,232 | 139,232 | 139,232 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel Combustion | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.1 | 1.1 | 1.1 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | Natural gas use rate (2 turbines + 3 compressors) | kg natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holme | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produce | 212,858,000 | 212,858,000 | 212,858,000 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas u | 3,775,910 | 3,775,910 | 3,775,910 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 203,156,165,359 | 203,156,165,359 | 203,156,165,359 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 23,769,271 | 23,769,271 | 23,769,271 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 10,781,551 | 10,781,551 | 10,781,551 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Combustion (Turbines and Compressors) | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 85.2 | 85.2 | 85.2 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Purchased natural gas rate | purchased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 7.29E-03 | 7.29E-03 | 7.29E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased n | 1,551,572 | 1,551,572 | 1,551,572 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 260,875 | 260,875 | 260,875 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 28,078 | 28,078 | 28,078 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 7.1 | 7.1 | 7.1 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 954,647 | 954,647 | 954,647 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 2,125 | 2,125 | 2,125 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 1,217,647 | 1,217,647 | 1,217,647 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas Upstream | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 9.6 | 9.6 | 9.6 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holme | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ productio | 830,148 | 830,148 | 830,148 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ productio | 1,548,727 | 1,548,727 | 1,548,727 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ productio | 1,311,841 | 1,311,841 | 1,311,841 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ product | 1,504,017 | 1,504,017 | 1,504,017 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the i | 5,194,732 | 5,194,732 | 5,194,732 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL Production | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 253,502,940 | 253,502,940 | 253,502,940 | |
| **GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION)** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – EOR reinjection gas | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of I | 212,860,764 | 212,860,732 | 212,860,797 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Electricity | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Electricity | Electricity used | MWh | | | | Derived | Derived from the electricity ra | 2,936 | 2,936 | 2,936 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Electricity | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and th | 1,937,778 | 1,937,778 | 1,937,779 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Electricity | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 15.3 | 15.3 | 15.3 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extract | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas u | 408 | 408 | 408 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas ( | 69 | 69 | 69 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas ( | 7 | 7 | 7 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas ( | 0 | 0 | 0 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 251 | 251 | 251 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 1 | 1 | 1 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 320 | 320 | 320 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Upstream | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial B | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas ( | 1,119 | 1,119 | 1,119 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas ( | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas ( | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 0.7 | 0.7 | 0.7 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 6.1 | 6.1 | 6.1 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 1,126 | 1,126 | 1,126 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – Natural Gas Combustion (Industrial Boiler) | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.009 | 0.009 | 0.009 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extract | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extract | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extract | 6.29E-03 | 6.29E-03 | 6.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery rat | 281,910 | 281,910 | 281,910 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery rat | 766,539 | 766,539 | 766,539 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery rat | 1,339,901 | 1,339,900 | 1,339,901 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 14,180,085 | 14,180,083 | 14,180,087 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 37,253,792 | 37,253,786 | 37,253,797 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionation) – C3 to C5 Gas Production | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 67,263,008 | 67,262,998 | 67,263,019 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Membrane) – Fluid for Compression | Mass of fluid for compression | kg fluid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of I | 212,860,764 | 212,860,732 | 212,860,797 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Electricity Upstream | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Electricity Upstream | Energy use | MWh | | | | Derived | Derived from the mass of fluic | 4,239 | 4,239 | 4,239 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Electricity Upstream | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and th | 2,797,520 | 2,797,519 | 2,797,520 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Electricity Upstream | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 22.1 | 22.1 | 22.1 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Fugitive Emissions | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Fugitive Emissions | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the compressor | 7,013 | 7,013 | 7,013 | |
| Gate-to-Gate | Gas Processing (Membrane) – Compressor Fugitive Emissions | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Dehydration Electricity Upstream | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | Gas Processing (Membrane) – Dehydration Electricity Upstream | Energy usage | kWh | | | | Derived | Derived from the energy usag | 41,004 | 41,004 | 41,004 | |
| Gate-to-Gate | Gas Processing (Membrane) – Dehydration Electricity Upstream | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 41.0 | 41.0 | 41.0 | |
| Gate-to-Gate | Gas Processing (Membrane) – Dehydration Electricity Upstream | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and th | 27,062 | 27,062 | 27,062 | |
| Gate-to-Gate | Gas Processing (Membrane) – Dehydration Electricity Upstream | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.21 | 0.21 | 0.21 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller Electricity Upstream | Electricity rate per unit of gas | Wh / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Stream | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller Electricity Upstream | Electricity used | MWh | | | | Derived | Derived from the electricity ra | 355 | 355 | 355 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller Electricity Upstream | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and th | 234,615 | 234,615 | 234,615 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller Electricity Upstream | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.85 | 1.85 | 1.85 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Membrane Separation | Product hydrocarbon stream from membrane separation | kg hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (2015 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | Gas Processing (Membrane) – Membrane Separation | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of fluic | 74,766,149 | 74,766,138 | 74,766,160 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Inflow | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, $CO_2$ Recovery | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas f | 68,638,187 | 68,638,176 | 68,638,197 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Solvent Upstream | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Memb | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Gas Processing (Membrane) - Post-Membrane Amine $CO_2$ Capture, Solvent Upstream | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 6,877 | 6,877 | 6,877 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Memb | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas u | 4,559,541 | 4,347,157 | 4,771,925 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Gas | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Gas | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Gas | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas ( | 766,621 | 730,912 | 802,331 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas ( | 82,511 | 78,668 | 86,355 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas ( | 21 | 20 | 22 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 2,805,383 | 2,674,708 | 2,936,058 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP f | 6,245 | 5,954 | 6,536 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$, | 3,578,249 | 3,411,574 | 3,744,924 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Upstream | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 28.3 | 27.0 | 29.6 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial B | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.26E-05 | 5.26E-05 | 5.26E-05 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial B | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 12,520,602 | 11,937,391 | 13,103,813 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 240 | 229 | 251 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 230 | 219 | 240 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 8,159 | 7,779 | 8,539 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP f | 68,404 | 65,218 | 71,590 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$, | 12,597,166 | 12,010,389 | 13,183,943 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Natural Gas Combustion | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 99.5 | 94.9 | 104.2 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 6,127,962 | 6,127,961 | 6,127,963 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Memb | 10% | 10% | 10% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Memb | 8% | 8% | 8% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Memb | 14% | 14% | 14% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Memb | 24% | 24% | 24% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Memb | 6% | 6% | 6% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Memb | 14% | 14% | 14% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Memb | 20% | 20% | 20% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 509,145 | 509,145 | 509,145 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 841,175 | 841,175 | 841,175 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 1,440,941 | 1,440,941 | 1,440,941 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 339,133 | 339,133 | 339,133 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 865,491 | 865,491 | 865,491 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Memb | 1,215,408 | 1,215,408 | 1,215,408 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post-Membrane Amine $CO_2$ Capture, Sales Gas Stream (NGL) | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 299,044,555 | 299,044,510 | 299,044,600 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **206.4** | **206.3** | **206.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **96.2** | **96.2** | **96.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **15.3** | **15.3** | **15.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **152.1** | **146.1** | **158.0** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,441.5** | **1,441.5** | **1,441.5** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **222.0** | **222.0** | **222.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (2008 | 260 | 260 | 260 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/ton | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | Crude oil transport by pipeline to refinery | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degrees | 850 | 850 | 850 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ to | 135 | 135 | 135 | |
| Downstream | Crude oil transport by pipeline to refinery | Mass of crude oil transported | kg | | | | | Derived from the barrels of oi | 126,609,267 | 126,609,267 | 126,609,267 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy use | kWh | | | | | Derived from the one-way ene | 5,947,172 | 5,286,376 | 6,607,969 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5,947 | 5,286 | 6,608 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way ene | 3,925,134 | 3,489,008 | 4,361,260 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissio | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP f | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | ion of total refinery production (kerosene and kerosene-based jet | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$e / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2$e / bbl crude | | | | Derived | Product-weighted average em | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | Fuel transport to point-of-sale | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Applying IPCC 100-year GWP f | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Applying IPCC 100-year GWP f | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | Fuel transport to point-of-sale | Transport-weighted average emissions factor | kg $CO_2$e / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (20 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 71,823,232 | 67,833,052 | 76,312,184 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 11,075,151 | 7,554,347 | 16,997,281 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 57 | 39 | 87 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 184,586 | 209,197 | 189,585 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 29,157,000 | 18,358,111 | 41,305,750 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 150 | 94 | 212 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 165,223,000 | 165,223,000 | 165,223,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2015 | 2015 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.03 | 0.003 | 0.13 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **207** | **133** | **299** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 194,861 | 194,861 | 194,861 | System Data | Based on Oil Production | 194,861 | 194,861 | 194,861 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 25,039,639 | 24,747,347 | 25,331,930 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 40 | 40 | 40 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,060 | 2,060 | 2,060 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.49 | 0.49 | 0.49 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 165,223,000 | 165,223,000 | 165,223,000 | System Data | Based on Pure CO2 from Gas | 165,223,000 | 165,223,000 | 165,223,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 25.0 | 25.0 | 25.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,300 | 1,300 | 1,300 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 41.5% | 41.5% | 41.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 68,545,124 | 68,545,124 | 68,545,124 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 351.8 | 351.8 | 351.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 253,278,000 | 253,278,000 | 253,278,000 | System Data | Based on System Metering | 253,278,000 | 253,278,000 | 253,278,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 693.9 | 693.9 | 693.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 401,480,000 | 401,480,000 | 401,480,000 | System Data | Based on Injection Metering | 401,480,000 | 401,480,000 | 401,480,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 1,099.9 | 1,099.9 | 1,099.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 36.9% | 36.9% | 36.9% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 148,202,000 | 148,202,000 | 148,202,000 | System Data | Based on Injection Metering | 148,202,000 | 148,202,000 | 148,202,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 761 | 761 | 761 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,482 | 0 | 7,410 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 36.9% | 36.9% | 36.9% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 4.94 | 4.94 | 4.94 | System Data | Based on System Metering Br | 4.9 | 4.9 | 4.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 4.9 | 4.9 | 4.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 4,257 | 4,207 | 4,306 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 123,695,814 | 122,251,894 | 125,139,734 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 123,695,814 | 122,251,894 | 125,139,734 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2015 | 2015 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 2,436 | 2,436 | 2,436 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 25,040 | 24,747 | 25,332 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 25 | 25 | 25 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 16,526 | 16,333 | 16,719 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.87E+00 | 1.87E+00 | 1.87E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 376388 | 376388 | 376388 | System Data | System Data | 376,388 | 376,388 | 376,388 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 20,570,282 | 20,570,282 | 20,570,282 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 105.6 | 105.6 | 105.6 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 11 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 5,263,616 | 5,263,616 | 5,263,616 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 27.0 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 25,833,898 | 25,833,898 | 25,833,898 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 132.6 | 132.6 | 132.6 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 358 | 358 | 358 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 987629 | 987629 | 987629 | System Data | Chester 10 and Dover 36 Faci | 987,629 | 987,629 | 987,629 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 988 | 988 | 988 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 651,835 | 651,835 | 651,835 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 3.3 | 3.3 | 3.3 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 530,000 | 530,000 | 530,000 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 1,442,926 | 1,442,926 | 1,442,926 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 10,892 | 5,383 | 22,039 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 250 | 247 | 253 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 42 | 42 | 43 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 5 | 4 | 5 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 154 | 152 | 156 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 197 | 194 | 199 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 688 | 680 | 696 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.4 | 0.4 | 0.5 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 4 | 4 | 4 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 692 | 684 | 700 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 250 | 247 | 253 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 238 | 235 | 241 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 712 | 704 | 721 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 253,278,000 | 253,278,000 | 253,278,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 2,405,339 | 2,405,339 | 2,405,339 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 61,644 | 61,644 | 61,644 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 51,974 | 51,974 | 51,974 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 3.26E+04 | 3.26E+04 | 3.26E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2.18E+02 | 2.18E+02 | 2.18E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.31E-01 | 6.31E-01 | 6.31E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 7,395 | 7,395 | 7,395 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 188 | 188 | 188 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 40,142 | 40,142 | 40,142 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 163,612 | 163,612 | 163,612 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 23.4 | 23.4 | 23.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 4.2 | 4.2 | 4.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 797 | 797 | 797 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,262 | 1,262 | 1,262 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 165,671 | 165,671 | 165,671 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.9 | 0.9 | 0.9 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 253,278,000 | 253,278,000 | 253,278,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 4,492,925 | 4,492,925 | 4,492,925 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 241,733,866,004 | 241,733,866,004 | 241,733,866,004 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 28,282,862 | 28,282,862 | 28,282,862 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 12,828,880 | 12,828,880 | 12,828,880 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 65.8 | 65.8 | 65.8 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,846,203 | 1,846,203 | 1,846,203 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 310,412 | 310,412 | 310,412 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 33,410 | 33,410 | 33,410 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 8.5 | 8.5 | 8.5 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,135,927 | 1,135,927 | 1,135,927 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,529 | 2,529 | 2,529 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,448,868 | 1,448,868 | 1,448,868 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 7.4 | 7.4 | 7.4 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 987,786 | 987,786 | 987,786 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,842,818 | 1,842,818 | 1,842,818 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,560,948 | 1,560,948 | 1,560,948 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,789,618 | 1,789,618 | 1,789,618 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 6,181,170 | 6,181,170 | 6,181,170 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 301,641,083 | 301,641,083 | 301,641,083 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 253,282,257 | 253,282,207 | 253,282,306 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 3,494 | 3,494 | 3,494 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 2,305,755 | 2,305,755 | 2,305,756 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 11.8 | 11.8 | 11.8 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 485 | 485 | 485 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 82 | 82 | 82 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 9 | 9 | 9 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 298 | 298 | 298 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 381 | 381 | 381 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1,332 | 1,332 | 1,332 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.9 | 0.9 | 0.9 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7.3 | 7.3 | 7.3 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,340 | 1,340 | 1,340 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.007 | 0.007 | 0.007 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 335,444 | 335,444 | 335,444 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 912,102 | 912,102 | 912,102 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,594,343 | 1,594,343 | 1,594,343 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 16,872,832 | 16,872,829 | 16,872,836 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 44,328,153 | 44,328,144 | 44,328,161 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 80,036,011 | 80,035,996 | 80,036,027 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | fluid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 253,282,257 | 253,282,207 | 253,282,306 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 5,044 | 5,044 | 5,044 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 3,328,759 | 3,328,758 | 3,328,759 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 17.1 | 17.1 | 17.1 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 8,345 | 8,345 | 8,345 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.04 | 0.04 | 0.04 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 48,790 | 48,790 | 48,790 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 32,201 | 32,201 | 32,201 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.17 | 0.17 | 0.17 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 423 | 423 | 423 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 279,168 | 279,168 | 279,168 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.43 | 1.43 | 1.43 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 88,963,971 | 88,963,954 | 88,963,989 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 81,672,331 | 81,672,315 | 81,672,347 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 8,183 | 8,183 | 8,183 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 5,425,382 | 5,172,667 | 5,678,097 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 912,200 | 869,709 | 954,690 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 98,180 | 93,607 | 102,753 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 25 | 24 | 26 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 3,338,115 | 3,182,625 | 3,493,605 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 7,431 | 7,084 | 7,777 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 4,257,746 | 4,059,419 | 4,456,072 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 21.9 | 20.8 | 22.9 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 14,898,219 | 14,204,258 | 15,592,181 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 286 | 272 | 299 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 273 | 260 | 286 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 9,709 | 9,256 | 10,161 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 81,394 | 77,603 | 85,185 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 14,989,322 | 14,291,117 | 15,687,527 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 76.9 | 73.3 | 80.5 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 7,291,640 | 7,291,639 | 7,291,642 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 605,830 | 605,830 | 605,830 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,000,911 | 1,000,911 | 1,000,911 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,714,570 | 1,714,570 | 1,714,570 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 403,533 | 403,533 | 403,533 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,029,844 | 1,029,844 | 1,029,844 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,446,210 | 1,446,210 | 1,446,210 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 355,832,039 | 355,831,969 | 355,832,109 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **143.5** | **143.5** | **143.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **74.3** | **74.3** | **74.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **11.8** | **11.8** | **11.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **117.5** | **112.9** | **122.1** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **760.6** | **760.6** | **760.6** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **351.8** | **351.8** | **351.8** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 194,961,503 | 194,961,503 | 194,961,503 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 9,157,858 | 8,140,318 | 10,175,398 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 9,158 | 8,140 | 10,175 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 6,044,186 | 5,372,610 | 6,715,762 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 68,594,679 | 64,783,864 | 72,881,847 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 10,577,308 | 7,214,769 | 16,233,230 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 75 | 51 | 115 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 176,288 | 199,794 | 181,063 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 27,846,353 | 17,532,889 | 39,449,000 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 197 | 124 | 280 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 157,796,000 | 157,796,000 | 157,796,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2014 | 2014 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.005 | 0.18 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **272** | **175** | **395** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 141,140 | 141,140 | 141,140 | System Data | Based on Oil Production | 141,140 | 141,140 | 141,140 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 18,136,490 | 17,924,780 | 18,348,200 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 56 | 56 | 56 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,894 | 2,894 | 2,894 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.35 | 0.35 | 0.35 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 157,796,000 | 157,796,000 | 157,796,000 | System Data | Based on Pure CO2 from Gas | 157,796,000 | 157,796,000 | 157,796,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 36.0 | 36.0 | 36.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,872 | 1,872 | 1,872 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 45.4% | 45.4% | 45.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 71,608,561 | 71,608,561 | 71,608,561 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 507.4 | 507.4 | 507.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 264,215,000 | 264,215,000 | 264,215,000 | System Data | Based on System Metering | 264,215,000 | 264,215,000 | 264,215,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 723.9 | 723.9 | 723.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 408,528,000 | 408,528,000 | 408,528,000 | System Data | Based on Injection Metering | 408,528,000 | 408,528,000 | 408,528,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 1,119.3 | 1,119.3 | 1,119.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 35.3% | 35.3% | 35.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 144,313,000 | 144,313,000 | 144,313,000 | System Data | Based on Injection Metering | 144,313,000 | 144,313,000 | 144,313,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,022 | 1,022 | 1,022 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,443 | 0 | 7,216 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 35.3% | 35.3% | 35.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 3.94 | 3.94 | 3.94 | System Data | Based on System Metering Br | 3.9 | 3.9 | 3.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 3.9 | 3.9 | 3.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 3,083 | 3,047 | 3,119 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 71,457,771 | 70,623,633 | 72,291,908 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 71,457,771 | 70,623,633 | 72,291,908 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2014 | 2014 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,764 | 1,764 | 1,764 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 18,136 | 17,925 | 18,348 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 18 | 18 | 18 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 11,970 | 11,830 | 12,110 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.95E+00 | 1.95E+00 | 1.95E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 360641 | 360641 | 360641 | System Data | System Data | 360,641 | 360,641 | 360,641 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 19,709,680 | 19,709,680 | 19,709,680 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 139.6 | 139.6 | 139.6 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 5,490,908 | 5,490,908 | 5,490,908 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 38.9 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 25,200,588 | 25,200,588 | 25,200,588 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 178.6 | 178.6 | 178.6 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 365 | 365 | 365 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 947149 | 947149 | 947149 | System Data | Chester 10 and Dover 36 Faci | 947,149 | 947,149 | 947,149 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 947 | 947 | 947 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 625,118 | 625,118 | 625,118 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 4.4 | 4.4 | 4.4 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Venti | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Venti | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 383,885 | 383,885 | 383,885 | |
| Gate-to-Gate | Water Separation – Venti | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 1,045,128 | 1,045,128 | 1,045,128 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Venti | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 7,889 | 3,899 | 15,963 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 181 | 179 | 183 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 30 | 30 | 31 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 112 | 110 | 113 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 142 | 141 | 144 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 498 | 492 | 504 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 3 | 3 | 3 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 501 | 495 | 507 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 181 | 179 | 183 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 172 | 170 | 174 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 516 | 510 | 522 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 264,215,000 | 264,215,000 | 264,215,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 2,509,206 | 2,509,206 | 2,509,206 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 64,306 | 64,306 | 64,306 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 54,219 | 54,219 | 54,219 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 3.40E+04 | 3.40E+04 | 3.40E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2.27E+02 | 2.27E+02 | 2.27E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.59E-01 | 6.59E-01 | 6.59E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7,715 | 7,715 | 7,715 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 196 | 196 | 196 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 41,875 | 41,875 | 41,875 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 170,677 | 170,677 | 170,677 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 24.5 | 24.5 | 24.5 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 4.4 | 4.4 | 4.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 832 | 832 | 832 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,316 | 1,316 | 1,316 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 172,825 | 172,825 | 172,825 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.2 | 1.2 | 1.2 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 264,215,000 | 264,215,000 | 264,215,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 4,686,937 | 4,686,937 | 4,686,937 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 252,172,369,516 | 252,172,369,516 | 252,172,369,516 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 29,504,167 | 29,504,167 | 29,504,167 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 13,382,854 | 13,382,854 | 13,382,854 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 94.8 | 94.8 | 94.8 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,925,926 | 1,925,926 | 1,925,926 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 323,817 | 323,817 | 323,817 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 34,852 | 34,852 | 34,852 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 8.9 | 8.9 | 8.9 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,184,979 | 1,184,979 | 1,184,979 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,638 | 2,638 | 2,638 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,511,433 | 1,511,433 | 1,511,433 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 10.7 | 10.7 | 10.7 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 1,030,440 | 1,030,440 | 1,030,440 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,922,394 | 1,922,394 | 1,922,394 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,628,353 | 1,628,353 | 1,628,353 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,866,897 | 1,866,897 | 1,866,897 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 6,448,084 | 6,448,084 | 6,448,084 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 314,666,488 | 314,666,488 | 314,666,488 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 264,218,083 | 264,218,047 | 264,218,119 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 3,644 | 3,644 | 3,644 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 2,405,310 | 2,405,309 | 2,405,310 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 17.0 | 17.0 | 17.0 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 506 | 506 | 506 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 85 | 85 | 85 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 9 | 9 | 9 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 311 | 311 | 311 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 397 | 397 | 397 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1,389 | 1,389 | 1,389 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.9 | 0.9 | 0.9 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7.6 | 7.6 | 7.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,398 | 1,398 | 1,398 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.010 | 0.010 | 0.010 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 349,927 | 349,927 | 349,927 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 951,483 | 951,483 | 951,483 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,663,181 | 1,663,181 | 1,663,181 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 17,601,341 | 17,601,339 | 17,601,344 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 46,242,084 | 46,242,078 | 46,242,091 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 83,491,682 | 83,491,670 | 83,491,693 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 264,218,083 | 264,218,047 | 264,218,119 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 5,261 | 5,261 | 5,261 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 3,472,483 | 3,472,482 | 3,472,483 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 24.6 | 24.6 | 24.6 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 8,706 | 8,706 | 8,706 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 50,897 | 50,897 | 50,897 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 50.9 | 50.9 | 50.9 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 33,592 | 33,592 | 33,592 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.24 | 0.24 | 0.24 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 441 | 441 | 441 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 291,221 | 291,221 | 291,221 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.06 | 2.06 | 2.06 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 92,805,119 | 92,805,106 | 92,805,132 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 85,198,652 | 85,198,640 | 85,198,663 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 8,536 | 8,536 | 8,536 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 5,659,631 | 5,396,004 | 5,923,257 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 951,585 | 907,260 | 995,910 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 102,419 | 97,648 | 107,190 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 26 | 25 | 27 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,482,243 | 3,320,040 | 3,644,446 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7,751 | 7,390 | 8,112 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 4,441,580 | 4,234,691 | 4,648,469 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 31.5 | 30.0 | 32.9 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 15,541,472 | 14,817,549 | 16,265,395 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 298 | 284 | 312 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 285 | 272 | 298 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 10,128 | 9,656 | 10,600 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 84,908 | 80,953 | 88,863 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 15,636,508 | 14,908,158 | 16,364,858 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 110.8 | 105.6 | 115.9 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 7,606,467 | 7,606,466 | 7,606,468 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 631,987 | 631,987 | 631,987 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,044,127 | 1,044,127 | 1,044,127 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,788,599 | 1,788,599 | 1,788,599 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 420,956 | 420,956 | 420,956 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,074,309 | 1,074,309 | 1,074,309 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,508,652 | 1,508,652 | 1,508,652 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 371,195,600 | 371,195,549 | 371,195,651 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **190.6** | **190.6** | **190.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **107.0** | **107.0** | **107.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **17.1** | **17.1** | **17.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **169.2** | **162.6** | **175.8** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,022.5** | **1,022.5** | **1,022.5** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **507.4** | **507.4** | **507.4** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 141,212,795 | 141,212,795 | 141,212,795 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 6,633,139 | 5,896,123 | 7,370,154 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 6,633 | 5,896 | 7,370 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 4,377,872 | 3,891,441 | 4,864,302 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | Coal mining, processing, and transport | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | Coal mining, processing, and transport | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 87,289,594 | 82,440,172 | 92,745,193 | |
| Upstream | Coal mining, processing, and transport | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | Coal mining, processing, and transport | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 13,460,066 | 9,181,094 | 20,657,463 | |
| Upstream | Coal mining, processing, and transport | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 93 | 64 | 143 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 224,334 | 254,246 | 230,410 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 35,435,647 | 22,311,333 | 50,200,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 246 | 155 | 349 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 200,802,000 | 200,802,000 | 200,802,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2013 | 2013 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.005 | 0.18 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **340** | **219** | **492** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil produced | bbl crude | 143,982 | 143,982 | 143,982 | System Data | Based on Oil Production | 143,982 | 143,982 | 143,982 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 18,501,687 | 18,285,714 | 18,717,660 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 62 | 62 | 62 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,221 | 3,221 | 3,221 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.31 | 0.31 | 0.31 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 200,802,000 | 200,802,000 | 200,802,000 | System Data | Based on Pure CO2 from Gas | 200,802,000 | 200,802,000 | 200,802,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 36.9 | 36.9 | 36.9 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,917 | 1,917 | 1,917 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 32.0% | 32.0% | 32.0% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 64,318,641 | 64,318,641 | 64,318,641 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 446.7 | 446.7 | 446.7 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ produced (recycled) | kg $CO_2$ | 276,068,000 | 276,068,000 | 276,068,000 | System Data | Based on System Metering | 276,068,000 | 276,068,000 | 276,068,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 756.4 | 756.4 | 756.4 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ injected | kg $CO_2$ | 463,710,000 | 463,710,000 | 463,710,000 | System Data | Based on Injection Metering | 463,710,000 | 463,710,000 | 463,710,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 1,270.4 | 1,270.4 | 1,270.4 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 40.5% | 40.5% | 40.5% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ stored | kg $CO_2$ | 187,641,000 | 187,641,000 | 187,641,000 | System Data | Based on Injection Metering | 187,641,000 | 187,641,000 | 187,641,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,303 | 1,303 | 1,303 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,876 | 0 | 9,382 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 40.5% | 40.5% | 40.5% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine production rate | kg brine / kg crude | 2.5 | 2.5 | 2.5 | System Data | Based on System Metering Bt | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 3,145 | 3,109 | 3,182 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine production | kg brine | | | | Derived | Derived from the brine produ | 46,254,218 | 45,714,285 | 46,794,150 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 46,254,218 | 45,714,285 | 46,794,150 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2013 | 2013 | 1 | 1 | 1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas production | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| **GATE-TO-GATE: LAND USE** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 1 | | System Data | Cargas 3-2 HD2 (Lateral)Piase | 1 | 1 | 1 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 12,141 | 12,141 | 12,141 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 90,600 | 90,600 | 90,600 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.6 | 0.6 | 0.6 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,800 | 1,800 | 1,800 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 18,502 | 18,286 | 18,718 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 19 | 18 | 19 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 12,211 | 12,069 | 12,354 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | Compressor power | MW | | | | Derived | NA,Derived from the compre | 2.04E+00 | 2.04E+00 | 2.04E+00 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | Compressor energy | MCF | 422125 | 422125 | 422125 | System Data | System Data | 422,125 | 422,125 | 422,125 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 23,069,891 | 23,069,891 | 23,069,891 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 160.2 | 160.2 | 160.2 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 dat | Derived from the $CO_2$ recycle | 5,737,237 | 5,737,237 | 5,737,237 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 39.8 | 33.8 | 33.8 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 28,807,128 | 28,807,128 | 28,807,128 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compression and | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 200.1 | 200.1 | 200.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 414 | 414 | 414 | |
| Gate-to-Gate | Well Operations – $CO_2$ Compressor Fugitives | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity | kWh | 1067894 | 1067894 | 1067894 | System Data | Chester 10 and Dover 36 Faci | 1,067,894 | 1,067,894 | 1,067,894 | |
| Gate-to-Gate | Well Operations – Facility Electricity | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 1,068 | 1,068 | 1,068 | |
| Gate-to-Gate | Well Operations – Facility Electricity | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 704,810 | 704,810 | 704,810 | |
| Gate-to-Gate | Well Operations – Facility Electricity | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 4.9 | 4.9 | 4.9 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 391,615 | 391,615 | 391,615 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 1,066,172 | 1,066,172 | 1,066,172 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Venting | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 8,048 | 3,977 | 16,284 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 185 | 183 | 187 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 31 | 31 | 31 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 114 | 113 | 115 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 145 | 144 | 147 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 508 | 502 | 514 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3 | 3 | 3 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 511 | 505 | 517 | |
| Gate-to-Gate | Oil, Gas, and Water Separation – Natural Gas | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 185 | 183 | 187 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 176 | 174 | 178 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 526 | 520 | 533 | |
| Gate-to-Gate | Crude Storage – Venting and Flaring | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | Methane released to atmosphere | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Storage – Venting and Flaring | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | Brine Disposal – Injection Well Electricity | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – $CO_2$ Ready for | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 276,068,000 | 276,068,000 | 276,068,000 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 2,621,772 | 2,621,772 | 2,621,772 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 67,190 | 67,190 | 67,190 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 56,651 | 56,651 | 56,651 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 3.55E+04 | 3.55E+04 | 3.55E+04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2.37E+02 | 2.37E+02 | 2.37E+02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.88E-01 | 6.88E-01 | 6.88E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 8,061 | 8,061 | 8,061 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 205 | 205 | 205 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 43,754 | 43,754 | 43,754 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 178,334 | 178,334 | 178,334 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 25.6 | 25.6 | 25.6 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 4.6 | 4.6 | 4.6 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 869 | 869 | 869 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,375 | 1,375 | 1,375 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 180,578 | 180,578 | 180,578 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.3 | 1.3 | 1.3 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 276,068,000 | 276,068,000 | 276,068,000 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 4,897,199 | 4,897,199 | 4,897,199 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 263,485,122,751 | 263,485,122,751 | 263,485,122,751 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 30,827,759 | 30,827,759 | 30,827,759 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 13,983,225 | 13,983,225 | 13,983,225 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 97.1 | 97.1 | 97.1 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Purchased natural gas rate | hased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 2,012,325 | 2,012,325 | 2,012,325 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 338,343 | 338,343 | 338,343 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 36,416 | 36,416 | 36,416 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 9.2 | 9.2 | 9.2 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,238,138 | 1,238,138 | 1,238,138 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,756 | 2,756 | 2,756 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,579,238 | 1,579,238 | 1,579,238 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 11.0 | 11.0 | 11.0 | RH |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 1,076,667 | 1,076,667 | 1,076,667 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 2,008,635 | 2,008,635 | 2,008,635 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,701,403 | 1,701,403 | 1,701,403 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,950,648 | 1,950,648 | 1,950,648 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 6,737,353 | 6,737,353 | 6,737,353 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | Gas Processing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 328,782,802 | 328,782,802 | 328,782,802 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 276,071,145 | 276,071,109 | 276,071,182 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Electricity used | MWh | | | | Derived | Derived from the electricity r | 3,808 | 3,808 | 3,808 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 2,513,214 | 2,513,214 | 2,513,214 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 17.5 | 17.5 | 17.5 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 529 | 529 | 529 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 89 | 89 | 89 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 10 | 10 | 10 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 325 | 325 | 325 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 415 | 415 | 415 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial E | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1,452 | 1,452 | 1,452 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.03 | 0.03 | 0.03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.9 | 0.9 | 0.9 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7.9 | 7.9 | 7.9 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,461 | 1,461 | 1,461 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.010 | 0.010 | 0.010 | RF |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 365,625 | 365,625 | 365,625 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 994,168 | 994,167 | 994,168 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,737,793 | 1,737,792 | 1,737,793 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 18,390,953 | 18,390,951 | 18,390,956 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 48,316,546 | 48,316,540 | 48,316,553 | |
| Gate-to-Gate | Gas Processing (Refrigeration/Fractionat | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 87,237,194 | 87,237,182 | 87,237,205 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Membrane) – Fluid for | Mass of fluid for compression | fluid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 276,071,145 | 276,071,109 | 276,071,182 | |
| Gate-to-Gate | Gas Processing (Membrane) – | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – | Energy use | MWh | | | | Derived | Derived from the mass of flui | 5,497 | 5,497 | 5,497 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 3,628,261 | 3,628,261 | 3,628,262 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 25.2 | 25.2 | 25.2 | M |
| Gate-to-Gate | Gas Processing (Membrane) – | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 9,096 | 9,096 | 9,096 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | Gas Processing (Membrane) – | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | Gas Processing (Membrane) – | Energy usage | kWh | | | | Derived | Derived from the energy usag | 53,180 | 53,180 | 53,180 | |
| Gate-to-Gate | Gas Processing (Membrane) – | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 53.2 | 53.2 | 53.2 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 35,099 | 35,099 | 35,099 | |
| Gate-to-Gate | Gas Processing (Membrane) – | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.24 | 0.24 | 0.24 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller | Electricity used | MWh | | | | Derived | Derived from the electricity r | 461 | 461 | 461 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 304,286 | 304,286 | 304,286 | |
| Gate-to-Gate | Gas Processing (Membrane) – Chiller | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.11 | 2.11 | 2.11 | M |
| Gate-to-Gate | Gas Processing (Membrane) – | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | Gas Processing (Membrane) – | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 96,968,441 | 96,968,428 | 96,968,453 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 89,020,740 | 89,020,729 | 89,020,752 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Gas Processing (Membrane) - Post- | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 8,919 | 8,919 | 8,919 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 5,913,527 | 5,638,074 | 6,188,979 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 994,274 | 947,961 | 1,040,588 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 107,014 | 102,029 | 111,998 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 27 | 26 | 28 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 3,638,460 | 3,468,980 | 3,807,939 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 8,099 | 7,722 | 8,476 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 4,640,833 | 4,424,663 | 4,857,004 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 32.2 | 30.7 | 33.7 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 16,238,676 | 15,482,277 | 16,995,075 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 311 | 297 | 326 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 298 | 284 | 312 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 10,582 | 10,089 | 11,075 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 88,717 | 84,585 | 92,850 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 16,337,976 | 15,576,951 | 17,099,000 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 113.5 | 108.2 | 118.8 | M |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 7,947,700 | 7,947,699 | 7,947,701 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 660,339 | 660,339 | 660,339 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,090,968 | 1,090,968 | 1,090,968 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,868,837 | 1,868,837 | 1,868,837 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 439,841 | 439,841 | 439,841 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,122,504 | 1,122,504 | 1,122,504 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,576,331 | 1,576,331 | 1,576,331 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | Gas Processing (Membrane) – Post- | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 387,847,770 | 387,847,719 | 387,847,822 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **213.2** | **213.1** | **213.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **109.6** | **109.6** | **109.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **17.5** | **17.5** | **17.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **173.3** | **166.5** | **180.1** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **1,303.2** | **1,303.2** | **1,303.2** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **446.7** | **446.7** | **446.7** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | Crude oil transport by pipeline to refinery | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | Crude oil transport by pipeline to refinery | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | Crude oil transport by pipeline to refinery | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 144,056,261 | 144,056,261 | 144,056,261 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy use | kWh | | | | | Derived from the one-way en | 6,766,704 | 6,014,848 | 7,518,560 | |
| Downstream | Crude oil transport by pipeline to refinery | One-way energy use | MWh | | | | | Unit conversion from kWh to | 6,767 | 6,015 | 7,519 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 4,466,025 | 3,969,800 | 4,962,250 | |
| Downstream | Crude oil transport by pipeline to refinery | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | Fuel transport to point-of-sale | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | Fuel transport to point-of-sale | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 75,171,763 | 70,995,554 | 79,869,998 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 11,591,495 | 7,906,544 | 17,789,725 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 92 | 63 | 141 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 193,192 | 218,950 | 198,424 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 30,516,353 | 19,214,000 | 43,231,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 243 | 153 | 344 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 172,926,000 | 172,926,000 | 172,926,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2012 | 2012 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.005 | 0.20 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **335** | **216** | **485** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 125,805 | 125,805 | 125,805 | System Data | Based on Oil Production | 125,805 | 125,805 | 125,805 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 16,165,943 | 15,977,235 | 16,354,650 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 58 | 58 | 58 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,006 | 3,006 | 3,006 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.33 | 0.33 | 0.33 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 172,926,000 | 172,926,000 | 172,926,000 | System Data | Based on Pure CO2 from Gas | 172,926,000 | 172,926,000 | 172,926,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 33.4 | 33.4 | 33.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,735 | 1,735 | 1,735 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 26.8% | 26.8% | 26.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 46,294,370 | 46,294,370 | 46,294,370 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 368.0 | 368.0 | 368.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 218,298,000 | 218,298,000 | 218,298,000 | System Data | Based on System Metering | 218,298,000 | 218,298,000 | 218,298,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 598.1 | 598.1 | 598.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 378,155,000 | 378,155,000 | 378,155,000 | System Data | Based on Injection Metering | 378,155,000 | 378,155,000 | 378,155,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 1,036.0 | 1,036.0 | 1,036.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 42.3% | 42.3% | 42.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 159,857,000 | 159,857,000 | 159,857,000 | System Data | Based on Injection Metering | 159,857,000 | 159,857,000 | 159,857,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,271 | 1,271 | 1,271 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,599 | 0 | 7,993 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 42.3% | 42.3% | 42.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 3.32 | 3.32 | 3.32 | System Data | Based on System Metering Br | 3.3 | 3.3 | 3.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 3.3 | 3.3 | 3.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,748 | 2,716 | 2,780 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 53,670,929 | 53,044,420 | 54,297,438 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 53,670,929 | 53,044,420 | 54,297,438 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2012 | 2012 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,573 | 1,573 | 1,573 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 16,166 | 15,977 | 16,355 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 16 | 16 | 16 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 10,670 | 10,545 | 10,794 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.61E+00 | 1.61E+00 | 1.61E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 369013 | 369013 | 369013 | System Data | System Data | 369,013 | 369,013 | 369,013 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 20,167,225 | 20,167,225 | 20,167,225 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 160.3 | 160.3 | 160.3 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 4,536,663 | 4,536,663 | 4,536,663 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 36.1 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 24,703,887 | 24,703,887 | 24,703,887 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 196.4 | 196.4 | 196.4 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 337 | 337 | 337 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 1016193 | 1016193 | 1016193 | System Data | Chester 10 and Dover 36 Faci | 1,016,193 | 1,016,193 | 1,016,193 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 1,016 | 1,016 | 1,016 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 670,687 | 670,687 | 670,687 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 5.3 | 5.3 | 5.3 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 342,176 | 342,176 | 342,176 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 931,574 | 931,574 | 931,574 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 7,032 | 3,475 | 14,229 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 162 | 160 | 164 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 27 | 27 | 27 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 99 | 98 | 101 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 127 | 125 | 128 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 444 | 439 | 449 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 447 | 441 | 452 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 162 | 160 | 164 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 154 | 152 | 155 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 460 | 455 | 465 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 218,298,000 | 218,298,000 | 218,298,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 2,073,140 | 2,073,140 | 2,073,140 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 53,130 | 53,130 | 53,130 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 44,796 | 44,796 | 44,796 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.81E+04 | 2.81E+04 | 2.81E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.87E+02 | 1.87E+02 | 1.87E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.44E-01 | 5.44E-01 | 5.44E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 6,374 | 6,374 | 6,374 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 162 | 162 | 162 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 34,598 | 34,598 | 34,598 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 141,016 | 141,016 | 141,016 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 20.2 | 20.2 | 20.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 3.6 | 3.6 | 3.6 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 687 | 687 | 687 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,087 | 1,087 | 1,087 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 142,790 | 142,790 | 142,790 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.1 | 1.1 | 1.1 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 218,298,000 | 218,298,000 | 218,298,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 3,872,411 | 3,872,411 | 3,872,411 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 208,348,216,114 | 208,348,216,114 | 208,348,216,114 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 24,376,741 | 24,376,741 | 24,376,741 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 11,057,095 | 11,057,095 | 11,057,095 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 87.9 | 87.9 | 87.9 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,591,226 | 1,591,226 | 1,591,226 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 267,542 | 267,542 | 267,542 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 28,795 | 28,795 | 28,795 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 7.3 | 7.3 | 7.3 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 979,045 | 979,045 | 979,045 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,179 | 2,179 | 2,179 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,248,766 | 1,248,766 | 1,248,766 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 9.9 | 9.9 | 9.9 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 851,364 | 851,364 | 851,364 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,588,308 | 1,588,308 | 1,588,308 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,345,367 | 1,345,367 | 1,345,367 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,542,455 | 1,542,455 | 1,542,455 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 5,327,494 | 5,327,494 | 5,327,494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 259,981,701 | 259,981,701 | 259,981,701 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 218,300,748 | 218,300,716 | 218,300,780 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 3,011 | 3,011 | 3,011 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,987,301 | 1,987,301 | 1,987,301 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 15.8 | 15.8 | 15.8 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 418 | 418 | 418 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 70 | 70 | 70 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 8 | 8 | 8 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 257 | 257 | 257 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 328 | 328 | 328 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1,148 | 1,148 | 1,148 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.7 | 0.7 | 0.7 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 6.3 | 6.3 | 6.3 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,155 | 1,155 | 1,155 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.009 | 0.009 | 0.009 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 289,115 | 289,115 | 289,115 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 786,129 | 786,129 | 786,129 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,374,144 | 1,374,144 | 1,374,144 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 14,542,479 | 14,542,477 | 14,542,481 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 38,205,870 | 38,205,864 | 38,205,875 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 68,982,018 | 68,982,008 | 68,982,028 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | fluid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 218,300,748 | 218,300,716 | 218,300,780 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 4,347 | 4,347 | 4,347 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,869,015 | 2,869,014 | 2,869,015 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 22.8 | 22.8 | 22.8 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 7,193 | 7,193 | 7,193 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 42,052 | 42,052 | 42,052 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 42.1 | 42.1 | 42.1 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 27,754 | 27,754 | 27,754 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.22 | 0.22 | 0.22 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 365 | 365 | 365 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 240,611 | 240,611 | 240,611 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.91 | 1.91 | 1.91 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 76,676,913 | 76,676,902 | 76,676,924 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 70,392,341 | 70,392,331 | 70,392,351 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 7,053 | 7,053 | 7,053 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 4,676,067 | 4,458,256 | 4,893,879 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 786,213 | 749,592 | 822,835 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 84,620 | 80,678 | 88,562 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 21 | 20 | 22 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,877,079 | 2,743,064 | 3,011,094 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 6,404 | 6,106 | 6,703 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 3,669,697 | 3,498,762 | 3,840,631 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 29.2 | 27.8 | 30.5 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 12,840,585 | 12,242,470 | 13,438,701 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 246 | 235 | 258 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 235 | 224 | 246 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 8,368 | 7,978 | 8,758 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 70,152 | 66,885 | 73,420 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 12,919,106 | 12,317,332 | 13,520,879 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 102.7 | 97.9 | 107.5 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 6,284,572 | 6,284,571 | 6,284,573 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 522,157 | 522,157 | 522,157 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 862,673 | 862,673 | 862,673 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,477,766 | 1,477,766 | 1,477,766 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 347,800 | 347,800 | 347,800 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 887,610 | 887,610 | 887,610 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,246,470 | 1,246,470 | 1,246,470 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 306,687,098 | 306,687,053 | 306,687,143 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **209.4** | **209.3** | **209.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **99.2** | **99.2** | **99.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **15.8** | **15.8** | **15.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **156.9** | **150.7** | **163.0** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **1,270.7** | **1,270.7** | **1,270.7** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **368.0** | **368.0** | **368.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 125,869,886 | 125,869,886 | 125,869,886 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 5,912,442 | 5,255,504 | 6,569,380 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5,912 | 5,256 | 6,569 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,902,212 | 3,468,633 | 4,335,791 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | ining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | ining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | ining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | ining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 75,833,818 | 71,620,828 | 80,573,432 | |
| Upstream | ining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | ining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 11,693,584 | 7,976,179 | 17,946,403 | |
| Upstream | ining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 95 | 65 | 146 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 194,893 | 220,879 | 200,171 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 30,785,118 | 19,383,222 | 43,612,250 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 251 | 158 | 356 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 174,449,000 | 174,449,000 | 174,449,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2011 | 2011 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.006 | 0.21 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **347** | **223** | **502** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 122,594 | 122,594 | 122,594 | System Data | Based on Oil Production | 122,594 | 122,594 | 122,594 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 15,753,329 | 15,569,438 | 15,937,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 55 | 55 | 55 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,842 | 2,842 | 2,842 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.35 | 0.35 | 0.35 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 174,449,000 | 174,449,000 | 174,449,000 | System Data | Based on Pure CO2 from Gas | 174,449,000 | 174,449,000 | 174,449,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 28.6 | 28.6 | 28.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,484 | 1,484 | 1,484 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 8.5% | 8.5% | 8.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 14,841,521 | 14,841,521 | 14,841,521 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 121.1 | 121.1 | 121.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 181,942,000 | 181,942,000 | 181,942,000 | System Data | Based on System Metering | 181,942,000 | 181,942,000 | 181,942,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 498.5 | 498.5 | 498.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 348,405,000 | 348,405,000 | 348,405,000 | System Data | Based on Injection Metering | 348,405,000 | 348,405,000 | 348,405,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 954.5 | 954.5 | 954.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 47.8% | 47.8% | 47.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 166,463,000 | 166,463,000 | 166,463,000 | System Data | Based on Injection Metering | 166,463,000 | 166,463,000 | 166,463,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,358 | 1,358 | 1,358 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,665 | 0 | 8,323 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 47.8% | 47.8% | 47.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 2.82 | 2.82 | 2.82 | System Data | Based on System Metering Br | 2.8 | 2.8 | 2.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 2.8 | 2.8 | 2.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,678 | 2,647 | 2,709 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 44,424,388 | 43,905,815 | 44,942,960 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 44,424,388 | 43,905,815 | 44,942,960 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2011 | 2011 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,532 | 1,532 | 1,532 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 15,753 | 15,569 | 15,937 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 16 | 16 | 16 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 10,397 | 10,276 | 10,519 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.35E+00 | 1.35E+00 | 1.35E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 353103 | 353103 | 353103 | System Data | System Data | 353,103 | 353,103 | 353,103 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 19,297,715 | 19,297,715 | 19,297,715 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 157.4 | 157.4 | 157.4 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,781,113 | 3,781,113 | 3,781,113 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 30.8 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 23,078,828 | 23,078,828 | 23,078,828 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 188.3 | 188.3 | 188.3 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 311 | 311 | 311 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 770569 | 770569 | 770569 | System Data | Chester 10 and Dover 36 Faci | 770,569 | 770,569 | 770,569 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 771 | 771 | 771 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 508,576 | 508,576 | 508,576 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 4.1 | 4.1 | 4.1 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 333,442 | 333,442 | 333,442 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 907,796 | 907,796 | 907,796 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 6,853 | 3,386 | 13,865 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 158 | 156 | 159 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 26 | 26 | 27 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 97 | 96 | 98 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 124 | 122 | 125 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 433 | 428 | 438 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 435 | 430 | 440 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 158 | 156 | 159 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 150 | 148 | 151 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 448 | 443 | 453 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 181,942,000 | 181,942,000 | 181,942,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,727,873 | 1,727,873 | 1,727,873 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 44,282 | 44,282 | 44,282 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 37,336 | 37,336 | 37,336 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.34E+04 | 2.34E+04 | 2.34E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.56E+02 | 1.56E+02 | 1.56E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.54E-01 | 4.54E-01 | 4.54E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,313 | 5,313 | 5,313 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 135 | 135 | 135 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 28,836 | 28,836 | 28,836 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 117,531 | 117,531 | 117,531 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 16.8 | 16.8 | 16.8 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 3.0 | 3.0 | 3.0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 573 | 573 | 573 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 906 | 906 | 906 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 119,010 | 119,010 | 119,010 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.0 | 1.0 | 1.0 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 181,942,000 | 181,942,000 | 181,942,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 3,227,488 | 3,227,488 | 3,227,488 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 173,649,282,798 | 173,649,282,798 | 173,649,282,798 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 20,316,966 | 20,316,966 | 20,316,966 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 9,215,613 | 9,215,613 | 9,215,613 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 75.2 | 75.2 | 75.2 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,326,218 | 1,326,218 | 1,326,218 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 222,984 | 222,984 | 222,984 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 24,000 | 24,000 | 24,000 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.1 | 6.1 | 6.1 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 815,992 | 815,992 | 815,992 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,816 | 1,816 | 1,816 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,040,793 | 1,040,793 | 1,040,793 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 8.5 | 8.5 | 8.5 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 709,575 | 709,575 | 709,575 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,323,786 | 1,323,786 | 1,323,786 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,121,306 | 1,121,306 | 1,121,306 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,285,570 | 1,285,570 | 1,285,570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 4,440,237 | 4,440,237 | 4,440,237 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 216,683,573 | 216,683,573 | 216,683,573 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 181,944,678 | 181,944,647 | 181,944,709 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,510 | 2,510 | 2,510 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,656,334 | 1,656,333 | 1,656,334 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 13.5 | 13.5 | 13.5 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 348 | 348 | 348 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 59 | 59 | 59 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 6 | 6 | 6 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 214 | 214 | 214 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 273 | 273 | 273 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 957 | 957 | 957 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.6 | 0.6 | 0.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5.2 | 5.2 | 5.2 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 963 | 963 | 963 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.008 | 0.008 | 0.008 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 240,965 | 240,965 | 240,965 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 655,206 | 655,206 | 655,206 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,145,292 | 1,145,292 | 1,145,292 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 12,120,557 | 12,120,555 | 12,120,559 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 31,843,018 | 31,843,012 | 31,843,023 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 57,493,669 | 57,493,660 | 57,493,679 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 181,944,678 | 181,944,647 | 181,944,709 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 3,623 | 3,623 | 3,623 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,391,205 | 2,391,205 | 2,391,206 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 19.5 | 19.5 | 19.5 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 5,995 | 5,995 | 5,995 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.05 | 0.05 | 0.05 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 35,048 | 35,048 | 35,048 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 35.0 | 35.0 | 35.0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 23,132 | 23,132 | 23,132 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.19 | 0.19 | 0.19 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 304 | 304 | 304 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 200,539 | 200,539 | 200,539 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.64 | 1.64 | 1.64 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 63,907,047 | 63,907,036 | 63,907,058 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 58,669,116 | 58,669,106 | 58,669,126 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 5,878 | 5,878 | 5,878 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,897,310 | 3,715,772 | 4,078,847 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 655,276 | 624,754 | 685,799 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 70,527 | 67,242 | 73,812 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 18 | 17 | 19 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,397,927 | 2,286,231 | 2,509,622 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,338 | 5,089 | 5,586 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 3,058,541 | 2,916,074 | 3,201,008 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 24.9 | 23.8 | 26.1 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 10,702,099 | 10,203,594 | 11,200,604 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 205 | 196 | 215 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 196 | 187 | 205 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 6,974 | 6,649 | 7,299 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 58,469 | 55,746 | 61,193 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 10,767,542 | 10,265,989 | 11,269,096 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 87.8 | 83.7 | 91.9 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 5,237,932 | 5,237,931 | 5,237,932 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 435,196 | 435,196 | 435,196 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 719,002 | 719,002 | 719,002 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,231,657 | 1,231,657 | 1,231,657 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 289,877 | 289,877 | 289,877 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 739,786 | 739,786 | 739,786 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,038,881 | 1,038,881 | 1,038,881 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 255,611,059 | 255,611,015 | 255,611,102 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **200.1** | **200.0** | **200.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **84.9** | **84.9** | **84.9** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **13.5** | **13.5** | **13.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **134.2** | **128.9** | **139.4** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,357.8** | **1,357.8** | **1,357.8** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **121.1** | **121.1** | **121.1** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 122,657,230 | 122,657,230 | 122,657,230 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 5,761,535 | 5,121,364 | 6,401,705 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5,762 | 5,121 | 6,402 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,802,613 | 3,380,100 | 4,225,126 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 68,474,701 | 64,670,551 | 72,754,369 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 10,558,807 | 7,202,149 | 16,204,836 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 105 | 72 | 161 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 175,980 | 199,444 | 180,746 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 27,797,647 | 17,502,222 | 39,380,000 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 277 | 174 | 392 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 157,520,000 | 157,520,000 | 157,520,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2010 | 2010 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.07 | 0.007 | 0.25 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **382** | **246** | **554** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 100,448 | 100,448 | 100,448 | System Data | Based on Oil Production | 100,448 | 100,448 | 100,448 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 12,907,568 | 12,756,896 | 13,058,240 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 61 | 61 | 61 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,145 | 3,145 | 3,145 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.32 | 0.32 | 0.32 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 157,520,000 | 157,520,000 | 157,520,000 | System Data | Based on Pure CO2 from Gas | 157,520,000 | 157,520,000 | 157,520,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 31.0 | 31.0 | 31.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,609 | 1,609 | 1,609 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 4.6% | 4.6% | 4.6% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 7,212,447 | 7,212,447 | 7,212,447 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 71.8 | 71.8 | 71.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 161,638,000 | 161,638,000 | 161,638,000 | System Data | Based on System Metering | 161,638,000 | 161,638,000 | 161,638,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 442.8 | 442.8 | 442.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 315,875,000 | 315,875,000 | 315,875,000 | System Data | Based on Injection Metering | 315,875,000 | 315,875,000 | 315,875,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 865.4 | 865.4 | 865.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 48.8% | 48.8% | 48.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 154,237,000 | 154,237,000 | 154,237,000 | System Data | Based on Injection Metering | 154,237,000 | 154,237,000 | 154,237,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,535 | 1,535 | 1,535 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,542 | 0 | 7,712 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 48.8% | 48.8% | 48.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 3.13 | 3.13 | 3.13 | System Data | Based on System Metering Br | 3.1 | 3.1 | 3.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 3.1 | 3.1 | 3.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,194 | 2,169 | 2,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 40,400,688 | 39,929,084 | 40,872,291 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 40,400,688 | 39,929,084 | 40,872,291 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2010 | 2010 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,256 | 1,256 | 1,256 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 12,908 | 12,757 | 13,058 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 13 | 13 | 13 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 8,519 | 8,420 | 8,618 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.20E+00 | 1.20E+00 | 1.20E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 257229 | 257229 | 257229 | System Data | System Data | 257,229 | 257,229 | 257,229 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 14,058,028 | 14,058,028 | 14,058,028 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 140.0 | 140.0 | 140.0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,359,156 | 3,359,156 | 3,359,156 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 33.4 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 17,417,184 | 17,417,184 | 17,417,184 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 173.4 | 173.4 | 173.4 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 282 | 282 | 282 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 827513 | 827513 | 827513 | System Data | Chester 10 and Dover 36 Faci | 827,513 | 827,513 | 827,513 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 828 | 828 | 828 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 546,159 | 546,159 | 546,159 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 5.4 | 5.4 | 5.4 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 273,208 | 273,208 | 273,208 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 743,807 | 743,807 | 743,807 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 5,615 | 2,775 | 11,361 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 129 | 128 | 131 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 22 | 21 | 22 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 79 | 78 | 80 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 101 | 100 | 102 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 354 | 350 | 359 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 357 | 352 | 361 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 129 | 128 | 131 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 123 | 121 | 124 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 367 | 363 | 372 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 161,638,000 | 161,638,000 | 161,638,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,535,049 | 1,535,049 | 1,535,049 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 39,340 | 39,340 | 39,340 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 33,169 | 33,169 | 33,169 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.08E+04 | 2.08E+04 | 2.08E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.39E+02 | 1.39E+02 | 1.39E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.03E-01 | 4.03E-01 | 4.03E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,720 | 4,720 | 4,720 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 120 | 120 | 120 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 25,618 | 25,618 | 25,618 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 104,415 | 104,415 | 104,415 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 15.0 | 15.0 | 15.0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.7 | 2.7 | 2.7 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 509 | 509 | 509 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 805 | 805 | 805 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 105,729 | 105,729 | 105,729 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.1 | 1.1 | 1.1 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 161,638,000 | 161,638,000 | 161,638,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,867,313 | 2,867,313 | 2,867,313 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 154,270,716,893 | 154,270,716,893 | 154,270,716,893 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 18,049,674 | 18,049,674 | 18,049,674 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 8,187,188 | 8,187,188 | 8,187,188 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 81.5 | 81.5 | 81.5 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,178,218 | 1,178,218 | 1,178,218 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 198,100 | 198,100 | 198,100 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 21,321 | 21,321 | 21,321 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.4 | 5.4 | 5.4 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 724,931 | 724,931 | 724,931 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,614 | 1,614 | 1,614 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 924,645 | 924,645 | 924,645 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 9.2 | 9.2 | 9.2 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 630,389 | 630,389 | 630,389 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,176,057 | 1,176,057 | 1,176,057 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 996,172 | 996,172 | 996,172 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,142,106 | 1,142,106 | 1,142,106 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,944,724 | 3,944,724 | 3,944,724 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 192,502,552 | 192,502,552 | 192,502,552 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 161,640,194 | 161,640,169 | 161,640,220 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,230 | 2,230 | 2,230 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,471,492 | 1,471,491 | 1,471,492 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 14.6 | 14.6 | 14.6 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 310 | 310 | 310 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 52 | 52 | 52 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 6 | 6 | 6 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 190 | 190 | 190 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 243 | 243 | 243 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | Fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 850 | 850 | 850 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.6 | 0.6 | 0.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.6 | 4.6 | 4.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 855 | 855 | 855 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.009 | 0.009 | 0.009 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 214,074 | 214,074 | 214,074 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 582,087 | 582,087 | 582,087 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,017,481 | 1,017,481 | 1,017,481 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 10,767,939 | 10,767,937 | 10,767,941 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 28,289,432 | 28,289,428 | 28,289,436 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 51,077,547 | 51,077,539 | 51,077,555 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 161,640,194 | 161,640,169 | 161,640,220 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 3,219 | 3,219 | 3,219 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,124,354 | 2,124,354 | 2,124,354 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 21.1 | 21.1 | 21.1 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 5,326 | 5,326 | 5,326 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.05 | 0.05 | 0.05 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 31,137 | 31,137 | 31,137 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 31.1 | 31.1 | 31.1 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 20,550 | 20,550 | 20,550 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.20 | 0.20 | 0.20 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 270 | 270 | 270 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 178,160 | 178,160 | 178,160 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.77 | 1.77 | 1.77 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 56,775,211 | 56,775,202 | 56,775,220 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 52,121,817 | 52,121,809 | 52,121,825 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 5,222 | 5,222 | 5,222 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,462,381 | 3,301,103 | 3,623,660 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 582,150 | 555,033 | 609,266 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 62,657 | 59,738 | 65,575 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 16 | 15 | 17 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,130,325 | 2,031,094 | 2,229,556 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,742 | 4,521 | 4,963 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,717,217 | 2,590,649 | 2,843,785 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 27.1 | 25.8 | 28.3 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 9,507,777 | 9,064,903 | 9,950,650 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 182 | 174 | 191 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 174 | 166 | 182 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 6,196 | 5,907 | 6,485 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 51,944 | 49,525 | 54,364 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 9,565,917 | 9,120,335 | 10,011,498 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 95.2 | 90.8 | 99.7 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,653,394 | 4,653,393 | 4,653,395 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 386,630 | 386,630 | 386,630 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 638,764 | 638,764 | 638,764 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,094,208 | 1,094,208 | 1,094,208 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 257,528 | 257,528 | 257,528 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 657,228 | 657,228 | 657,228 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 922,945 | 922,945 | 922,945 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 227,085,626 | 227,085,590 | 227,085,662 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **186.6** | **186.5** | **186.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **92.0** | **92.0** | **92.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **14.7** | **14.7** | **14.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **145.5** | **139.8** | **151.2** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,535.5** | **1,535.5** | **1,535.5** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **71.8** | **71.8** | **71.8** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 100,499,808 | 100,499,808 | 100,499,808 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 4,720,742 | 4,196,215 | 5,245,269 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 4,721 | 4,196 | 5,245 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,115,690 | 2,769,502 | 3,461,877 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 49,061,653 | 46,336,006 | 52,128,007 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 7,565,313 | 5,160,291 | 11,610,654 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 66 | 45 | 101 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 126,089 | 142,900 | 129,503 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 19,916,824 | 12,540,222 | 28,215,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 173 | 109 | 245 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 112,862,000 | 112,862,000 | 112,862,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2009 | 2009 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.06 | 0.006 | 0.22 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **239** | **154** | **347** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 114,943 | 114,943 | 114,943 | System Data | Based on Oil Production | 114,943 | 114,943 | 114,943 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 14,770,176 | 14,597,761 | 14,942,590 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 38 | 38 | 38 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,987 | 1,987 | 1,987 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.50 | 0.50 | 0.50 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 112,862,000 | 112,862,000 | 112,862,000 | System Data | Based on Pure CO2 from Gas | 112,862,000 | 112,862,000 | 112,862,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 28.8 | 28.8 | 28.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,496 | 1,496 | 1,496 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 67.1% | 67.1% | 67.1% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 75,767,180 | 75,767,180 | 75,767,180 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 659.2 | 659.2 | 659.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 171,918,000 | 171,918,000 | 171,918,000 | System Data | Based on System Metering | 171,918,000 | 171,918,000 | 171,918,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 471.0 | 471.0 | 471.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 228,423,000 | 228,423,000 | 228,423,000 | System Data | Based on Injection Metering | 228,423,000 | 228,423,000 | 228,423,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 625.8 | 625.8 | 625.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 24.7% | 24.7% | 24.7% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 56,505,000 | 56,505,000 | 56,505,000 | System Data | Based on Injection Metering | 56,505,000 | 56,505,000 | 56,505,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 492 | 492 | 492 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 565 | 0 | 2,825 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 24.7% | 24.7% | 24.7% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 1.36 | 1.36 | 1.36 | System Data | Based on System Metering Br | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,511 | 2,482 | 2,540 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 20,087,439 | 19,852,955 | 20,321,922 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 20,087,439 | 19,852,955 | 20,321,922 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2009 | 2009 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,437 | 1,437 | 1,437 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 14,770 | 14,598 | 14,943 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 15 | 15 | 15 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 9,748 | 9,635 | 9,862 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.27E+00 | 1.27E+00 | 1.27E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 229542 | 229542 | 229542 | System Data | System Data | 229,542 | 229,542 | 229,542 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 12,544,883 | 12,544,883 | 12,544,883 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 109.1 | 109.1 | 109.1 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,572,795 | 3,572,795 | 3,572,795 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 31.1 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 16,117,678 | 16,117,678 | 16,117,678 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 140.2 | 140.2 | 140.2 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 204 | 204 | 204 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 676422 | 676422 | 676422 | System Data | Chester 10 and Dover 36 Faci | 676,422 | 676,422 | 676,422 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 676 | 676 | 676 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 446,439 | 446,439 | 446,439 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 3.9 | 3.9 | 3.9 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 312,632 | 312,632 | 312,632 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 851,141 | 851,141 | 851,141 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 6,425 | 3,175 | 13,000 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 148 | 146 | 149 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 25 | 25 | 25 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 91 | 90 | 92 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 116 | 115 | 117 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 406 | 401 | 410 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 408 | 403 | 413 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 148 | 146 | 149 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 140 | 139 | 142 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 420 | 415 | 425 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 171,918,000 | 171,918,000 | 171,918,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,632,677 | 1,632,677 | 1,632,677 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 41,842 | 41,842 | 41,842 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 35,279 | 35,279 | 35,279 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.21E+04 | 2.21E+04 | 2.21E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.48E+02 | 1.48E+02 | 1.48E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.29E-01 | 4.29E-01 | 4.29E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,020 | 5,020 | 5,020 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 128 | 128 | 128 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 27,247 | 27,247 | 27,247 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 111,055 | 111,055 | 111,055 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 15.9 | 15.9 | 15.9 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.9 | 2.9 | 2.9 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 541 | 541 | 541 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 856 | 856 | 856 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 112,453 | 112,453 | 112,453 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.0 | 1.0 | 1.0 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 171,918,000 | 171,918,000 | 171,918,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 3,049,671 | 3,049,671 | 3,049,671 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 164,082,165,746 | 164,082,165,746 | 164,082,165,746 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 19,197,613 | 19,197,613 | 19,197,613 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 8,707,884 | 8,707,884 | 8,707,884 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 75.8 | 75.8 | 75.8 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,253,151 | 1,253,151 | 1,253,151 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 210,699 | 210,699 | 210,699 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 22,678 | 22,678 | 22,678 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.8 | 5.8 | 5.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 771,036 | 771,036 | 771,036 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,716 | 1,716 | 1,716 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 983,451 | 983,451 | 983,451 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 8.6 | 8.6 | 8.6 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 670,481 | 670,481 | 670,481 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,250,853 | 1,250,853 | 1,250,853 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,059,528 | 1,059,528 | 1,059,528 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,214,742 | 1,214,742 | 1,214,742 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 4,195,605 | 4,195,605 | 4,195,605 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 204,745,504 | 204,745,504 | 204,745,504 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 171,920,511 | 171,920,482 | 171,920,540 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,371 | 2,371 | 2,371 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,565,079 | 1,565,078 | 1,565,079 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 13.6 | 13.6 | 13.6 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 329 | 329 | 329 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 55 | 55 | 55 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 6 | 6 | 6 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 203 | 203 | 203 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 258 | 258 | 258 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 904 | 904 | 904 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.6 | 0.6 | 0.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.9 | 4.9 | 4.9 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 910 | 910 | 910 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.008 | 0.008 | 0.008 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 227,689 | 227,689 | 227,690 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 619,108 | 619,108 | 619,108 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,082,193 | 1,082,193 | 1,082,193 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 11,452,780 | 11,452,778 | 11,452,782 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 30,088,640 | 30,088,635 | 30,088,645 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 54,326,079 | 54,326,070 | 54,326,089 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 171,920,511 | 171,920,482 | 171,920,540 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 3,423 | 3,423 | 3,423 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,259,463 | 2,259,463 | 2,259,463 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 19.7 | 19.7 | 19.7 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 5,664 | 5,664 | 5,664 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.05 | 0.05 | 0.05 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 33,117 | 33,117 | 33,117 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 33.1 | 33.1 | 33.1 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 21,857 | 21,857 | 21,857 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.19 | 0.19 | 0.19 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 287 | 287 | 287 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 189,491 | 189,491 | 189,491 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.65 | 1.65 | 1.65 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 60,386,115 | 60,386,104 | 60,386,125 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 55,436,765 | 55,436,755 | 55,436,774 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 5,554 | 5,554 | 5,554 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,682,589 | 3,511,053 | 3,854,124 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 619,174 | 590,333 | 648,015 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 66,642 | 63,537 | 69,746 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 17 | 16 | 18 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,265,814 | 2,160,272 | 2,371,356 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,044 | 4,809 | 5,279 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,890,032 | 2,755,414 | 3,024,650 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 25.1 | 24.0 | 26.3 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 10,112,471 | 9,641,431 | 10,583,511 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 194 | 185 | 203 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 185 | 177 | 194 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 6,590 | 6,283 | 6,897 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 55,248 | 52,674 | 57,821 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 10,174,309 | 9,700,388 | 10,648,229 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 88.5 | 84.4 | 92.6 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,949,350 | 4,949,349 | 4,949,351 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 411,219 | 411,219 | 411,219 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 679,389 | 679,389 | 679,389 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,163,800 | 1,163,800 | 1,163,800 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 273,906 | 273,906 | 273,906 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 699,028 | 699,028 | 699,028 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 981,644 | 981,644 | 981,644 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 241,528,272 | 241,528,231 | 241,528,314 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **151.8** | **151.8** | **152.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **85.5** | **85.5** | **85.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **13.6** | **13.6** | **13.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **135.2** | **129.9** | **140.5** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **491.6** | **491.6** | **491.6** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **659.2** | **659.2** | **659.2** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 115,002,284 | 115,002,284 | 115,002,284 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 5,401,962 | 4,801,744 | 6,002,180 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5,402 | 4,802 | 6,002 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,565,295 | 3,169,151 | 3,961,439 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | ining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | ining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | ining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | ining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 64,921,423 | 61,314,678 | 68,979,012 | |
| Upstream | ining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.1 | 0.1 | 0.1 | |
| Upstream | ining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 10,010,892 | 6,828,417 | 15,363,938 | |
| Upstream | ining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 79 | 54 | 121 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 166,848 | 189,095 | 171,367 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 26,355,176 | 16,594,000 | 37,336,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 208 | 131 | 295 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 149,346,000 | 149,346,000 | 149,346,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2008 | 2008 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.005 | 0.20 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **287** | **185** | **416** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 126,646 | 126,646 | 126,646 | System Data | Based on Oil Production | 126,646 | 126,646 | 126,646 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 16,274,011 | 16,084,042 | 16,463,980 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 40 | 40 | 40 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,098 | 2,098 | 2,098 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.48 | 0.48 | 0.48 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 149,346,000 | 149,346,000 | 149,346,000 | System Data | Based on Pure CO2 from Gas | 149,346,000 | 149,346,000 | 149,346,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 22.1 | 22.1 | 22.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,146 | 1,146 | 1,146 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 16.9% | 16.9% | 16.9% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 25,272,530 | 25,272,530 | 25,272,530 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 199.6 | 199.6 | 199.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 145,159,000 | 145,159,000 | 145,159,000 | System Data | Based on System Metering | 145,159,000 | 145,159,000 | 145,159,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 397.7 | 397.7 | 397.7 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 265,753,000 | 265,753,000 | 265,753,000 | System Data | Based on Injection Metering | 265,753,000 | 265,753,000 | 265,753,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 728.1 | 728.1 | 728.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 45.4% | 45.4% | 45.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 120,595,000 | 120,595,000 | 120,595,000 | System Data | Based on Injection Metering | 120,595,000 | 120,595,000 | 120,595,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 952 | 952 | 952 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,206 | 0 | 6,030 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 45.4% | 45.4% | 45.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 1.81 | 1.81 | 1.81 | System Data | Based on System Metering Br | 1.8 | 1.8 | 1.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 1.8 | 1.8 | 1.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,767 | 2,734 | 2,799 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 29,455,960 | 29,112,116 | 29,799,804 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 29,455,960 | 29,112,116 | 29,799,804 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2008 | 2008 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 4 | | System Data | 1 Injection well | 4 | 4 | 4 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 40,469 | 40,469 | 40,469 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 42,492 | 42,492 | 42,492 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 317,100 | 317,100 | 317,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 2.5 | 2.5 | 2.5 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,583 | 1,583 | 1,583 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 16,274 | 16,084 | 16,464 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 16 | 16 | 16 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 10,741 | 10,615 | 10,866 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.07E+00 | 1.07E+00 | 1.07E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 250047 | 250047 | 250047 | System Data | System Data | 250,047 | 250,047 | 250,047 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 13,665,519 | 13,665,519 | 13,665,519 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 107.9 | 107.9 | 107.9 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,016,690 | 3,016,690 | 3,016,690 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 23.8 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 16,682,209 | 16,682,209 | 16,682,209 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 131.7 | 131.7 | 131.7 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 237 | 237 | 237 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 779103 | 779103 | 779103 | System Data | Chester 10 and Dover 36 Faci | 779,103 | 779,103 | 779,103 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 779 | 779 | 779 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 514,208 | 514,208 | 514,208 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 4.1 | 4.1 | 4.1 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Venti | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Venti | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 344,463 | 344,463 | 344,463 | |
| Gate-to-Gate | Water Separation – Venti | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 937,801 | 937,801 | 937,801 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Venti | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 7,079 | 3,498 | 14,324 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 163 | 161 | 165 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 27 | 27 | 28 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 100 | 99 | 101 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 128 | 126 | 129 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 447 | 442 | 452 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 450 | 444 | 455 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 163 | 161 | 165 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 155 | 153 | 156 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 463 | 458 | 468 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 145,159,000 | 145,159,000 | 145,159,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,378,551 | 1,378,551 | 1,378,551 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 35,329 | 35,329 | 35,329 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 29,788 | 29,788 | 29,788 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.87E+04 | 1.87E+04 | 1.87E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.25E+02 | 1.25E+02 | 1.25E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.62E-01 | 3.62E-01 | 3.62E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,239 | 4,239 | 4,239 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 108 | 108 | 108 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 23,006 | 23,006 | 23,006 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 93,770 | 93,770 | 93,770 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 13.4 | 13.4 | 13.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.4 | 2.4 | 2.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 457 | 457 | 457 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 723 | 723 | 723 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 94,950 | 94,950 | 94,950 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.7 | 0.7 | 0.7 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 145,159,000 | 145,159,000 | 145,159,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,574,990 | 2,574,990 | 2,574,990 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 138,542,811,674 | 138,542,811,674 | 138,542,811,674 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 16,209,509 | 16,209,509 | 16,209,509 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 7,352,504 | 7,352,504 | 7,352,504 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 58.1 | 58.1 | 58.1 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,058,098 | 1,058,098 | 1,058,098 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 177,904 | 177,904 | 177,904 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 19,148 | 19,148 | 19,148 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.9 | 4.9 | 4.9 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 651,024 | 651,024 | 651,024 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,449 | 1,449 | 1,449 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 830,377 | 830,377 | 830,377 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 6.6 | 6.6 | 6.6 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 566,121 | 566,121 | 566,121 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,056,158 | 1,056,158 | 1,056,158 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 894,613 | 894,613 | 894,613 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,025,668 | 1,025,668 | 1,025,668 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,542,560 | 3,542,560 | 3,542,560 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 172,876,910 | 172,876,910 | 172,876,910 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 145,161,767 | 145,161,734 | 145,161,799 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,002 | 2,002 | 2,002 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,321,480 | 1,321,480 | 1,321,481 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 10.4 | 10.4 | 10.4 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 278 | 278 | 278 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 47 | 47 | 47 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 171 | 171 | 171 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 218 | 218 | 218 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 763 | 763 | 763 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.2 | 4.2 | 4.2 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 768 | 768 | 768 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.006 | 0.006 | 0.006 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 192,251 | 192,250 | 192,251 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 522,746 | 522,746 | 522,746 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 913,754 | 913,754 | 913,754 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 9,670,200 | 9,670,198 | 9,670,202 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 25,405,463 | 25,405,457 | 25,405,468 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 45,870,441 | 45,870,431 | 45,870,451 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 145,161,767 | 145,161,734 | 145,161,799 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,891 | 2,891 | 2,891 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,907,787 | 1,907,786 | 1,907,787 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 15.1 | 15.1 | 15.1 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,783 | 4,783 | 4,783 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.04 | 0.04 | 0.04 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 27,963 | 27,963 | 27,963 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 28.0 | 28.0 | 28.0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 18,455 | 18,455 | 18,455 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.15 | 0.15 | 0.15 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 242 | 242 | 242 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 159,997 | 159,997 | 159,997 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.26 | 1.26 | 1.26 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 50,987,256 | 50,987,245 | 50,987,267 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 46,808,253 | 46,808,242 | 46,808,263 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,690 | 4,690 | 4,690 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,109,409 | 2,964,572 | 3,254,245 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 522,802 | 498,450 | 547,154 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 56,269 | 53,648 | 58,890 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 14 | 14 | 15 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,913,149 | 1,824,034 | 2,002,264 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,259 | 4,060 | 4,457 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,440,210 | 2,326,545 | 2,553,875 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 19.3 | 18.4 | 20.2 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial E | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 8,538,505 | 8,140,780 | 8,936,230 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 164 | 156 | 171 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 157 | 149 | 164 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,564 | 5,305 | 5,823 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 46,649 | 44,476 | 48,822 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 8,590,718 | 8,190,561 | 8,990,875 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 67.8 | 64.7 | 71.0 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,179,003 | 4,179,002 | 4,179,004 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 347,215 | 347,215 | 347,215 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 573,645 | 573,645 | 573,645 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 982,659 | 982,659 | 982,659 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 231,274 | 231,274 | 231,274 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 590,227 | 590,227 | 590,227 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 828,855 | 828,855 | 828,855 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 203,935,357 | 203,935,311 | 203,935,402 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **145.9** | **145.8** | **146.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **65.5** | **65.5** | **65.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **10.4** | **10.4** | **10.4** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **103.6** | **99.6** | **107.7** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **952.2** | **952.2** | **952.2** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **199.6** | **199.6** | **199.6** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 126,711,320 | 126,711,320 | 126,711,320 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 5,951,966 | 5,290,637 | 6,613,296 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5,952 | 5,291 | 6,613 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,928,298 | 3,491,820 | 4,364,775 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | ining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | ining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | ining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | ining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 11,679,214 | 11,030,369 | 12,409,165 | |
| Upstream | ining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | ining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 1,800,936 | 1,228,416 | 2,763,937 | |
| Upstream | ining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 18 | 12 | 27 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 30,016 | 34,018 | 30,829 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 4,741,235 | 2,985,222 | 6,716,750 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 47 | 29 | 66 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 26,867,000 | 26,867,000 | 26,867,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2007 | 2007 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.07 | 0.007 | 0.25 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **65** | **42** | **94** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 101,525 | 101,525 | 101,525 | System Data | Based on Oil Production | 101,525 | 101,525 | 101,525 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 13,045,963 | 12,893,675 | 13,198,250 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 28 | 28 | 28 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,453 | 1,453 | 1,453 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.69 | 0.69 | 0.69 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 26,867,000 | 26,867,000 | 26,867,000 | System Data | Based on Pure CO2 from Gas | 26,867,000 | 26,867,000 | 26,867,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 25.3 | 25.3 | 25.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,314 | 1,314 | 1,314 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 89.4% | 89.4% | 89.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 24,032,526 | 24,032,526 | 24,032,526 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 236.7 | 236.7 | 236.7 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 133,450,000 | 133,450,000 | 133,450,000 | System Data | Based on System Metering | 133,450,000 | 133,450,000 | 133,450,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 365.6 | 365.6 | 365.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 147,529,000 | 147,529,000 | 147,529,000 | System Data | Based on Injection Metering | 147,529,000 | 147,529,000 | 147,529,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 404.2 | 404.2 | 404.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 9.5% | 9.5% | 9.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 14,079,000 | 14,079,000 | 14,079,000 | System Data | Based on Injection Metering | 14,079,000 | 14,079,000 | 14,079,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 139 | 139 | 139 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 141 | 0 | 704 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 9.5% | 9.5% | 9.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 1.39 | 1.39 | 1.39 | System Data | Based on System Metering Br | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,218 | 2,192 | 2,244 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 18,133,888 | 17,922,208 | 18,345,568 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 18,133,888 | 17,922,208 | 18,345,568 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2007 | 2007 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 2.5 | | System Data | St. Charlton 4-30St. Charlton | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 25,293 | 25,293 | 25,293 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 27,316 | 27,316 | 27,316 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 203,850 | 203,850 | 203,850 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 2.0 | 2.0 | 2.0 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,269 | 1,269 | 1,269 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 13,046 | 12,894 | 13,198 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 13 | 13 | 13 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 8,610 | 8,510 | 8,711 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 9.87E-01 | 9.87E-01 | 9.87E-01 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 112624 | 112624 | 112624 | System Data | System Data | 112,624 | 112,624 | 112,624 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 6,155,104 | 6,155,104 | 6,155,104 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 60.6 | 60.6 | 60.6 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,773,354 | 2,773,354 | 2,773,354 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 27.3 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 8,928,458 | 8,928,458 | 8,928,458 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 87.9 | 87.9 | 87.9 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 132 | 132 | 132 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 212694 | 212694 | 212694 | System Data | Chester 10 and Dover 36 Faci | 212,694 | 212,694 | 212,694 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 213 | 213 | 213 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 140,378 | 140,378 | 140,378 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.4 | 1.4 | 1.4 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 276,137 | 276,137 | 276,137 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 751,783 | 751,783 | 751,783 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 5,675 | 2,804 | 11,482 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 130 | 129 | 132 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 22 | 22 | 22 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 80 | 79 | 81 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 102 | 101 | 104 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 358 | 354 | 362 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 360 | 356 | 365 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 130 | 129 | 132 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 124 | 122 | 125 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 371 | 367 | 375 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 133,450,000 | 133,450,000 | 133,450,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,267,353 | 1,267,353 | 1,267,353 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 32,480 | 32,480 | 32,480 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 27,385 | 27,385 | 27,385 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.72E+04 | 1.72E+04 | 1.72E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.15E+02 | 1.15E+02 | 1.15E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.33E-01 | 3.33E-01 | 3.33E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,897 | 3,897 | 3,897 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 99 | 99 | 99 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 21,150 | 21,150 | 21,150 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 86,206 | 86,206 | 86,206 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 12.4 | 12.4 | 12.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.2 | 2.2 | 2.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 420 | 420 | 420 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 665 | 665 | 665 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 87,291 | 87,291 | 87,291 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.9 | 0.9 | 0.9 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 133,450,000 | 133,450,000 | 133,450,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,367,283 | 2,367,283 | 2,367,283 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 127,367,495,078 | 127,367,495,078 | 127,367,495,078 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 14,901,997 | 14,901,997 | 14,901,997 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 6,759,427 | 6,759,427 | 6,759,427 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 66.6 | 66.6 | 66.6 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 972,749 | 972,749 | 972,749 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 163,554 | 163,554 | 163,554 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 17,603 | 17,603 | 17,603 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.5 | 4.5 | 4.5 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 598,510 | 598,510 | 598,510 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,332 | 1,332 | 1,332 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 763,396 | 763,396 | 763,396 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.5 | 7.5 | 7.5 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 520,456 | 520,456 | 520,456 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 970,965 | 970,965 | 970,965 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 822,450 | 822,450 | 822,450 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 942,934 | 942,934 | 942,934 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,256,805 | 3,256,805 | 3,256,805 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 158,932,093 | 158,932,093 | 158,932,093 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 133,452,218 | 133,452,192 | 133,452,244 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,841 | 1,841 | 1,841 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,214,882 | 1,214,882 | 1,214,883 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 12.0 | 12.0 | 12.0 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 256 | 256 | 256 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 43 | 43 | 43 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 157 | 157 | 157 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 201 | 201 | 201 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 702 | 702 | 702 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3.8 | 3.8 | 3.8 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 706 | 706 | 706 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.007 | 0.007 | 0.007 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 176,743 | 176,742 | 176,743 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 480,579 | 480,578 | 480,579 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 840,045 | 840,045 | 840,046 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 8,890,149 | 8,890,147 | 8,890,150 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 23,356,118 | 23,356,113 | 23,356,122 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 42,170,278 | 42,170,270 | 42,170,286 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 133,452,218 | 133,452,192 | 133,452,244 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,657 | 2,657 | 2,657 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,753,894 | 1,753,894 | 1,753,894 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 17.3 | 17.3 | 17.3 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,397 | 4,397 | 4,397 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.04 | 0.04 | 0.04 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 25,707 | 25,707 | 25,707 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 25.7 | 25.7 | 25.7 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 16,967 | 16,967 | 16,967 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.17 | 0.17 | 0.17 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 223 | 223 | 223 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 147,091 | 147,091 | 147,091 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.45 | 1.45 | 1.45 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 46,874,343 | 46,874,334 | 46,874,352 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 43,032,441 | 43,032,433 | 43,032,449 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,311 | 4,311 | 4,311 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 2,858,586 | 2,725,433 | 2,991,740 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 480,630 | 458,242 | 503,018 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 51,730 | 49,321 | 54,140 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 13 | 13 | 14 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,758,824 | 1,676,898 | 1,840,750 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,915 | 3,733 | 4,097 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,243,369 | 2,138,873 | 2,347,866 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 22.1 | 21.1 | 23.1 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 7,849,742 | 7,484,100 | 8,215,384 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 150 | 143 | 157 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 144 | 137 | 151 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,115 | 4,877 | 5,354 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 42,886 | 40,888 | 44,883 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 7,897,743 | 7,529,865 | 8,265,622 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 77.8 | 74.2 | 81.4 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 3,841,902 | 3,841,901 | 3,841,903 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 319,206 | 319,206 | 319,206 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 527,371 | 527,371 | 527,371 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 903,392 | 903,392 | 903,392 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 212,618 | 212,618 | 212,618 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 542,616 | 542,616 | 542,616 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 761,995 | 761,995 | 761,995 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 187,484,806 | 187,484,770 | 187,484,842 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **98.9** | **98.9** | **99.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **75.2** | **75.2** | **75.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **12.0** | **12.0** | **12.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **118.8** | **114.2** | **123.5** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **138.7** | **138.7** | **138.7** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **236.7** | **236.7** | **236.7** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 101,577,363 | 101,577,363 | 101,577,363 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 4,771,358 | 4,241,207 | 5,301,509 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 4,771 | 4,241 | 5,302 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,149,096 | 2,799,196 | 3,498,996 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 41,728,183 | 39,409,951 | 44,336,195 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 6,434,491 | 4,388,958 | 9,875,156 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 110 | 75 | 168 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 107,242 | 121,540 | 110,146 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 16,939,765 | 10,665,778 | 23,998,000 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 288 | 182 | 408 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 95,992,000 | 95,992,000 | 95,992,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2006 | 2006 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.11 | 0.011 | 0.43 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **398** | **256** | **577** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 58,747 | 58,747 | 58,747 | System Data | Based on Oil Production | 58,747 | 58,747 | 58,747 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 7,548,990 | 7,460,869 | 7,637,110 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 66 | 66 | 66 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,430 | 3,430 | 3,430 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.29 | 0.29 | 0.29 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 95,992,000 | 95,992,000 | 95,992,000 | System Data | Based on Pure CO2 from Gas | 95,992,000 | 95,992,000 | 95,992,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 37.3 | 37.3 | 37.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,936 | 1,936 | 1,936 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 22.8% | 22.8% | 22.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 21,928,105 | 21,928,105 | 21,928,105 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 373.3 | 373.3 | 373.3 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 113,747,000 | 113,747,000 | 113,747,000 | System Data | Based on System Metering | 113,747,000 | 113,747,000 | 113,747,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 311.6 | 311.6 | 311.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 201,510,000 | 201,510,000 | 201,510,000 | System Data | Based on Injection Metering | 201,510,000 | 201,510,000 | 201,510,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 552.1 | 552.1 | 552.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 43.6% | 43.6% | 43.6% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 87,763,000 | 87,763,000 | 87,763,000 | System Data | Based on Injection Metering | 87,763,000 | 87,763,000 | 87,763,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,494 | 1,494 | 1,494 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 878 | 0 | 4,388 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 43.6% | 43.6% | 43.6% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 3.92 | 3.92 | 3.92 | System Data | Based on System Metering Br | 3.9 | 3.9 | 3.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 3.9 | 3.9 | 3.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,283 | 1,268 | 1,298 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 29,592,039 | 29,246,606 | 29,937,471 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 29,592,039 | 29,246,606 | 29,937,471 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2006 | 2006 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 1 | | System Data | Pomarzynski 6-35 | 1 | 1 | 1 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 12,141 | 12,141 | 12,141 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 90,600 | 90,600 | 90,600 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.5 | 1.5 | 1.5 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 734 | 734 | 734 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 7,549 | 7,461 | 7,637 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 8 | 7 | 8 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 4,982 | 4,924 | 5,040 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 8.41E-01 | 8.41E-01 | 8.41E-01 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 184183 | 184183 | 184183 | System Data | System Data | 184,183 | 184,183 | 184,183 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 10,065,932 | 10,065,932 | 10,065,932 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 171.3 | 171.3 | 171.3 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,363,887 | 2,363,887 | 2,363,887 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 40.2 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 12,429,819 | 12,429,819 | 12,429,819 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 211.6 | 211.6 | 211.6 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 180 | 180 | 180 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 514584 | 514584 | 514584 | System Data | Chester 10 and Dover 36 Faci | 514,584 | 514,584 | 514,584 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 515 | 515 | 515 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 339,625 | 339,625 | 339,625 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 5.8 | 5.8 | 5.8 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 159,785 | 159,785 | 159,785 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 435,016 | 435,016 | 435,016 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 3,284 | 1,623 | 6,644 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 75 | 75 | 76 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 13 | 13 | 13 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 1 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 46 | 46 | 47 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 59 | 59 | 60 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 207 | 205 | 210 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 209 | 206 | 211 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 75 | 75 | 76 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 72 | 71 | 73 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 215 | 212 | 217 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 113,747,000 | 113,747,000 | 113,747,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,080,236 | 1,080,236 | 1,080,236 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 27,684 | 27,684 | 27,684 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 23,342 | 23,342 | 23,342 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.46E+04 | 1.46E+04 | 1.46E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 9.77E+01 | 9.77E+01 | 9.77E+01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 2.84E-01 | 2.84E-01 | 2.84E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,321 | 3,321 | 3,321 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 85 | 85 | 85 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 18,028 | 18,028 | 18,028 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 73,478 | 73,478 | 73,478 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 10.5 | 10.5 | 10.5 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 1.9 | 1.9 | 1.9 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 358 | 358 | 358 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 567 | 567 | 567 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 74,403 | 74,403 | 74,403 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.3 | 1.3 | 1.3 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 113,747,000 | 113,747,000 | 113,747,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,017,770 | 2,017,770 | 2,017,770 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 108,562,536,250 | 108,562,536,250 | 108,562,536,250 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 12,701,817 | 12,701,817 | 12,701,817 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 5,761,442 | 5,761,442 | 5,761,442 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 98.1 | 98.1 | 98.1 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 829,129 | 829,129 | 829,129 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 139,406 | 139,406 | 139,406 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 15,004 | 15,004 | 15,004 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.8 | 3.8 | 3.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 510,144 | 510,144 | 510,144 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,136 | 1,136 | 1,136 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 650,686 | 650,686 | 650,686 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 11.1 | 11.1 | 11.1 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 443,614 | 443,614 | 443,614 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 827,608 | 827,608 | 827,608 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 701,021 | 701,021 | 701,021 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 803,716 | 803,716 | 803,716 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 2,775,960 | 2,775,960 | 2,775,960 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 135,466,832 | 135,466,832 | 135,466,832 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 113,748,283 | 113,748,268 | 113,748,298 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,569 | 1,569 | 1,569 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,035,508 | 1,035,508 | 1,035,508 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 17.6 | 17.6 | 17.6 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 218 | 218 | 218 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 37 | 37 | 37 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 4 | 4 | 4 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 134 | 134 | 134 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 171 | 171 | 171 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | Fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 598 | 598 | 598 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.4 | 0.4 | 0.4 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3.3 | 3.3 | 3.3 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 602 | 602 | 602 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.010 | 0.010 | 0.010 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 150,647 | 150,647 | 150,647 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 409,622 | 409,622 | 409,622 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 716,014 | 716,014 | 716,015 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 7,577,537 | 7,577,536 | 7,577,538 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 19,907,637 | 19,907,634 | 19,907,640 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 35,943,927 | 35,943,922 | 35,943,932 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 113,748,283 | 113,748,268 | 113,748,298 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,265 | 2,265 | 2,265 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,494,935 | 1,494,935 | 1,494,935 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 25.4 | 25.4 | 25.4 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 3,748 | 3,748 | 3,748 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 21,912 | 21,912 | 21,912 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 21.9 | 21.9 | 21.9 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 14,462 | 14,462 | 14,462 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.25 | 0.25 | 0.25 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 190 | 190 | 190 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 125,373 | 125,373 | 125,373 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.13 | 2.13 | 2.13 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 39,953,446 | 39,953,441 | 39,953,451 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 36,678,793 | 36,678,788 | 36,678,798 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 3,675 | 3,675 | 3,675 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 2,436,522 | 2,323,029 | 2,550,016 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 409,666 | 390,584 | 428,748 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 44,092 | 42,038 | 46,146 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 11 | 11 | 12 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,499,137 | 1,429,307 | 1,568,967 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,337 | 3,182 | 3,493 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,912,140 | 1,823,073 | 2,001,208 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 32.5 | 31.0 | 34.1 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 6,690,745 | 6,379,089 | 7,002,400 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 128 | 122 | 134 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 123 | 117 | 128 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,360 | 4,157 | 4,563 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 36,554 | 34,851 | 38,256 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 6,731,658 | 6,418,097 | 7,045,220 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 114.6 | 109.2 | 119.9 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 3,274,653 | 3,274,653 | 3,274,654 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 272,076 | 272,076 | 272,076 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 449,506 | 449,506 | 449,506 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 770,008 | 770,008 | 770,008 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 181,225 | 181,225 | 181,225 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 462,500 | 462,500 | 462,500 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 649,488 | 649,488 | 649,488 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 159,803,075 | 159,803,054 | 159,803,096 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **226.5** | **226.4** | **226.9** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **110.7** | **110.7** | **110.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **17.6** | **17.6** | **17.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **175.0** | **168.2** | **181.9** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **1,493.9** | **1,493.9** | **1,493.9** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **373.3** | **373.3** | **373.3** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.1** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 58,777,300 | 58,777,300 | 58,777,300 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 2,760,925 | 2,454,156 | 3,067,695 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 2,761 | 2,454 | 3,068 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,822,211 | 1,619,743 | 2,024,679 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | al mining, processing, and transp | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | al mining, processing, and transp | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | al mining, processing, and transp | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | al mining, processing, and transp | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | al mining, processing, and transp | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | al mining, processing, and transp | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | al mining, processing, and transp | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/to | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netwo | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2005 | 2005 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.12 | 0.012 | 0.46 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Crude oil produced | bbl crude | 55,325 | 55,325 | 55,325 | System Data | Based on Oil Production | 55,325 | 55,325 | 55,325 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 7,109,263 | 7,026,275 | 7,192,250 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 46 | 46 | 46 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,366 | 2,366 | 2,366 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.42 | 0.42 | 0.42 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 45.0 | 45.0 | 45.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,339 | 2,339 | 2,339 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 98.8% | 98.8% | 98.8% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ produced (recycled) | kg $CO_2$ | 129,414,000 | 129,414,000 | 129,414,000 | System Data | Based on System Metering | 129,414,000 | 129,414,000 | 129,414,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 354.6 | 354.6 | 354.6 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ injected | kg $CO_2$ | 130,914,000 | 130,914,000 | 130,914,000 | System Data | Based on Injection Metering | 130,914,000 | 130,914,000 | 130,914,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 358.7 | 358.7 | 358.7 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 1.1% | 1.1% | 1.1% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ stored | kg $CO_2$ | 1,500,000 | 1,500,000 | 1,500,000 | System Data | Based on Injection Metering | 1,500,000 | 1,500,000 | 1,500,000 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 27 | 27 | 27 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 15 | 0 | 75 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 1.1% | 1.1% | 1.1% | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Brine production rate | kg brine / kg crude | 1.42 | 1.42 | 1.42 | System Data | Based on System Metering Br | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 1.4 | 1.4 | 1.4 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,209 | 1,194 | 1,223 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Brine production | kg brine | | | | Derived | Derived from the brine produ | 10,095,153 | 9,977,311 | 10,212,995 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 10,095,153 | 9,977,311 | 10,212,995 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2005 | 2005 | 1 | 1 | 1 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | Oil, $CO_2$, brine, and gas productio | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| **GATE-TO-GATE: LAND USE** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 692 | 692 | 692 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 7,109 | 7,026 | 7,192 | |
| Gate-to-Gate | Well Operations – Artificial Lift | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 7 | 7 | 7 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 4,692 | 4,637 | 4,747 | |
| Gate-to-Gate | Well Operations – Artificial Lift | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | Compressor power | MW | | | | Derived | NA,Derived from the compre | 9.57E-01 | 9.57E-01 | 9.57E-01 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | Compressor energy | MCF | 27589 | 27589 | 27589 | System Data | System Data | 27,589 | 27,589 | 27,589 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 1,507,789 | 1,507,789 | 1,507,789 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 27.3 | 27.3 | 27.3 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,689,478 | 2,689,478 | 2,689,478 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 48.6 | 33.8 | 33.8 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 4,197,267 | 4,197,267 | 4,197,267 | |
| Gate-to-Gate | ons – $CO_2$ Compression and Inject | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 75.9 | 75.9 | 75.9 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – $CO_2$ Compressor Fug | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | Operations – $CO_2$ Compressor Fug | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 117 | 117 | 117 | |
| Gate-to-Gate | Operations – $CO_2$ Compressor Fug | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Vell Operations – Facility Electricit | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Vell Operations – Facility Electricit | Facility electricity | kWh | 94295 | 94295 | 94295 | System Data | Chester 10 and Dover 36 Faci | 94,295 | 94,295 | 94,295 | |
| Gate-to-Gate | Vell Operations – Facility Electricit | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 94 | 94 | 94 | |
| Gate-to-Gate | Vell Operations – Facility Electricit | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 62,235 | 62,235 | 62,235 | |
| Gate-to-Gate | Vell Operations – Facility Electricit | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.1 | 1.1 | 1.1 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | nd Water Separation – Venting a | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | nd Water Separation – Venting a | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | nd Water Separation – Venting a | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Cor | 150,478 | 150,478 | 150,478 | |
| Gate-to-Gate | nd Water Separation – Venting a | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | nd Water Separation – Venting a | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | nd Water Separation – Venting a | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 409,676 | 409,676 | 409,676 | |
| Gate-to-Gate | nd Water Separation – Venting a | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | nd Water Separation – Venting a | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | nd Water Separation – Venting a | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncont | 3,093 | 1,528 | 6,257 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 71 | 70 | 72 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 12 | 12 | 12 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 1 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 44 | 43 | 44 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 56 | 55 | 56 | |
| Gate-to-Gate | Separation – Natural Gas Upstrea | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 195 | 193 | 198 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | eparation – Natural Gas Combust | Natural gas combustion N2O emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | eparation – Natural Gas Combust | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 196 | 194 | 199 | |
| Gate-to-Gate | eparation – Natural Gas Combust | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | rude Storage – Venting and Flarin | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | rude Storage – Venting and Flarin | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 71 | 70 | 72 | |
| Gate-to-Gate | rude Storage – Venting and Flarin | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | rude Storage – Venting and Flarin | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 68 | 67 | 68 | |
| Gate-to-Gate | rude Storage – Venting and Flarin | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | rude Storage – Venting and Flarin | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | rude Storage – Venting and Flarin | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 202 | 200 | 205 | |
| Gate-to-Gate | rude Storage – Venting and Flarin | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | rine Storage – Venting and Flarin | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| **GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | e Disposal – Injection Well Electr | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | e Disposal – Injection Well Electr | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | e Disposal – Injection Well Electr | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | e Disposal – Injection Well Electr | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | e Disposal – Injection Well Electr | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES)** | | | | | | | | | | | | |
| Gate-to-Gate | ng (Ryan-Holmes) – $CO_2$ Ready fo | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 129,414,000 | 129,414,000 | 129,414,000 | |
| Gate-to-Gate | ocessing (Ryan-Holmes) – Diesel D | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | ocessing (Ryan-Holmes) – Diesel D | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal ene | 1,229,023 | 1,229,023 | 1,229,023 | |
| Gate-to-Gate | ocessing (Ryan-Holmes) – Diesel D | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | ocessing (Ryan-Holmes) – Diesel D | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | ocessing (Ryan-Holmes) – Diesel D | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 31,497 | 31,497 | 31,497 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 26,557 | 26,557 | 26,557 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.66E+04 | 1.66E+04 | 1.66E+04 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.11E+02 | 1.11E+02 | 1.11E+02 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.23E-01 | 3.23E-01 | 3.23E-01 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,779 | 3,779 | 3,779 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | Natural gas combustion N2O emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 96 | 96 | 96 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 20,511 | 20,511 | 20,511 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – Diesel U | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.4 | 0.4 | 0.4 | RH |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 83,599 | 83,599 | 83,599 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 12.0 | 12.0 | 12.0 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.2 | 2.2 | 2.2 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 407 | 407 | 407 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 645 | 645 | 645 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 84,651 | 84,651 | 84,651 | |
| Gate-to-Gate | essing (Ryan-Holmes) – Diesel Cor | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.5 | 1.5 | 1.5 | RH |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 129,414,000 | 129,414,000 | 129,414,000 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,295,688 | 2,295,688 | 2,295,688 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 123,515,451,540 | 123,515,451,540 | 123,515,451,540 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | Emissions factor for natural gas | lb CO2 / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | $CO_2$ emissions | lb CO2 | | | | Derived | Derived from the emissions fa | 14,451,308 | 14,451,308 | 14,451,308 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 6,554,998 | 6,554,998 | 6,554,998 | |
| Gate-to-Gate | nes) – Natural Gas Combustion (T | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 118.5 | 118.5 | 118.5 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 943,329 | 943,329 | 943,329 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 158,607 | 158,607 | 158,607 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 17,071 | 17,071 | 17,071 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.3 | 4.3 | 4.3 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 580,409 | 580,409 | 580,409 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,292 | 1,292 | 1,292 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 740,308 | 740,308 | 740,308 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Natural Gas | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 13.4 | 13.4 | 13.4 | RH |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 504,715 | 504,715 | 504,715 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 941,599 | 941,599 | 941,599 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 797,576 | 797,576 | 797,576 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 914,417 | 914,417 | 914,417 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,158,308 | 3,158,308 | 3,158,308 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | cessing (Ryan-Holmes) – NGL Pro | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 154,125,424 | 154,125,424 | 154,125,424 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | Refrigeration/Fractionation) – EO | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 129,415,209 | 129,415,194 | 129,415,223 | |
| Gate-to-Gate | ing (Refrigeration/Fractionation) | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | ing (Refrigeration/Fractionation) | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,785 | 1,785 | 1,785 | |
| Gate-to-Gate | ing (Refrigeration/Fractionation) | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,178,132 | 1,178,131 | 1,178,132 | |
| Gate-to-Gate | ing (Refrigeration/Fractionation) | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 21.3 | 21.3 | 21.3 | RF |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 248 | 248 | 248 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 42 | 42 | 42 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 4 | 4 | 4 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 152 | 152 | 152 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 194 | 194 | 194 | |
| Gate-to-Gate | efrigeration/Fractionation) – Natu | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.004 | 0.004 | 0.004 | RF |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial E | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 681 | 681 | 681 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.4 | 0.4 | 0.4 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | Natural gas combustion N2O emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 3.7 | 3.7 | 3.7 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 685 | 685 | 685 | |
| Gate-to-Gate | n/Fractionation) – Natural Gas Co | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.012 | 0.012 | 0.012 | RF |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 171,396 | 171,396 | 171,396 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 466,041 | 466,041 | 466,041 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 814,634 | 814,633 | 814,634 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 8,621,216 | 8,621,215 | 8,621,217 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 22,649,581 | 22,649,579 | 22,649,584 | |
| Gate-to-Gate | frigeration/Fractionation) – C3 to | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 40,894,602 | 40,894,598 | 40,894,607 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | ssing (Membrane) – Fluid for Cor | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 129,415,209 | 129,415,194 | 129,415,223 | |
| Gate-to-Gate | (Membrane) – Compressor Electr | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | (Membrane) – Compressor Electr | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,577 | 2,577 | 2,577 | |
| Gate-to-Gate | (Membrane) – Compressor Electr | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,700,838 | 1,700,837 | 1,700,838 | |
| Gate-to-Gate | (Membrane) – Compressor Electr | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 30.7 | 30.7 | 30.7 | M |
| Gate-to-Gate | g (Membrane) – Compressor Fugi | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | g (Membrane) – Compressor Fugi | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the compressor | 4,264 | 4,264 | 4,264 | |
| Gate-to-Gate | g (Membrane) – Compressor Fugi | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.08 | 0.08 | 0.08 | M |
| Gate-to-Gate | (Membrane) – Dehydration Elect | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | (Membrane) – Dehydration Elect | Energy usage | kWh | | | | Derived | Derived from the energy usag | 24,930 | 24,930 | 24,930 | |
| Gate-to-Gate | (Membrane) – Dehydration Elect | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 24.9 | 24.9 | 24.9 | |
| Gate-to-Gate | (Membrane) – Dehydration Elect | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 16,454 | 16,454 | 16,454 | |
| Gate-to-Gate | (Membrane) – Dehydration Elect | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.30 | 0.30 | 0.30 | M |
| Gate-to-Gate | ng (Membrane) – Chiller Electrici | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | ng (Membrane) – Chiller Electrici | Electricity used | MWh | | | | Derived | Derived from the electricity r | 216 | 216 | 216 | |
| Gate-to-Gate | ng (Membrane) – Chiller Electrici | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 142,641 | 142,641 | 142,641 | |
| Gate-to-Gate | ng (Membrane) – Chiller Electrici | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.58 | 2.58 | 2.58 | M |
| Gate-to-Gate | ssing (Membrane) – Membrane S | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | ssing (Membrane) – Membrane S | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 45,456,366 | 45,456,361 | 45,456,371 | |
| Gate-to-Gate | nbrane) – Post-Membrane Amine | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ane) – Post-Membrane Amine CO | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 41,730,684 | 41,730,679 | 41,730,688 | |
| Gate-to-Gate | e) – Post-Membrane Amine $CO_2$ C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | e) - Post-Membrane Amine $CO_2$ C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,181 | 4,181 | 4,181 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Meml | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 2,772,113 | 2,642,987 | 2,901,238 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 466,091 | 444,380 | 487,801 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 50,165 | 47,829 | 52,502 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 13 | 12 | 13 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,705,618 | 1,626,171 | 1,785,066 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 3,797 | 3,620 | 3,974 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 2,175,506 | 2,074,171 | 2,276,841 | |
| Gate-to-Gate | – Post-Membrane Amine $CO_2$ Cap | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 39.3 | 37.5 | 41.2 | M |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial E | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 7,612,283 | 7,257,702 | 7,966,863 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 146 | 139 | 153 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 140 | 133 | 146 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 4,961 | 4,730 | 5,192 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | Natural gas combustion N2O emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 41,588 | 39,651 | 43,526 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 7,658,832 | 7,302,083 | 8,015,581 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Capt | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 138.4 | 132.0 | 144.9 | M |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 3,725,682 | 3,725,682 | 3,725,682 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Meml | 10% | 10% | 10% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Meml | 8% | 8% | 8% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Meml | 14% | 14% | 14% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Meml | 24% | 24% | 24% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Meml | 6% | 6% | 6% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Meml | 14% | 14% | 14% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Meml | 20% | 20% | 20% | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 309,550 | 309,550 | 309,550 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 511,418 | 511,418 | 511,418 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 876,064 | 876,064 | 876,064 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 206,186 | 206,186 | 206,186 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 526,201 | 526,201 | 526,201 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Meml | 738,945 | 738,945 | 738,945 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | - Post-Membrane Amine $CO_2$ Cap | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 181,813,279 | 181,813,259 | 181,813,298 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **84.9** | **84.8** | **85.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **133.8** | **133.8** | **133.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **21.3** | **21.3** | **21.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **211.5** | **203.2** | **219.7** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **27.1** | **27.1** | **27.1** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | de oil transport by pipeline to refi | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | de oil transport by pipeline to refi | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | de oil transport by pipeline to refi | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | de oil transport by pipeline to refi | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | de oil transport by pipeline to refi | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degrees | 850 | 850 | 850 | |
| Downstream | de oil transport by pipeline to refi | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | de oil transport by pipeline to refi | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 55,353,535 | 55,353,535 | 55,353,535 | |
| Downstream | de oil transport by pipeline to refi | One-way energy use | kWh | | | | | Derived from the one-way en | 2,600,102 | 2,311,202 | 2,889,002 | |
| Downstream | de oil transport by pipeline to refi | One-way energy use | MWh | | | | | Unit conversion from kWh to | 2,600 | 2,311 | 2,889 | |
| Downstream | de oil transport by pipeline to refi | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | de oil transport by pipeline to refi | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,716,067 | 1,525,393 | 1,906,742 | |
| Downstream | de oil transport by pipeline to refi | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissio | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | Fuel transport to point-of-sale | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | Fuel transport to point-of-sale | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | Fuel transport to point-of-sale | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | Fuel transport to point-of-sale | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2004 | 2004 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.13 | 0.013 | 0.48 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 52,875 | 52,875 | 52,875 | System Data | Based on Oil Production | 52,875 | 52,875 | 52,875 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 6,794,438 | 6,715,125 | 6,873,750 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 57 | 57 | 57 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,972 | 2,972 | 2,972 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.34 | 0.34 | 0.34 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 55.5 | 55.5 | 55.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,882 | 2,882 | 2,882 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 96.9% | 96.9% | 96.9% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 152,394,000 | 152,394,000 | 152,394,000 | System Data | Based on System Metering | 152,394,000 | 152,394,000 | 152,394,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 417.5 | 417.5 | 417.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 157,122,000 | 157,122,000 | 157,122,000 | System Data | Based on Injection Metering | 157,122,000 | 157,122,000 | 157,122,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 430.5 | 430.5 | 430.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 3.0% | 3.0% | 3.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 4,728,000 | 4,728,000 | 4,728,000 | System Data | Based on Injection Metering | 4,728,000 | 4,728,000 | 4,728,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 89 | 89 | 89 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 47 | 0 | 236 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 3.0% | 3.0% | 3.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.393 | 0.393 | 0.393 | System Data | Based on System Metering Br | 0.4 | 0.4 | 0.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.4 | 0.4 | 0.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,155 | 1,142 | 1,169 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 2,670,214 | 2,639,044 | 2,701,384 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 2,670,214 | 2,639,044 | 2,701,384 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2004 | 2004 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 661 | 661 | 661 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 6,794 | 6,715 | 6,874 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 7 | 7 | 7 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 4,484 | 4,432 | 4,537 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.13E+00 | 1.13E+00 | 1.13E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 107098 | 107098 | 107098 | System Data | System Data | 107,098 | 107,098 | 107,098 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 5,853,098 | 5,853,098 | 5,853,098 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 110.7 | 110.7 | 110.7 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,167,048 | 3,167,048 | 3,167,048 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 59.9 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 9,020,146 | 9,020,146 | 9,020,146 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 170.6 | 170.6 | 170.6 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 140 | 140 | 140 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 124544 | 124544 | 124544 | System Data | Chester 10 and Dover 36 Faci | 124,544 | 124,544 | 124,544 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 125 | 125 | 125 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 82,199 | 82,199 | 82,199 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.6 | 1.6 | 1.6 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 143,814 | 143,814 | 143,814 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 391,534 | 391,534 | 391,534 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 2,956 | 1,461 | 5,980 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 68 | 67 | 69 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 11 | 11 | 12 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 1 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 42 | 41 | 42 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 53 | 53 | 54 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 187 | 184 | 189 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion N2O emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 188 | 186 | 190 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 68 | 67 | 69 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 65 | 64 | 65 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 193 | 191 | 196 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 152,394,000 | 152,394,000 | 152,394,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,447,261 | 1,447,261 | 1,447,261 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 37,090 | 37,090 | 37,090 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 31,272 | 31,272 | 31,272 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.96E+04 | 1.96E+04 | 1.96E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.31E+02 | 1.31E+02 | 1.31E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.80E-01 | 3.80E-01 | 3.80E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,450 | 4,450 | 4,450 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion N2O emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 113 | 113 | 113 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 24,153 | 24,153 | 24,153 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.5 | 0.5 | 0.5 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 98,443 | 98,443 | 98,443 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 14.1 | 14.1 | 14.1 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 480 | 480 | 480 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 759 | 759 | 759 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 99,682 | 99,682 | 99,682 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.9 | 1.9 | 1.9 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 152,394,000 | 152,394,000 | 152,394,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,703,333 | 2,703,333 | 2,703,333 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 145,448,048,294 | 145,448,048,294 | 145,448,048,294 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 17,017,422 | 17,017,422 | 17,017,422 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 7,718,966 | 7,718,966 | 7,718,966 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 146.0 | 146.0 | 146.0 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,110,836 | 1,110,836 | 1,110,836 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 186,771 | 186,771 | 186,771 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 20,102 | 20,102 | 20,102 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.1 | 5.1 | 5.1 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 683,472 | 683,472 | 683,472 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,521 | 1,521 | 1,521 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 871,765 | 871,765 | 871,765 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 16.5 | 16.5 | 16.5 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 594,338 | 594,338 | 594,338 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,108,799 | 1,108,799 | 1,108,799 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 939,202 | 939,202 | 939,202 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,076,789 | 1,076,789 | 1,076,789 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,719,128 | 3,719,128 | 3,719,128 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 181,493,423 | 181,493,423 | 181,493,423 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 152,395,155 | 152,395,142 | 152,395,169 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,102 | 2,102 | 2,102 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,387,329 | 1,387,329 | 1,387,330 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 26.2 | 26.2 | 26.2 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 292 | 292 | 292 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 49 | 49 | 49 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 180 | 180 | 180 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 229 | 229 | 229 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.004 | 0.004 | 0.004 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 801 | 801 | 801 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion N2O emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.4 | 4.4 | 4.4 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 806 | 806 | 806 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.015 | 0.015 | 0.015 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 201,830 | 201,830 | 201,830 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 548,795 | 548,794 | 548,795 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 959,286 | 959,286 | 959,286 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 10,152,065 | 10,152,064 | 10,152,066 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 26,671,413 | 26,671,411 | 26,671,415 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 48,156,158 | 48,156,154 | 48,156,162 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 152,395,155 | 152,395,142 | 152,395,169 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 3,035 | 3,035 | 3,035 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,002,851 | 2,002,851 | 2,002,851 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 37.9 | 37.9 | 37.9 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 5,021 | 5,021 | 5,021 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.09 | 0.09 | 0.09 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 29,356 | 29,356 | 29,356 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 29.4 | 29.4 | 29.4 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 19,375 | 19,375 | 19,375 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.37 | 0.37 | 0.37 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 254 | 254 | 254 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 167,970 | 167,970 | 167,970 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 3.18 | 3.18 | 3.18 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 53,527,943 | 53,527,938 | 53,527,948 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 49,140,701 | 49,140,696 | 49,140,705 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,923 | 4,923 | 4,923 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,264,350 | 3,112,296 | 3,416,403 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 548,853 | 523,288 | 574,419 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 59,073 | 56,321 | 61,825 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 15 | 14 | 16 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,008,481 | 1,914,926 | 2,102,036 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,471 | 4,263 | 4,679 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,561,805 | 2,442,476 | 2,681,134 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 48.5 | 46.2 | 50.7 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 8,963,978 | 8,546,435 | 9,381,520 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 172 | 164 | 180 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 164 | 157 | 172 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,842 | 5,569 | 6,114 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion N2O emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 48,973 | 46,692 | 51,254 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 9,018,792 | 8,598,697 | 9,438,888 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 170.6 | 162.6 | 178.5 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,387,242 | 4,387,242 | 4,387,243 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 364,516 | 364,516 | 364,516 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 602,229 | 602,229 | 602,229 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,031,625 | 1,031,625 | 1,031,625 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 242,798 | 242,798 | 242,798 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 619,638 | 619,638 | 619,638 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 870,157 | 870,157 | 870,157 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 214,097,424 | 214,097,405 | 214,097,443 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **180.1** | **180.0** | **180.4** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **164.8** | **164.8** | **164.8** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **26.3** | **26.3** | **26.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **260.5** | **250.3** | **270.7** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **89.4** | **89.4** | **89.4** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 52,902,271 | 52,902,271 | 52,902,271 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 2,484,960 | 2,208,853 | 2,761,066 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 2,485 | 2,209 | 2,761 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,640,073 | 1,457,843 | 1,822,304 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2003 | 2003 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.14 | 0.014 | 0.53 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **1** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 48,027 | 48,027 | 48,027 | System Data | Based on Oil Production | 48,027 | 48,027 | 48,027 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 6,171,470 | 6,099,429 | 6,243,510 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 62 | 62 | 62 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 3,209 | 3,209 | 3,209 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.31 | 0.31 | 0.31 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 57.1 | 57.1 | 57.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,967 | 2,967 | 2,967 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 91.9% | 91.9% | 91.9% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 142,512,000 | 142,512,000 | 142,512,000 | System Data | Based on System Metering | 142,512,000 | 142,512,000 | 142,512,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 390.4 | 390.4 | 390.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 154,097,000 | 154,097,000 | 154,097,000 | System Data | Based on Injection Metering | 154,097,000 | 154,097,000 | 154,097,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 422.2 | 422.2 | 422.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 7.5% | 7.5% | 7.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 11,585,000 | 11,585,000 | 11,585,000 | System Data | Based on Injection Metering | 11,585,000 | 11,585,000 | 11,585,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 241 | 241 | 241 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 116 | 0 | 579 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 7.5% | 7.5% | 7.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.2 | 0.2 | 0.2 | System Data | Based on System Metering Br | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,049 | 1,037 | 1,061 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 1,234,294 | 1,219,886 | 1,248,702 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 1,234,294 | 1,219,886 | 1,248,702 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2003 | 2003 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0.5 | | System Data | Lawnichak & Myszkier 2-33 H | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 5,059 | 5,059 | 5,059 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 7,082 | 7,082 | 7,082 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 52,850 | 52,850 | 52,850 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.1 | 1.1 | 1.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 600 | 600 | 600 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 6,171 | 6,099 | 6,244 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 6 | 6 | 6 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 4,073 | 4,026 | 4,121 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.05E+00 | 1.05E+00 | 1.05E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 108252 | 108252 | 108252 | System Data | System Data | 108,252 | 108,252 | 108,252 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 5,916,167 | 5,916,167 | 5,916,167 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 123.2 | 123.2 | 123.2 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,961,680 | 2,961,680 | 2,961,680 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 61.7 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 8,877,847 | 8,877,847 | 8,877,847 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 184.9 | 184.9 | 184.9 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 138 | 138 | 138 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 149134 | 149134 | 149134 | System Data | Chester 10 and Dover 36 Faci | 149,134 | 149,134 | 149,134 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 149 | 149 | 149 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 98,428 | 98,428 | 98,428 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 2.0 | 2.0 | 2.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Venti | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Venti | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 130,628 | 130,628 | 130,628 | |
| Gate-to-Gate | Water Separation – Venti | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 355,635 | 355,635 | 355,635 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Venti | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 2,685 | 1,327 | 5,432 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 62 | 61 | 62 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 10 | 10 | 10 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 1 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 38 | 38 | 38 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 48 | 48 | 49 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 169 | 167 | 171 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 171 | 169 | 172 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 62 | 61 | 62 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 59 | 58 | 59 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 176 | 174 | 178 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 142,512,000 | 142,512,000 | 142,512,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,353,413 | 1,353,413 | 1,353,413 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 34,685 | 34,685 | 34,685 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 29,244 | 29,244 | 29,244 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.83E+04 | 1.83E+04 | 1.83E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.22E+02 | 1.22E+02 | 1.22E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.55E-01 | 3.55E-01 | 3.55E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,161 | 4,161 | 4,161 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 106 | 106 | 106 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 22,587 | 22,587 | 22,587 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.5 | 0.5 | 0.5 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 92,060 | 92,060 | 92,060 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 13.2 | 13.2 | 13.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.4 | 2.4 | 2.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 449 | 449 | 449 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 710 | 710 | 710 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 93,218 | 93,218 | 93,218 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.9 | 1.9 | 1.9 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 142,512,000 | 142,512,000 | 142,512,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,528,035 | 2,528,035 | 2,528,035 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 136,016,459,037 | 136,016,459,037 | 136,016,459,037 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 15,913,926 | 15,913,926 | 15,913,926 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 7,218,429 | 7,218,429 | 7,218,429 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 150.3 | 150.3 | 150.3 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,038,804 | 1,038,804 | 1,038,804 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 174,660 | 174,660 | 174,660 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 18,799 | 18,799 | 18,799 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.8 | 4.8 | 4.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 639,152 | 639,152 | 639,152 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,423 | 1,423 | 1,423 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 815,235 | 815,235 | 815,235 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 17.0 | 17.0 | 17.0 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 555,798 | 555,798 | 555,798 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,036,899 | 1,036,899 | 1,036,899 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 878,299 | 878,299 | 878,299 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,006,965 | 1,006,965 | 1,006,965 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,477,960 | 3,477,960 | 3,477,960 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 169,724,469 | 169,724,469 | 169,724,469 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 142,513,049 | 142,513,037 | 142,513,061 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,966 | 1,966 | 1,966 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,297,368 | 1,297,368 | 1,297,368 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 27.0 | 27.0 | 27.0 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 273 | 273 | 273 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 46 | 46 | 46 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 168 | 168 | 168 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 214 | 214 | 214 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.004 | 0.004 | 0.004 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 749 | 749 | 749 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.1 | 4.1 | 4.1 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 754 | 754 | 754 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.016 | 0.016 | 0.016 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 188,743 | 188,743 | 188,743 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 513,208 | 513,208 | 513,208 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 897,081 | 897,081 | 897,081 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 9,493,751 | 9,493,751 | 9,493,752 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 24,941,898 | 24,941,896 | 24,941,900 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 45,033,459 | 45,033,455 | 45,033,462 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 142,513,049 | 142,513,037 | 142,513,061 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,838 | 2,838 | 2,838 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,872,976 | 1,872,976 | 1,872,976 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 39.0 | 39.0 | 39.0 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,696 | 4,696 | 4,696 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.10 | 0.10 | 0.10 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 27,453 | 27,453 | 27,453 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 27.5 | 27.5 | 27.5 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 18,119 | 18,119 | 18,119 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.38 | 0.38 | 0.38 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 238 | 238 | 238 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 157,078 | 157,078 | 157,078 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 3.27 | 3.27 | 3.27 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 50,056,909 | 50,056,904 | 50,056,913 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 45,954,158 | 45,954,154 | 45,954,162 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,604 | 4,604 | 4,604 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,052,672 | 2,910,479 | 3,194,866 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 513,263 | 489,355 | 537,171 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 55,242 | 52,669 | 57,816 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 14 | 13 | 15 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,878,240 | 1,790,752 | 1,965,729 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,181 | 3,986 | 4,376 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,395,684 | 2,284,093 | 2,507,275 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 49.9 | 47.6 | 52.2 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 8,382,706 | 7,992,239 | 8,773,173 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 161 | 153 | 168 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 154 | 147 | 161 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,463 | 5,208 | 5,717 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 45,798 | 43,664 | 47,931 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 8,433,966 | 8,041,112 | 8,826,821 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 175.6 | 167.4 | 183.8 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,102,750 | 4,102,750 | 4,102,751 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 340,879 | 340,879 | 340,879 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 563,178 | 563,178 | 563,178 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 964,729 | 964,729 | 964,729 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 227,054 | 227,054 | 227,054 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 579,457 | 579,457 | 579,457 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 813,732 | 813,732 | 813,732 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 200,214,218 | 200,214,200 | 200,214,235 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **195.7** | **195.5** | **196.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **169.7** | **169.7** | **169.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **27.0** | **27.0** | **27.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **268.2** | **257.7** | **278.7** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **241.2** | **241.2** | **241.2** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 48,051,771 | 48,051,771 | 48,051,771 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 2,257,119 | 2,006,328 | 2,507,910 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 2,257 | 2,006 | 2,508 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,489,698 | 1,324,176 | 1,655,221 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | ining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | ining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | ining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | ining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | ining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | ining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | ining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2002 | 2002 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.13 | 0.013 | 0.50 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 51,059 | 51,059 | 51,059 | System Data | Based on Oil Production | 51,059 | 51,059 | 51,059 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 6,561,082 | 6,484,493 | 6,637,670 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 51 | 51 | 51 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,656 | 2,656 | 2,656 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.38 | 0.38 | 0.38 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 50.9 | 50.9 | 50.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,643 | 2,643 | 2,643 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 99.5% | 99.5% | 99.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 134,945,000 | 134,945,000 | 134,945,000 | System Data | Based on System Metering | 134,945,000 | 134,945,000 | 134,945,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 369.7 | 369.7 | 369.7 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 135,610,000 | 135,610,000 | 135,610,000 | System Data | Based on Injection Metering | 135,610,000 | 135,610,000 | 135,610,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 371.5 | 371.5 | 371.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 0.5% | 0.5% | 0.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 665,000 | 665,000 | 665,000 | System Data | Based on Injection Metering | 665,000 | 665,000 | 665,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 13 | 13 | 13 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 7 | 0 | 33 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 0.5% | 0.5% | 0.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.058 | 0.058 | 0.058 | System Data | Based on System Metering Bi | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,115 | 1,102 | 1,128 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 380,543 | 376,101 | 384,985 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 380,543 | 376,101 | 384,985 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2002 | 2002 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 638 | 638 | 638 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 6,561 | 6,484 | 6,638 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 7 | 6 | 7 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 4,330 | 4,280 | 4,381 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 9.98E-01 | 9.98E-01 | 9.98E-01 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 90853 | 90853 | 90853 | System Data | System Data | 90,853 | 90,853 | 90,853 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 4,965,280 | 4,965,280 | 4,965,280 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 97.2 | 97.2 | 97.2 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,804,423 | 2,804,423 | 2,804,423 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 54.9 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 7,769,703 | 7,769,703 | 7,769,703 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 152.2 | 152.2 | 152.2 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 121 | 121 | 121 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 94225 | 94225 | 94225 | System Data | Chester 10 and Dover 36 Faci | 94,225 | 94,225 | 94,225 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 94 | 94 | 94 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 62,189 | 62,189 | 62,189 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.2 | 1.2 | 1.2 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 138,875 | 138,875 | 138,875 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 378,087 | 378,087 | 378,087 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 2,854 | 1,410 | 5,775 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 66 | 65 | 66 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 11 | 11 | 11 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 1 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 40 | 40 | 41 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 51 | 51 | 52 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 180 | 178 | 182 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 181 | 179 | 183 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 66 | 65 | 66 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 62 | 62 | 63 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 187 | 184 | 189 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 134,945,000 | 134,945,000 | 134,945,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,281,550 | 1,281,550 | 1,281,550 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 32,843 | 32,843 | 32,843 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 27,692 | 27,692 | 27,692 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.73E+04 | 1.73E+04 | 1.73E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.16E+02 | 1.16E+02 | 1.16E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.36E-01 | 3.36E-01 | 3.36E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,940 | 3,940 | 3,940 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 100 | 100 | 100 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 21,387 | 21,387 | 21,387 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.4 | 0.4 | 0.4 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 87,172 | 87,172 | 87,172 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 12.5 | 12.5 | 12.5 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.3 | 2.3 | 2.3 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 425 | 425 | 425 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 672 | 672 | 672 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 88,269 | 88,269 | 88,269 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.7 | 1.7 | 1.7 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 134,945,000 | 134,945,000 | 134,945,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,393,803 | 2,393,803 | 2,393,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 128,794,354,614 | 128,794,354,614 | 128,794,354,614 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 15,068,939 | 15,068,939 | 15,068,939 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 6,835,150 | 6,835,150 | 6,835,150 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 133.9 | 133.9 | 133.9 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | hased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 983,646 | 983,646 | 983,646 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 165,386 | 165,386 | 165,386 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 17,800 | 17,800 | 17,800 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.5 | 4.5 | 4.5 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 605,215 | 605,215 | 605,215 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,347 | 1,347 | 1,347 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 771,948 | 771,948 | 771,948 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 15.1 | 15.1 | 15.1 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 526,286 | 526,286 | 526,286 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 981,842 | 981,842 | 981,842 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 831,664 | 831,664 | 831,664 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 953,498 | 953,498 | 953,498 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,293,290 | 3,293,290 | 3,293,290 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 160,712,561 | 160,712,561 | 160,712,561 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 134,946,115 | 134,946,102 | 134,946,128 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,861 | 1,861 | 1,861 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,228,482 | 1,228,482 | 1,228,482 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 24.1 | 24.1 | 24.1 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 258 | 258 | 258 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 43 | 43 | 43 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 159 | 159 | 159 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 203 | 203 | 203 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.004 | 0.004 | 0.004 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 710 | 710 | 710 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3.9 | 3.9 | 3.9 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 714 | 714 | 714 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.014 | 0.014 | 0.014 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 178,721 | 178,721 | 178,721 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 485,958 | 485,958 | 485,958 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 849,449 | 849,449 | 849,449 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 8,989,667 | 8,989,666 | 8,989,668 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 23,617,572 | 23,617,570 | 23,617,574 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 42,642,343 | 42,642,339 | 42,642,347 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 134,946,115 | 134,946,102 | 134,946,128 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,687 | 2,687 | 2,687 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,773,527 | 1,773,527 | 1,773,528 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 34.7 | 34.7 | 34.7 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,446 | 4,446 | 4,446 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.09 | 0.09 | 0.09 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 25,995 | 25,995 | 25,995 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 26.0 | 26.0 | 26.0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 17,157 | 17,157 | 17,157 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.34 | 0.34 | 0.34 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 225 | 225 | 225 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 148,738 | 148,738 | 148,738 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.91 | 2.91 | 2.91 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 47,399,066 | 47,399,061 | 47,399,070 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 43,514,157 | 43,514,153 | 43,514,161 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,360 | 4,360 | 4,360 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 2,890,586 | 2,755,943 | 3,025,230 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 486,010 | 463,372 | 508,649 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 52,309 | 49,873 | 54,746 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 13 | 13 | 14 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,778,513 | 1,695,669 | 1,861,356 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,959 | 3,775 | 4,143 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,268,482 | 2,162,816 | 2,374,148 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 44.4 | 42.4 | 46.5 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 7,937,614 | 7,567,880 | 8,307,349 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 152 | 145 | 159 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 146 | 139 | 152 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,173 | 4,932 | 5,414 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 43,366 | 41,346 | 45,386 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 7,986,153 | 7,614,157 | 8,358,148 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 156.4 | 149.1 | 163.7 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 3,884,909 | 3,884,909 | 3,884,909 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 322,780 | 322,780 | 322,780 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 533,275 | 533,275 | 533,275 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 913,505 | 913,505 | 913,505 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 214,998 | 214,998 | 214,998 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 548,690 | 548,690 | 548,690 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 770,525 | 770,525 | 770,525 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 189,583,558 | 189,583,540 | 189,583,576 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **161.3** | **161.2** | **161.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **151.1** | **151.1** | **151.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **24.1** | **24.1** | **24.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **238.9** | **229.6** | **248.3** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **13.0** | **13.0** | **13.0** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 51,085,335 | 51,085,335 | 51,085,335 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 2,399,613 | 2,132,990 | 2,666,237 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 2,400 | 2,133 | 2,666 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,583,745 | 1,407,773 | 1,759,716 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2001 | 2001 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.10 | 0.010 | 0.38 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 67,547 | 67,547 | 67,547 | System Data | Based on Oil Production | 67,547 | 67,547 | 67,547 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 8,679,790 | 8,578,469 | 8,781,110 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 41 | 41 | 41 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,111 | 2,111 | 2,111 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.47 | 0.47 | 0.47 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 40.6 | 40.6 | 40.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,111 | 2,111 | 2,111 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 100.0% | 100.0% | 100.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 142,591,000 | 142,591,000 | 142,591,000 | System Data | Based on System Metering | 142,591,000 | 142,591,000 | 142,591,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 390.7 | 390.7 | 390.7 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 142,579,000 | 142,579,000 | 142,579,000 | System Data | Based on Injection Metering | 142,579,000 | 142,579,000 | 142,579,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 390.6 | 390.6 | 390.6 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 0.0% | 0.0% | 0.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | -12,000 | -12,000 | -12,000 | System Data | Based on Injection Metering | -12,000 | -12,000 | -12,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 0 | 0 | -1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 0.0% | 0.0% | 0.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.041 | 0.041 | 0.041 | System Data | Based on System Metering Bi | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,476 | 1,458 | 1,493 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 355,871 | 351,717 | 360,026 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 355,871 | 351,717 | 360,026 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2001 | 2001 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 844 | 844 | 844 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 8,680 | 8,578 | 8,781 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 9 | 9 | 9 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 5,729 | 5,662 | 5,796 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.05E+00 | 1.05E+00 | 1.05E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 95207 | 95207 | 95207 | System Data | System Data | 95,207 | 95,207 | 95,207 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 5,203,234 | 5,203,234 | 5,203,234 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 77.0 | 77.0 | 77.0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,963,322 | 2,963,322 | 2,963,322 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 43.9 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 8,166,556 | 8,166,556 | 8,166,556 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 120.9 | 120.9 | 120.9 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 127 | 127 | 127 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 96359 | 96359 | 96359 | System Data | Chester 10 and Dover 36 Faci | 96,359 | 96,359 | 96,359 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 96 | 96 | 96 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 63,597 | 63,597 | 63,597 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.9 | 0.9 | 0.9 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Venti | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Venti | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Venti | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 183,720 | 183,720 | 183,720 | |
| Gate-to-Gate | Water Separation – Venti | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 500,179 | 500,179 | 500,179 | |
| Gate-to-Gate | Water Separation – Venti | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Venti | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 3,776 | 1,866 | 7,640 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 87 | 86 | 88 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 15 | 14 | 15 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 53 | 53 | 54 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 68 | 67 | 69 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 238 | 236 | 241 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 240 | 237 | 243 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 87 | 86 | 88 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 82 | 81 | 83 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 247 | 244 | 250 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 142,591,000 | 142,591,000 | 142,591,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,354,163 | 1,354,163 | 1,354,163 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 34,704 | 34,704 | 34,704 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 29,261 | 29,261 | 29,261 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.83E+04 | 1.83E+04 | 1.83E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.22E+02 | 1.22E+02 | 1.22E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.56E-01 | 3.56E-01 | 3.56E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,164 | 4,164 | 4,164 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 106 | 106 | 106 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 22,599 | 22,599 | 22,599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 92,111 | 92,111 | 92,111 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 13.2 | 13.2 | 13.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.4 | 2.4 | 2.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 449 | 449 | 449 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 710 | 710 | 710 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 93,270 | 93,270 | 93,270 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.4 | 1.4 | 1.4 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 142,591,000 | 142,591,000 | 142,591,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,529,436 | 2,529,436 | 2,529,436 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 136,091,858,303 | 136,091,858,303 | 136,091,858,303 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 15,922,747 | 15,922,747 | 15,922,747 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 7,222,431 | 7,222,431 | 7,222,431 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 106.9 | 106.9 | 106.9 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,039,380 | 1,039,380 | 1,039,380 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 174,757 | 174,757 | 174,757 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 18,809 | 18,809 | 18,809 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.8 | 4.8 | 4.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 639,507 | 639,507 | 639,507 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,424 | 1,424 | 1,424 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 815,687 | 815,687 | 815,687 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 12.1 | 12.1 | 12.1 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 556,106 | 556,106 | 556,106 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,037,474 | 1,037,474 | 1,037,474 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 878,786 | 878,786 | 878,786 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,007,523 | 1,007,523 | 1,007,523 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,479,888 | 3,479,888 | 3,479,888 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 169,818,554 | 169,818,554 | 169,818,554 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 142,592,476 | 142,592,458 | 142,592,493 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,967 | 1,967 | 1,967 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,298,091 | 1,298,091 | 1,298,091 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 19.2 | 19.2 | 19.2 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 273 | 273 | 273 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 46 | 46 | 46 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 168 | 168 | 168 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 214 | 214 | 214 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 750 | 750 | 750 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.1 | 4.1 | 4.1 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 754 | 754 | 754 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.011 | 0.011 | 0.011 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 188,848 | 188,848 | 188,848 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 513,494 | 513,494 | 513,494 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 897,581 | 897,581 | 897,581 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 9,499,043 | 9,499,041 | 9,499,044 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 24,955,799 | 24,955,796 | 24,955,802 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 45,058,557 | 45,058,552 | 45,058,562 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 142,592,476 | 142,592,458 | 142,592,493 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,839 | 2,839 | 2,839 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,874,020 | 1,874,019 | 1,874,020 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 27.7 | 27.7 | 27.7 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,698 | 4,698 | 4,698 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.07 | 0.07 | 0.07 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 27,468 | 27,468 | 27,468 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 27.5 | 27.5 | 27.5 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 18,129 | 18,129 | 18,129 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.27 | 0.27 | 0.27 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 238 | 238 | 238 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 157,165 | 157,165 | 157,165 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.33 | 2.33 | 2.33 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 50,084,807 | 50,084,801 | 50,084,813 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 45,979,770 | 45,979,764 | 45,979,775 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,607 | 4,607 | 4,607 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,054,374 | 2,912,101 | 3,196,647 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 513,549 | 489,628 | 537,470 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 55,273 | 52,699 | 57,848 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 14 | 13 | 15 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,879,287 | 1,791,750 | 1,966,825 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,183 | 3,988 | 4,378 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,397,019 | 2,285,366 | 2,508,673 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 35.5 | 33.8 | 37.1 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 8,387,378 | 7,996,693 | 8,778,063 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 161 | 153 | 168 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 154 | 147 | 161 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,466 | 5,211 | 5,720 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 45,823 | 43,689 | 47,957 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 8,438,667 | 8,045,593 | 8,831,740 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 124.9 | 119.1 | 130.7 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,105,037 | 4,105,036 | 4,105,037 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 341,069 | 341,069 | 341,069 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 563,492 | 563,492 | 563,492 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 965,266 | 965,266 | 965,266 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 227,180 | 227,180 | 227,180 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 579,780 | 579,780 | 579,780 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 814,185 | 814,185 | 814,185 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 200,325,802 | 200,325,778 | 200,325,827 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **129.7** | **129.6** | **130.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **120.7** | **120.7** | **120.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **19.2** | **19.2** | **19.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **190.8** | **183.4** | **198.3** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **-0.2** | **-0.2** | **-0.2** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 67,581,839 | 67,581,839 | 67,581,839 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 3,174,498 | 2,821,776 | 3,527,220 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 3,174 | 2,822 | 3,527 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 2,095,169 | 1,862,372 | 2,327,965 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2000 | 2000 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.11 | 0.011 | 0.40 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 63,989 | 63,989 | 63,989 | System Data | Based on Oil Production | 63,989 | 63,989 | 63,989 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 8,222,587 | 8,126,603 | 8,318,570 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 48 | 48 | 48 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 2,484 | 2,484 | 2,484 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.40 | 0.40 | 0.40 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 43.2 | 43.2 | 43.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 2,246 | 2,246 | 2,246 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 89.4% | 89.4% | 89.4% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 143,711,000 | 143,711,000 | 143,711,000 | System Data | Based on System Metering | 143,711,000 | 143,711,000 | 143,711,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 393.7 | 393.7 | 393.7 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 158,970,000 | 158,970,000 | 158,970,000 | System Data | Based on Injection Metering | 158,970,000 | 158,970,000 | 158,970,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 435.5 | 435.5 | 435.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 9.6% | 9.6% | 9.6% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 15,259,000 | 15,259,000 | 15,259,000 | System Data | Based on Injection Metering | 15,259,000 | 15,259,000 | 15,259,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 238 | 238 | 238 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 153 | 0 | 763 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 9.6% | 9.6% | 9.6% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.08 | 0.08 | 0.08 | System Data | Based on System Metering Br | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 1,398 | 1,382 | 1,414 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 657,807 | 650,128 | 665,486 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 657,807 | 650,128 | 665,486 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 2000 | 2000 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 800 | 800 | 800 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 8,223 | 8,127 | 8,319 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 8 | 8 | 8 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 5,427 | 5,364 | 5,490 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.06E+00 | 1.06E+00 | 1.06E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 113206 | 113206 | 113206 | System Data | System Data | 113,206 | 113,206 | 113,206 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 6,186,912 | 6,186,912 | 6,186,912 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 96.7 | 96.7 | 96.7 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2,986,598 | 2,986,598 | 2,986,598 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 46.7 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 9,173,510 | 9,173,510 | 9,173,510 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 143.4 | 143.4 | 143.4 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 142 | 142 | 142 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 166698 | 166698 | 166698 | System Data | Chester 10 and Dover 36 Faci | 166,698 | 166,698 | 166,698 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 167 | 167 | 167 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 110,021 | 110,021 | 110,021 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.7 | 1.7 | 1.7 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 174,043 | 174,043 | 174,043 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 473,832 | 473,832 | 473,832 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 3,577 | 1,768 | 7,237 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 82 | 81 | 83 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 14 | 14 | 14 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1 | 1 | 2 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 51 | 50 | 51 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 65 | 64 | 65 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 226 | 223 | 228 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 227 | 225 | 230 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 82 | 81 | 83 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 78 | 77 | 79 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 234 | 231 | 237 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 143,711,000 | 143,711,000 | 143,711,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,364,800 | 1,364,800 | 1,364,800 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 34,977 | 34,977 | 34,977 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 29,491 | 29,491 | 29,491 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.85E+04 | 1.85E+04 | 1.85E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.23E+02 | 1.23E+02 | 1.23E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.58E-01 | 3.58E-01 | 3.58E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,196 | 4,196 | 4,196 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 107 | 107 | 107 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 22,777 | 22,777 | 22,777 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.4 | 0.4 | 0.4 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 92,834 | 92,834 | 92,834 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 13.3 | 13.3 | 13.3 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 2.4 | 2.4 | 2.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 452 | 452 | 452 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 716 | 716 | 716 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 94,002 | 94,002 | 94,002 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.5 | 1.5 | 1.5 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 143,711,000 | 143,711,000 | 143,711,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2,549,304 | 2,549,304 | 2,549,304 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 137,160,809,929 | 137,160,809,929 | 137,160,809,929 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 16,047,815 | 16,047,815 | 16,047,815 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 7,279,160 | 7,279,160 | 7,279,160 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 113.8 | 113.8 | 113.8 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,047,543 | 1,047,543 | 1,047,543 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 176,129 | 176,129 | 176,129 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 18,957 | 18,957 | 18,957 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.8 | 4.8 | 4.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 644,530 | 644,530 | 644,530 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,435 | 1,435 | 1,435 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 822,094 | 822,094 | 822,094 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 12.8 | 12.8 | 12.8 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 560,474 | 560,474 | 560,474 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,045,622 | 1,045,622 | 1,045,622 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 885,689 | 885,689 | 885,689 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,015,437 | 1,015,437 | 1,015,437 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 3,507,222 | 3,507,222 | 3,507,222 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 171,152,416 | 171,152,416 | 171,152,416 | |
| **GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION)** | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 143,712,398 | 143,712,382 | 143,712,414 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,982 | 1,982 | 1,982 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,308,286 | 1,308,286 | 1,308,286 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 20.4 | 20.4 | 20.4 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 275 | 275 | 275 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 46 | 46 | 46 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 5 | 5 | 5 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 169 | 169 | 169 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 216 | 216 | 216 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | Fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 756 | 756 | 756 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4.1 | 4.1 | 4.1 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 760 | 760 | 760 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.012 | 0.012 | 0.012 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 190,331 | 190,331 | 190,331 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 517,527 | 517,527 | 517,527 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 904,630 | 904,630 | 904,631 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 9,573,648 | 9,573,647 | 9,573,649 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 25,151,802 | 25,151,799 | 25,151,805 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 45,412,447 | 45,412,442 | 45,412,452 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 143,712,398 | 143,712,382 | 143,712,414 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 2,862 | 2,862 | 2,862 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,888,738 | 1,888,738 | 1,888,738 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 29.5 | 29.5 | 29.5 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 4,735 | 4,735 | 4,735 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.07 | 0.07 | 0.07 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 27,684 | 27,684 | 27,684 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 27.7 | 27.7 | 27.7 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 18,271 | 18,271 | 18,271 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.29 | 0.29 | 0.29 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 240 | 240 | 240 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 158,400 | 158,400 | 158,400 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.48 | 2.48 | 2.48 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 50,478,173 | 50,478,168 | 50,478,179 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 46,340,895 | 46,340,890 | 46,340,901 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 4,643 | 4,643 | 4,643 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 3,078,363 | 2,934,972 | 3,221,753 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 517,582 | 493,473 | 541,691 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 55,707 | 53,112 | 58,302 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 14 | 13 | 15 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,894,047 | 1,805,822 | 1,982,272 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 4,216 | 4,020 | 4,413 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 2,415,846 | 2,303,315 | 2,528,376 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 37.8 | 36.0 | 39.5 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 8,453,252 | 8,059,499 | 8,847,005 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 162 | 154 | 170 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 155 | 148 | 162 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,509 | 5,252 | 5,765 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 46,183 | 44,032 | 48,334 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 8,504,944 | 8,108,783 | 8,901,105 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 132.9 | 126.7 | 139.1 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 4,137,278 | 4,137,277 | 4,137,278 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 343,748 | 343,748 | 343,748 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 567,917 | 567,917 | 567,917 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 972,847 | 972,847 | 972,847 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 228,965 | 228,965 | 228,965 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 584,334 | 584,334 | 584,334 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 820,580 | 820,580 | 820,580 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 201,899,163 | 201,899,140 | 201,899,186 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **152.9** | **152.8** | **153.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **128.4** | **128.4** | **128.4** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **20.5** | **20.5** | **20.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **203.0** | **195.1** | **211.0** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **238.5** | **238.5** | **238.5** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 64,022,003 | 64,022,003 | 64,022,003 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 3,007,283 | 2,673,140 | 3,341,426 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 3,007 | 2,673 | 3,341 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 1,984,807 | 1,764,273 | 2,205,341 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | ining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | ining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | ining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | ining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | ining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | ining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | ining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1999 | 1999 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.07 | 0.007 | 0.25 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 102,758 | 102,758 | 102,758 | System Data | Based on Oil Production | 102,758 | 102,758 | 102,758 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 13,204,403 | 13,050,266 | 13,358,540 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 36 | 36 | 36 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,887 | 1,887 | 1,887 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.53 | 0.53 | 0.53 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 35.2 | 35.2 | 35.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,829 | 1,829 | 1,829 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 96.8% | 96.8% | 96.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 187,916,000 | 187,916,000 | 187,916,000 | System Data | Based on System Metering | 187,916,000 | 187,916,000 | 187,916,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 514.8 | 514.8 | 514.8 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 193,857,000 | 193,857,000 | 193,857,000 | System Data | Based on Injection Metering | 193,857,000 | 193,857,000 | 193,857,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 531.1 | 531.1 | 531.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 3.1% | 3.1% | 3.1% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 5,941,000 | 5,941,000 | 5,941,000 | System Data | Based on Injection Metering | 5,941,000 | 5,941,000 | 5,941,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 58 | 58 | 58 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 59 | 0 | 297 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 3.1% | 3.1% | 3.1% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.069 | 0.069 | 0.069 | System Data | Based on System Metering Bi | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,245 | 2,219 | 2,271 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 911,104 | 900,468 | 921,739 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 911,104 | 900,468 | 921,739 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1999 | 1999 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,284 | 1,284 | 1,284 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 13,204 | 13,050 | 13,359 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 13 | 13 | 13 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 8,715 | 8,613 | 8,817 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.39E+00 | 1.39E+00 | 1.39E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 132187 | 132187 | 132187 | System Data | System Data | 132,187 | 132,187 | 132,187 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 7,224,257 | 7,224,257 | 7,224,257 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 70.3 | 70.3 | 70.3 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 3,905,265 | 3,905,265 | 3,905,265 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 38.0 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 11,129,522 | 11,129,522 | 11,129,522 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 108.3 | 108.3 | 108.3 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 173 | 173 | 173 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 154079 | 154079 | 154079 | System Data | Chester 10 and Dover 36 Faci | 154,079 | 154,079 | 154,079 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 154 | 154 | 154 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 101,692 | 101,692 | 101,692 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.0 | 1.0 | 1.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 279,490 | 279,490 | 279,490 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 760,913 | 760,913 | 760,913 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 5,744 | 2,838 | 11,622 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 132 | 131 | 134 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 22 | 22 | 22 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 81 | 80 | 82 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 104 | 102 | 105 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 363 | 358 | 367 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 2 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 365 | 361 | 369 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 132 | 131 | 134 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 125 | 124 | 127 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 376 | 371 | 380 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 187,916,000 | 187,916,000 | 187,916,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,784,607 | 1,784,607 | 1,784,607 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 45,736 | 45,736 | 45,736 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 38,562 | 38,562 | 38,562 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.42E+04 | 2.42E+04 | 2.42E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.61E+02 | 1.61E+02 | 1.61E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 4.69E-01 | 4.69E-01 | 4.69E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,487 | 5,487 | 5,487 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 140 | 140 | 140 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 29,783 | 29,783 | 29,783 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.3 | 0.3 | 0.3 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 121,390 | 121,390 | 121,390 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 17.4 | 17.4 | 17.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 3.1 | 3.1 | 3.1 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 592 | 592 | 592 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 936 | 936 | 936 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 122,917 | 122,917 | 122,917 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.2 | 1.2 | 1.2 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 187,916,000 | 187,916,000 | 187,916,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 3,333,461 | 3,333,461 | 3,333,461 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 179,350,994,417 | 179,350,994,417 | 179,350,994,417 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 20,984,066 | 20,984,066 | 20,984,066 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 9,518,205 | 9,518,205 | 9,518,205 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 92.6 | 92.6 | 92.6 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,369,764 | 1,369,764 | 1,369,764 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 230,306 | 230,306 | 230,306 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 24,788 | 24,788 | 24,788 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.3 | 6.3 | 6.3 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 842,785 | 842,785 | 842,785 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1,876 | 1,876 | 1,876 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,074,967 | 1,074,967 | 1,074,967 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 10.5 | 10.5 | 10.5 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 732,874 | 732,874 | 732,874 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,367,252 | 1,367,252 | 1,367,252 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,158,123 | 1,158,123 | 1,158,123 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,327,781 | 1,327,781 | 1,327,781 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 4,586,031 | 4,586,031 | 4,586,031 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 223,798,300 | 223,798,300 | 223,798,300 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 187,918,245 | 187,918,219 | 187,918,271 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,592 | 2,592 | 2,592 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,710,714 | 1,710,714 | 1,710,714 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 16.6 | 16.6 | 16.6 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 360 | 360 | 360 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 61 | 61 | 61 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 7 | 7 | 7 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 221 | 221 | 221 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 282 | 282 | 282 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.003 | 0.003 | 0.003 | RF |
| Gate-to-Gate | fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 988 | 988 | 988 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.6 | 0.6 | 0.6 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5.4 | 5.4 | 5.4 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 994 | 994 | 994 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.010 | 0.010 | 0.010 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 248,877 | 248,877 | 248,877 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 676,718 | 676,718 | 676,718 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,182,894 | 1,182,894 | 1,182,894 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 12,518,496 | 12,518,495 | 12,518,498 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 32,888,481 | 32,888,476 | 32,888,485 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 59,381,289 | 59,381,280 | 59,381,297 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 187,918,245 | 187,918,219 | 187,918,271 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 3,742 | 3,742 | 3,742 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,469,713 | 2,469,713 | 2,469,713 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 24.0 | 24.0 | 24.0 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 6,192 | 6,192 | 6,192 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.06 | 0.06 | 0.06 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 36,199 | 36,199 | 36,199 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 36.2 | 36.2 | 36.2 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 23,891 | 23,891 | 23,891 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.23 | 0.23 | 0.23 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 314 | 314 | 314 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 207,123 | 207,123 | 207,124 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 2.02 | 2.02 | 2.02 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 66,005,229 | 66,005,220 | 66,005,238 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 60,595,327 | 60,595,318 | 60,595,335 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 6,071 | 6,071 | 6,071 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 4,025,265 | 3,837,768 | 4,212,762 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 676,790 | 645,265 | 708,315 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 72,843 | 69,450 | 76,236 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 19 | 18 | 19 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,476,655 | 2,361,292 | 2,592,018 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,513 | 5,256 | 5,770 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 3,158,958 | 3,011,814 | 3,306,103 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 30.7 | 29.3 | 32.2 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 11,053,468 | 10,538,596 | 11,568,339 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 212 | 202 | 222 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 203 | 193 | 212 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 7,203 | 6,868 | 7,539 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 60,389 | 57,576 | 63,202 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 11,121,060 | 10,603,040 | 11,639,080 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 108.2 | 103.2 | 113.3 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 5,409,902 | 5,409,901 | 5,409,903 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 449,485 | 449,485 | 449,485 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 742,608 | 742,608 | 742,608 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,272,095 | 1,272,095 | 1,272,095 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 299,394 | 299,394 | 299,394 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 764,074 | 764,074 | 764,074 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,072,989 | 1,072,989 | 1,072,989 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 264,003,223 | 264,003,186 | 264,003,260 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **117.0** | **117.0** | **117.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **104.6** | **104.6** | **104.6** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **16.7** | **16.7** | **16.7** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **165.3** | **158.8** | **171.8** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **57.8** | **57.8** | **57.8** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 102,810,999 | 102,810,999 | 102,810,999 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 4,829,305 | 4,292,715 | 5,365,894 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 4,829 | 4,293 | 5,366 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,187,341 | 2,833,192 | 3,541,490 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 0 | 0 | 0 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 0 | 0 | 0 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1998 | 1998 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.04 | 0.004 | 0.14 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **0** | **0** | **0** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 184,885 | 184,885 | 184,885 | System Data | Based on Oil Production | 184,885 | 184,885 | 184,885 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 23,757,723 | 23,480,395 | 24,035,050 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 31 | 31 | 31 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,635 | 1,635 | 1,635 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.61 | 0.61 | 0.61 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 0 | 0 | 0 | System Data | Based on Pure CO2 from Gas | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 21.2 | 21.2 | 21.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1,100 | 1,100 | 1,100 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | 51.5% | 51.5% | 51.5% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 203,459,000 | 203,459,000 | 203,459,000 | System Data | Based on System Metering | 203,459,000 | 203,459,000 | 203,459,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 557.4 | 557.4 | 557.4 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 302,222,000 | 302,222,000 | 302,222,000 | System Data | Based on Injection Metering | 302,222,000 | 302,222,000 | 302,222,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 828.0 | 828.0 | 828.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 32.7% | 32.7% | 32.7% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 98,763,000 | 98,763,000 | 98,763,000 | System Data | Based on Injection Metering | 98,763,000 | 98,763,000 | 98,763,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 534 | 534 | 534 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 988 | 0 | 4,938 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 32.7% | 32.7% | 32.7% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.059 | 0.059 | 0.059 | System Data | Based on System Metering Bi | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.1 | 0.1 | 0.1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 4,039 | 3,992 | 4,086 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 1,401,706 | 1,385,343 | 1,418,068 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 1,401,706 | 1,385,343 | 1,418,068 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1998 | 1998 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 2,311 | 2,311 | 2,311 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 23,758 | 23,480 | 24,035 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 24 | 23 | 24 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 15,680 | 15,497 | 15,863 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 1.51E+00 | 1.51E+00 | 1.51E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 247505 | 247505 | 247505 | System Data | System Data | 247,505 | 247,505 | 247,505 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 13,526,594 | 13,526,594 | 13,526,594 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 73.2 | 73.2 | 73.2 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 4,228,279 | 4,228,279 | 4,228,279 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 22.9 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 17,754,873 | 17,754,873 | 17,754,873 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 96.0 | 96.0 | 96.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 270 | 270 | 270 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 587848 | 587848 | 587848 | System Data | Chester 10 and Dover 36 Faci | 587,848 | 587,848 | 587,848 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 588 | 588 | 588 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 387,980 | 387,980 | 387,980 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 2.1 | 2.1 | 2.1 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 502,867 | 502,867 | 502,867 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 1,369,055 | 1,369,055 | 1,369,055 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 10,335 | 5,107 | 20,910 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 238 | 235 | 240 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 40 | 39 | 40 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 4 | 4 | 4 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 146 | 144 | 148 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 186 | 184 | 189 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 652 | 645 | 660 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.4 | 0.4 | 0.4 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 4 | 4 | 4 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 656 | 649 | 664 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 238 | 235 | 240 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 226 | 223 | 228 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 676 | 668 | 684 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 203,459,000 | 203,459,000 | 203,459,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1,932,217 | 1,932,217 | 1,932,217 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 49,519 | 49,519 | 49,519 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 41,751 | 41,751 | 41,751 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 2.62E+04 | 2.62E+04 | 2.62E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 1.75E+02 | 1.75E+02 | 1.75E+02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 5.07E-01 | 5.07E-01 | 5.07E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5,941 | 5,941 | 5,941 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 151 | 151 | 151 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 32,246 | 32,246 | 32,246 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.2 | 0.2 | 0.2 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 131,430 | 131,430 | 131,430 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 18.8 | 18.8 | 18.8 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 3.4 | 3.4 | 3.4 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 640 | 640 | 640 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,014 | 1,014 | 1,014 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 133,084 | 133,084 | 133,084 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.7 | 0.7 | 0.7 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 203,459,000 | 203,459,000 | 203,459,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 3,609,180 | 3,609,180 | 3,609,180 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 194,185,561,491 | 194,185,561,491 | 194,185,561,491 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 22,719,711 | 22,719,711 | 22,719,711 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 10,305,479 | 10,305,479 | 10,305,479 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 55.7 | 55.7 | 55.7 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1,483,061 | 1,483,061 | 1,483,061 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 249,355 | 249,355 | 249,355 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 26,838 | 26,838 | 26,838 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 6.8 | 6.8 | 6.8 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 912,494 | 912,494 | 912,494 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,031 | 2,031 | 2,031 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1,163,880 | 1,163,880 | 1,163,880 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 6.3 | 6.3 | 6.3 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 793,491 | 793,491 | 793,491 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1,480,341 | 1,480,341 | 1,480,341 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1,253,915 | 1,253,915 | 1,253,915 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1,437,606 | 1,437,606 | 1,437,606 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 4,965,353 | 4,965,353 | 4,965,353 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 242,309,214 | 242,309,214 | 242,309,214 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 203,463,039 | 203,462,992 | 203,463,086 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 2,806 | 2,806 | 2,806 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1,852,226 | 1,852,226 | 1,852,226 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 10.0 | 10.0 | 10.0 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 390 | 390 | 390 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 66 | 66 | 66 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 7 | 7 | 7 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 240 | 240 | 240 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 306 | 306 | 306 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.002 | 0.002 | 0.002 | RF |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1,070 | 1,070 | 1,070 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.02 | 0.02 | 0.02 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.7 | 0.7 | 0.7 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 5.8 | 5.8 | 5.8 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,076 | 1,076 | 1,076 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.006 | 0.006 | 0.006 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 269,464 | 269,464 | 269,464 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 732,697 | 732,696 | 732,697 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1,280,744 | 1,280,744 | 1,280,745 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 13,554,040 | 13,554,036 | 13,554,043 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 35,609,050 | 35,609,042 | 35,609,059 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 64,293,371 | 64,293,356 | 64,293,386 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 203,463,039 | 203,462,992 | 203,463,086 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 4,052 | 4,052 | 4,052 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 2,674,010 | 2,674,010 | 2,674,011 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 14.5 | 14.5 | 14.5 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 6,704 | 6,704 | 6,704 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.04 | 0.04 | 0.04 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 39,193 | 39,193 | 39,193 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 39.2 | 39.2 | 39.2 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 25,867 | 25,867 | 25,867 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.14 | 0.14 | 0.14 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 340 | 340 | 340 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 224,257 | 224,257 | 224,257 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 1.21 | 1.21 | 1.21 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 71,465,251 | 71,465,234 | 71,465,267 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 65,607,836 | 65,607,821 | 65,607,851 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 6,573 | 6,573 | 6,573 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 4,358,239 | 4,155,232 | 4,561,247 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 732,775 | 698,642 | 766,908 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 78,868 | 75,195 | 82,542 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 20 | 19 | 21 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2,681,526 | 2,556,620 | 2,806,432 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 5,969 | 5,691 | 6,247 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 3,420,271 | 3,260,954 | 3,579,587 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 18.5 | 17.6 | 19.4 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 11,967,822 | 11,410,359 | 12,525,286 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 229 | 219 | 240 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 219 | 209 | 230 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 7,799 | 7,436 | 8,162 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 65,384 | 62,339 | 68,430 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 12,041,005 | 11,480,133 | 12,601,878 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 65.1 | 62.1 | 68.2 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 5,857,415 | 5,857,414 | 5,857,416 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 486,666 | 486,666 | 486,666 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 804,038 | 804,038 | 804,038 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,377,324 | 1,377,324 | 1,377,324 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 324,160 | 324,160 | 324,160 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 827,279 | 827,279 | 827,279 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1,161,748 | 1,161,748 | 1,161,748 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 285,841,846 | 285,841,780 | 285,841,913 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **105.8** | **105.7** | **105.9** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **62.9** | **62.9** | **62.9** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **10.0** | **10.0** | **10.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **99.5** | **95.6** | **103.4** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **534.2** | **534.2** | **534.2** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 184,980,358 | 184,980,358 | 184,980,358 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 8,689,017 | 7,723,571 | 9,654,463 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 8,689 | 7,724 | 9,654 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 5,734,751 | 5,097,557 | 6,371,946 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 29,630,349 | 27,984,218 | 31,482,246 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.0 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 4,569,003 | 3,116,512 | 7,012,151 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 35 | 24 | 54 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 76,150 | 86,303 | 78,212 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 12,028,588 | 7,573,556 | 17,040,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 93 | 59 | 132 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 68,162,000 | 68,162,000 | 68,162,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1997 | 1997 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.05 | 0.005 | 0.20 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **128** | **83** | **186** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | |
|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 129,250 | 129,250 | 129,250 | System Data | Based on Oil Production | 129,250 | 129,250 | 129,250 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 16,608,625 | 16,414,750 | 16,802,500 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 28 | 28 | 28 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,435 | 1,435 | 1,435 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.70 | 0.70 | 0.70 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 68,162,000 | 68,162,000 | 68,162,000 | System Data | Based on Pure CO2 from Gas | 68,162,000 | 68,162,000 | 68,162,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 13.2 | 13.2 | 13.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 684 | 684 | 684 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | -9.8% | -9.8% | -9.8% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | -6,661,349 | -6,661,349 | -6,661,349 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | -51.5 | -51.5 | -51.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | 88,388,000 | 88,388,000 | 88,388,000 | System Data | Based on System Metering | 88,388,000 | 88,388,000 | 88,388,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 242.2 | 242.2 | 242.2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 185,415,000 | 185,415,000 | 185,415,000 | System Data | Based on Injection Metering | 185,415,000 | 185,415,000 | 185,415,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 508.0 | 508.0 | 508.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 52.3% | 52.3% | 52.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 97,026,000 | 97,026,000 | 97,026,000 | System Data | Based on Injection Metering | 97,026,000 | 97,026,000 | 97,026,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 751 | 751 | 751 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 970 | 0 | 4,851 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 52.3% | 52.3% | 52.3% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | 0.026 | 0.026 | 0.026 | System Data | Based on System Metering Br | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2,823 | 2,791 | 2,856 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 431,824 | 426,784 | 436,865 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 431,824 | 426,784 | 436,865 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1997 | 1997 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1,616 | 1,616 | 1,616 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 16,609 | 16,415 | 16,803 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 17 | 16 | 17 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 10,962 | 10,834 | 11,090 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 6.54E-01 | 6.54E-01 | 6.54E-01 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 136078 | 136078 | 136078 | System Data | System Data | 136,078 | 136,078 | 136,078 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 7,436,908 | 7,436,908 | 7,436,908 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 57.5 | 57.5 | 57.5 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 11 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 1,836,877 | 1,836,877 | 1,836,877 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 14.2 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 9,273,784 | 9,273,784 | 9,273,784 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 71.8 | 71.8 | 71.8 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 165 | 165 | 165 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 370548 | 370548 | 370548 | System Data | Chester 10 and Dover 36 Faci | 370,548 | 370,548 | 370,548 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 371 | 371 | 371 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 244,562 | 244,562 | 244,562 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.9 | 1.9 | 1.9 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Cor | 351,546 | 351,546 | 351,546 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 957,083 | 957,083 | 957,083 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 7,225 | 3,570 | 14,618 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 166 | 164 | 168 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 28 | 28 | 28 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 102 | 101 | 103 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 130 | 129 | 132 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 456 | 451 | 461 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 2 | 2 | 3 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 459 | 454 | 464 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 166 | 164 | 168 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 158 | 156 | 160 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 473 | 467 | 478 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well El | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 88,388,000 | 88,388,000 | 88,388,000 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 839,406 | 839,406 | 839,406 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 21,512 | 21,512 | 21,512 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 18,138 | 18,138 | 18,138 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.14E+04 | 1.14E+04 | 1.14E+04 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 7.59E+01 | 7.59E+01 | 7.59E+01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 2.20E-01 | 2.20E-01 | 2.20E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,581 | 2,581 | 2,581 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 66 | 66 | 66 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 14,008 | 14,008 | 14,008 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Diese | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 57,097 | 57,097 | 57,097 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 8.2 | 8.2 | 8.2 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 1.5 | 1.5 | 1.5 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 278 | 278 | 278 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 440 | 440 | 440 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 57,815 | 57,815 | 57,815 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.4 | 0.4 | 0.4 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 88,388,000 | 88,388,000 | 88,388,000 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 1,567,924 | 1,567,924 | 1,567,924 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 84,359,371,712 | 84,359,371,712 | 84,359,371,712 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 9,870,046 | 9,870,046 | 9,870,046 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 4,476,974 | 4,476,974 | 4,476,974 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 34.6 | 34.6 | 34.6 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 644,281 | 644,281 | 644,281 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 108,327 | 108,327 | 108,327 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 11,659 | 11,659 | 11,659 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 3.0 | 3.0 | 3.0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 396,412 | 396,412 | 396,412 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 882 | 882 | 882 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 505,621 | 505,621 | 505,621 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 3.9 | 3.9 | 3.9 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 344,714 | 344,714 | 344,714 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 643,100 | 643,100 | 643,100 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 544,734 | 544,734 | 544,734 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 624,534 | 624,534 | 624,534 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 2,157,081 | 2,157,081 | 2,157,081 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 105,265,566 | 105,265,566 | 105,265,566 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 88,390,823 | 88,390,791 | 88,390,856 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 1,219 | 1,219 | 1,219 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 804,666 | 804,666 | 804,666 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 6.2 | 6.2 | 6.2 | RF |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 169 | 169 | 169 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 28 | 28 | 28 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 3 | 3 | 3 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 104 | 104 | 104 | |
| Gate-to-Gate | geration/Fractionation) – f | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 133 | 133 | 133 | |
| Gate-to-Gate | geration/Fractionation) – f | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.001 | 0.001 | 0.001 | RF |
| Gate-to-Gate | Fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial E | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 465 | 465 | 465 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.01 | 0.01 | 0.01 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 468 | 468 | 468 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.004 | 0.004 | 0.004 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 117,064 | 117,064 | 117,064 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 318,307 | 318,307 | 318,307 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 556,396 | 556,396 | 556,396 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 5,888,306 | 5,888,304 | 5,888,309 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 15,469,705 | 15,469,700 | 15,469,711 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 27,931,088 | 27,931,077 | 27,931,098 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 88,390,823 | 88,390,791 | 88,390,856 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 1,760 | 1,760 | 1,760 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 1,161,675 | 1,161,675 | 1,161,676 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 9.0 | 9.0 | 9.0 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the compressor | 2,912 | 2,912 | 2,912 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.02 | 0.02 | 0.02 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 17,027 | 17,027 | 17,027 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 17.0 | 17.0 | 17.0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 11,238 | 11,238 | 11,238 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.09 | 0.09 | 0.09 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 148 | 148 | 148 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 97,424 | 97,424 | 97,424 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.75 | 0.75 | 0.75 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 31,046,781 | 31,046,769 | 31,046,792 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 28,502,133 | 28,502,123 | 28,502,144 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 2,856 | 2,856 | 2,856 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 1,893,358 | 1,805,165 | 1,981,551 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 318,341 | 303,512 | 333,169 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 34,263 | 32,667 | 35,859 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 9 | 8 | 9 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 1,164,940 | 1,110,677 | 1,219,204 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 2,593 | 2,472 | 2,714 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 1,485,874 | 1,416,662 | 1,555,087 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 11.5 | 11.0 | 12.0 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 5,199,203 | 4,957,023 | 5,441,384 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 100 | 95 | 104 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 95 | 91 | 100 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 3,388 | 3,230 | 3,546 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 28,405 | 27,082 | 29,728 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 5,230,996 | 4,987,335 | 5,474,658 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 40.5 | 38.6 | 42.4 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 2,544,648 | 2,544,647 | 2,544,649 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 211,423 | 211,423 | 211,423 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 349,300 | 349,300 | 349,300 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 598,353 | 598,353 | 598,353 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 140,826 | 140,826 | 140,826 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 359,397 | 359,397 | 359,397 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 504,700 | 504,700 | 504,700 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 124,178,801 | 124,178,755 | 124,178,847 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2$e / bbl** | | | | | | **81.3** | **81.3** | **81.5** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2$e / bbl** | | | | | | **39.1** | **39.1** | **39.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2$e / bbl** | | | | | | **6.2** | **6.2** | **6.2** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2$e / bbl** | | | | | | **61.8** | **59.4** | **64.2** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2$e / bbl** | | | | | | **750.7** | **750.7** | **750.7** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2$e / bbl** | | | | | | **-51.5** | **-51.5** | **-51.5** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2$e / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 129,316,663 | 129,316,663 | 129,316,663 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 6,074,346 | 5,399,419 | 6,749,273 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 6,074 | 5,399 | 6,749 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 4,009,068 | 3,563,616 | 4,454,520 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Upstream | hining, processing, and tra | Coal mining, processing, and transport | kg $CO_2$e / MWh | 13 | 18 | 26 | Literature | Jaramillo et al. (2007; 2009) | 18 | 13 | 26 | |
| Upstream | hining, processing, and tra | mining, processing, and transport (adjusted for net plant efficie | kg $CO_2$e / MWh | | | | Derived | Derived from the coal mining | 60 | 36 | 90 | |
| Upstream | hining, processing, and tra | Mass of coal required per unit of energy | kg coal / MWh | | | | Derived | Derived using the heat rate a | 389 | 324 | 403 | |
| Upstream | hining, processing, and tra | Mass of coal required | kg | | | | Derived | Derived using Eq. 2 and the p | 47,920,988 | 45,258,711 | 50,916,050 | |
| Upstream | hining, processing, and tra | Mass of coal required | Mt | | | | Derived | Unit conversion from kg to M | 0.0 | 0.0 | 0.1 | |
| Upstream | hining, processing, and tra | $_2$ emissions associated with coal mining, processing, and transp | kg $CO_2$e | | | | Derived | Derived from the adjusted en | 7,389,422 | 5,040,316 | 11,340,711 | |
| Upstream | hining, processing, and tra | missions factor associated with coal mining, processing, and tra | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 73894 | 50403 | 113407 | |
| **UPSTREAM: COAL-FIRED POWER PLANT** | | | | | | | | | | | | |
| Upstream | Coal-fired power plant | Net plant efficiency | fraction | 0.29 | 0.30 | 0.36 | Literature | IEA (2007); Rubin et al. (2007 | 0.30 | 0.36 | 0.29 | |
| Upstream | Coal-fired power plant | Heat rate | kJ/kWh | | | | Derived | Derived from one unit of elec | 12,000 | 10,000 | 12,414 | |
| Upstream | Coal-fired power plant | Select coal type | 1.0 | | | | | User selects from one of four types of coals from Rubin et al. (2007) Assume Pittsburgh #8 (bituminous) | | | | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kWh / kg | | 8.567 | | Literature | Lookup function based on us | 8.567 | 8.567 | 8.567 | |
| Upstream | Coal-fired power plant | High heating value (HHV) | kJ / kg | | | | Derived | Unit conversion from kWh/kg | 30,840 | 30,840 | 30,840 | |
| Upstream | Coal-fired power plant | Carbon fraction of the coal | % | | 73.8% | | Literature | Lookup function based on us | 73.8% | 73.8% | 73.8% | |
| Upstream | Coal-fired power plant | Coal plant emissions (adjusted for net plant efficiency) | kg $CO_2$ / MWh | | | | Derived | Derived using Eq. 1 and the H | 1053 | 878 | 1089 | |
| Upstream | Coal-fired power plant | $CO_2$ capture efficiency | % | 80% | 85% | 90% | Literature | Rubin et al. (2007) as publish | 85% | 90% | 80% | |
| Upstream | Coal-fired power plant | $CO_2$ captured for transport to $CO_2$ EOR field | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 895 | 790 | 871 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions rate from the coal plant | kg $CO_2$ / MWh | | | | Derived | Derived from coal plant emis | 158 | 88 | 218 | |
| Upstream | Coal-fired power plant | Energy needs of the coal plant | MWh | | | | Derived | Derived from the purchased ( | 123,157 | 139,578 | 126,493 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions from the coal plant | kg $CO_2$ | | | | Derived | Derived from the energy nee | 19,453,765 | 12,248,667 | 27,559,500 | |
| Upstream | Coal-fired power plant | $CO_2$ emissions factor from the coal plant | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 194,538 | 122,487 | 275,595 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (ELECTRICITY)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | lectricity needed per tonne of $CO_2$ transported (100 to 1000 km | kWh / tonne | | 0.00 | | Literature | No pipeline pumping needed | 0.00 | 0.00 | 0.00 | |
| Upstream | Pipeline transport of $CO_2$ | Electricity needed per kg of $CO_2$ transported (100 to 1000 km) | MWh / kg | | | | Derived | Unit conversion from kWh/tc | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Upstream | Pipeline transport of $CO_2$ | Kilograms of purchased $CO_2$ | kg | | | | Derived | Derived from incremental oil | 110,238,000 | 110,238,000 | 110,238,000 | |
| Upstream | Pipeline transport of $CO_2$ | Energy needed to pipeline $CO_2$ | MWh | | | | Derived | Derived from the electricity n | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | cle emission factor of the electricity used for pipeline transport | kg $CO_2$e / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions from pipeline electricity needs | kg $CO_2$e | | | | Derived | Derived from the life-cycle en | 0 | 0 | 0 | |
| Upstream | Pipeline transport of $CO_2$ | Emissions factor from pipeline electricity needs | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0 | 0 | 0 | |
| **UPSTREAM: PIPELINE TRANSPORT OF $CO_2$ (FUGITIVE EMISSIONS AND SERVICES)** | | | | | | | | | | | | |
| Upstream | Pipeline transport of $CO_2$ | Pipeline distance | km | 90 | 90 | 90 | System Data | based on Core pipeline netw | 90 | 90 | 90 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / km-yr | 7.5 | 75 | 282 | Literature | API (2009); Lamb et al. (2015 | 75 | 7 | 282 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ (leaks) | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 6,716 | 672 | 25,372 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / service-yr | 0.4 | 3.6 | 5.5 | Literature | API (2009); Lamb et al. (2015 | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | Number of pipeline services per year | services / year | 1 | 1 | 1 | System Data | System Data | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | ugitive emissions factor from pipeline transport of $CO_2$ (services | kg $CO_2$ / yr | | | | Derived | Derived from the fugitive em | 4 | 4 | 4 | |
| Upstream | Pipeline transport of $CO_2$ | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1996 | 1996 | 1 | 1 | 1 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions from pipeline transport of $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive em | 6,720 | 675 | 25,376 | |
| Upstream | Pipeline transport of $CO_2$ | Fugitive emissions factor from pipeline transport of $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 67.20 | 6.753 | 253.76 | s |
| **UPSTREAM: TOTAL (SUM OF EACH SUBSEGMENT)** | | | **kg $CO_2$e / bbl** | | | | | | **268,499** | **172,897** | **389,256** | |

Note: This portion of the model is taken directly from DOE NETL (2013a) and Cooney et al. (2015). The fluid balances come from the industry data set work of Azzolina et al. (2015).

| **GATE-TO-GATE: OIL, $CO_2$, BRINE, AND HYDROCARBON GAS BALANCE CALCULATIONS** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | OOIP | bbl OOIP | | 3,897,220 | | Constant | Back calculate to crude oil pr | 3,897,220 | 3,897,220 | 3,897,220 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Incremental oil recovery factor for EOR | %OOIP | 5.0% | 5.0% | 5.0% | Literature | Assume 5% | 5.0% | 5.0% | 5.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | bbl crude | 100 | 100 | 100 | System Data | Based on Oil Production | 100 | 100 | 100 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil density | kg crude / bbl | 127.0 | 128.5 | 130.0 | Dover 33 Oil | Dover 33 Oil API 43.6 | 128.5 | 127.0 | 130.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude oil produced | kg crude | | | | Derived | Derived from incremental oil | 12,850 | 12,700 | 13,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion to Mscf/bbl | 26,765 | 26,765 | 26,765 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Net $CO_2$ utilization rate | kg $CO_2$ / bbl | | | | Derived | Conversion to kg/bbl | 1,390,370 | 1,390,370 | 1,390,370 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Crude recovery ratio | bbl / tonne $CO_2$ | | | | Derived | Reciprocal of the net $CO_2$ util | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Purchased $CO_2$ requirement from Chester 10 | kg $CO_2$ | 110,238,000 | 110,238,000 | 110,238,000 | System Data | Based on Pure CO2 from Gas | 110,238,000 | 110,238,000 | 110,238,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | Mscf $CO_2$ / bbl | | | | Derived | Conversion from Mscf/bbl to | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ recycle rate | kg CO2 / bbl | | | | Derived | CO2 Recycle/BBL Oil Prod | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | % | | | | Derived | Derived from (CO2-recycle)/t | -139036900.0% | -139036900.0% | -139036900.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ | | | | Derived | Derived from the fugitive loss | ################ | ################ | ################ | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Fugitive loss rate of processed $CO_2$ | kg $CO_2$ / bbl | | | | Derived | Derived from the fugitive loss | ################ | ################ | ################ | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ produced (recycled) | kg $CO_2$ | - | - | - | System Data | Based on System Metering | 100 | 100 | 100 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ production rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ injected | kg $CO_2$ | 139,037,000 | 139,037,000 | 139,037,000 | System Data | Based on Injection Metering | 139,037,000 | 139,037,000 | 139,037,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Daily $CO_2$ injection rate | tonnes $CO_2$/day | | | | Derived | Derived from a unit conversio | 380.9 | 380.9 | 380.9 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ storage | % | | | | Derived | Derived from $CO_2$ injected, C | 100.0% | 100.0% | 100.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored | kg $CO_2$ | 139,037,000 | 139,037,000 | 139,037,000 | System Data | Based on Injection Metering | 139,037,000 | 139,037,000 | 139,037,000 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ stored factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored | 1,390,370 | 1,390,370 | 1,390,370 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage rate from storage over 100-year time period | % $CO_2$ stored | 0.000% | 0.001% | 0.005% | System Data | Based on reef MVA | 0.001% | 0.0% | 0.005% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage over time period | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ stored | 1,390 | 0 | 6,952 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ leakage from storage emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ stored, | 13.9 | 0.0 | 69.5 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$ retention | % | | | | Derived | Derived from $CO_2$ injected an | 100.0% | 100.0% | 100.0% | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production rate | kg gas / kg crude | 0.00017 | 0.00017 | 0.00017 | System Data | Based on System Metering G | 0.00017 | 0.00017 | 0.00017 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production rate | kg brine / kg crude | | | | System Data | Based on System Metering Bi | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection rate | kg brine / kg crude | | | | Derived | Correlation derived from DOE | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Hydrocarbon gas production | kg gas | | | | Derived | Derived from the hydrocarbo | 2 | 2 | 2 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine production | kg brine | | | | Derived | Derived from the brine produ | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | Brine injection | kg brine | | | | Derived | Derived from the brine inject | 0 | 0 | 0 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | yr | 1 | 1 | 1 | 1996 | 1996 | 1 | 1 | 1 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | days | 365 | 365 | 365 | Derived | Unit conversion from years to | 365 | 365 | 365 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | hours | 8,760 | 8,760 | 8,760 | Derived | Unit conversion from days to | 8,760 | 8,760 | 8,760 | |
| Gate-to-Gate | $CO_2$, brine, and gas produc | $CO_2$-EOR project duration | minutes | 525,600 | 525,600 | 525,600 | Derived | Unit conversion from hours t | 525,600 | 525,600 | 525,600 | |
| GATE-TO-GATE: LAND USE | | | | | | | | | | | | |
| Gate-to-Gate | Land use | Land area of gas processing facility | acre | | 0.5 | | System Data | Dover 36 Facility, distributed | 0.5 | 0.5 | 0.5 | |
| Gate-to-Gate | Land use | Land area of gas processing facility | $m^2$ | | | | Derived | Derived from unit conversion | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Well footprint | acre | | 2.5 | | Literature | Cooney et al. (2015) | 2.5 | 2.5 | 2.5 | |
| Gate-to-Gate | Land use | Well footprint | $m^2$ | | | | Derived | Derived from unit conversion | 10,117 | 10,117 | 10,117 | |
| Gate-to-Gate | Land use | Number of wells | count | | 0 | | System Data | 1 Injection well | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total footprint of all wells | $m^2$ | | | | Derived | Derived from the well footpri | 0 | 0 | 0 | |
| Gate-to-Gate | Land use | Total land area repurposed (gas processing facility + wells) | $m^2$ | | | | Derived | Derived from land area of the | 2,023 | 2,023 | 2,023 | |
| Gate-to-Gate | Land use | Emissions per sq meter of repurposed land | kg $CO_2$e / $m^2$ | | 7.5 | | Literature | Derived from Cooney et al. (2 | 7.5 | 7.5 | 7.5 | |
| Gate-to-Gate | Land use | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the land area re | 15,100 | 15,100 | 15,100 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Land use | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 151.0 | 151.0 | 151.0 | S |
| **GATE-TO-GATE: CONSTRUCTION (NOT CURRENTLY MODELED TAKEN DIRECTLY FROM COONEY ET AL. [2015])** | | | | | | | | | | | | |
| Gate-to-Gate | Construction | Water disposal well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | Injection well construction | kg $CO_2$e / bbl | | 0.0 | | System Data | Existing SWIW | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | EOR gas processing facility construction | kg $CO_2$e / bbl | | 0.0125 | | Literature | Taken from Cooney et al. (20 | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | Construction | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the $CO_2$ emissic | 1 | 1 | 1 | |
| Gate-to-Gate | Construction | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: WELL OPERATIONS – ARTIFICIAL LIFT** | | | | | | | | | | | | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity rate | kWh / kg crude | | 1.00E-03 | | System Data | Assume minor artificial lift, p | 1.00E-03 | 1.00E-03 | 1.00E-03 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | kWh | | | | Derived | Derived from the artificial lift | 13 | 13 | 13 | |
| Gate-to-Gate | ell Operations – Artificial L | Crude artificial lift pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 8 | 8 | 9 | |
| Gate-to-Gate | ell Operations – Artificial L | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSION AND INJECTION ELECTRICTIY** | | | | | | | | | | | | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power factor | MW/[tonne recycled $CO_2$/day] | | 2.70E-03 | | Literature | NA, Cooney et al. (2015) | 2.70E-03 | 2.70E-03 | 2.70E-03 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor power | MW | | | | Derived | NA,Derived from the compre | 7.40E-07 | 7.40E-07 | 7.40E-07 | |
| Gate-to-Gate | – $CO_2$ Compression and In | Compressor energy | MCF | 124631 | 124631 | 124631 | System Data | System Data | 124,631 | 124,631 | 124,631 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from CH4 | 6,811,308 | 6,811,308 | 6,811,308 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 68113.1 | 68113.1 | 68113.1 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power factor | MW/[tonne injected $CO_2$/day] | | | | System Data | NA, directly entered in line 1 | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump power | MW | | | | Derived | Derived from the pump powe | 0.000 | 0.000 | 0.000 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ pump energy | MWh | | | | Derived | Derived from the pump powe | 0 | 0 | 0 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions | kg $CO_2$e | | | | Based on 2017 data | Derived from the $CO_2$ recycle | 2 | 2 | 2 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 33.8 | 33.8 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions (total) | kg $CO_2$e | | | | Derived | Derived from the sum of com | 6,811,311 | 6,811,311 | 6,811,311 | |
| Gate-to-Gate | – $CO_2$ Compression and In | $CO_2$ emissions factor (total) | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 68,113.1 | 68,113.1 | 68,113.1 | S |
| **GATE-TO-GATE: WELL OPERATIONS – $CO_2$ COMPRESSOR FUGITIVE EMISSIONS** | | | | | | | | | | | | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions rate (direct to atmosphere) | kg $CO_2$e / MW-day | | 63.6 | | Literature | NA,Cooney et al. (2015) | 63.6 | 63.6 | 63.6 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions (direct to atmosphere) | kg $CO_2$e | | | | System Data | Subpart C Core forms | 124 | 124 | 124 | |
| Gate-to-Gate | rations – $CO_2$ Compressor | Compressor $CO_2$ emissions factor (direct to atmosphere) | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 1.2 | 1.2 | 1.2 | S |
| **GATE-TO-GATE: OPERATIONS – FACILITY ELECTRICITY** | | | | | | | | | | | | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity rate | kWh / kg CO2 injected | | 0.00E+00 | | Literature | NA,Cooney et al. (2015) | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | kWh | 502682 | 502682 | 502682 | System Data | Chester 10 and Dover 36 Faci | 502,682 | 502,682 | 502,682 | |
| Gate-to-Gate | Operations – Facility Elect | Facility electricity | MWh | | | | Derived | Unit conversion from kWh to | 503 | 503 | 503 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the MWh and t | 331,770 | 331,770 | 331,770 | |
| Gate-to-Gate | Operations – Facility Elect | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 3317.7 | 3317.7 | 3317.7 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC uncontrolled emissions rate to venting and flaring | kg VOC / kg crude | 4.35E-03 | 8.70E-03 | 1.74E-02 | Literature | DOE NETL (2015) "Oilfield Ga | 8.70E-03 | 4.35E-03 | 1.74E-02 | |
| Gate-to-Gate | Water Separation – Ventir | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | DOE NETL (2015) "Oilfield Ga | 95% | 95% | 95% | |
| Gate-to-Gate | Water Separation – Ventir | CH4 flared | kg CH4 | | | | System Data | Gas Processing data from Co | 272 | 272 | 272 | |
| Gate-to-Gate | Water Separation – Ventir | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) | 99% | 99% | 99% | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions rate | CH4 Emissions Factor | | | | Literature | DOE NETL (2015) "Oilfield Ga | 2.75 | 2.75 | 2.75 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the kg VOC and | 740 | 740 | 740 | |
| Gate-to-Gate | Water Separation – Ventir | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 7.4 | 7.4 | 7.4 | S |
| Gate-to-Gate | Water Separation – Ventir | Vent rate (% of VOC that is vented) | % | | | | Derived | Derived from (1 - VOC flare ra | 5% | 5% | 5% | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | Water Separation – Ventir | VOC vented | kg VOC | | | | Derived | Derived from the VOC uncon | 6 | 3 | 11 | |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS UPSTREAM (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage rate | kg natural gas / kg crude | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | DOE NETL (2015) "Oilfield Ga | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | aration – Natural Gas Ups | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: OIL, GAS, AND WATER SEPARATION – NATURAL GAS COMBUSTION (INDUSTRIAL BOILER)** | | | | | | | | | | | | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | NA for system, DOE NETL (20 | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | ration – Natural Gas Comb | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | ration – Natural Gas Comb | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: CRUDE STORAGE - VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent rate | kg VOC / kg crude throughput | 1.00E-05 | 1.00E-05 | 1.00E-05 | Literature | Included in Gas Processing Ve | 1.00E-05 | 1.00E-05 | 1.00E-05 | |
| Gate-to-Gate | e Storage – Venting and Fl | VOC vent | kg VOC | | | | Derived | Derived from VOC vent rate a | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Flare rate (% of vented VOC that is flared) | % | | 95% | | Literature | Cooney et al. (2015) and DOE | 95% | 95% | 95% | |
| Gate-to-Gate | e Storage – Venting and Fl | Flared VOC (accounting for flare rate) | kg VOC | | | | Derived | Derived from the kg VOC and | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Combustion efficiency | % | | 99% | | Literature | Cooney et al. (2015) and DOE | 99% | 99% | 99% | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted per kg VOC | kg $CO_2$ / kg VOC | | | | Derived | Assumes VOC = 100% pentan | 3.03 | 3.03 | 3.03 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emitted from flare | kg $CO_2$ | | | | Derived | Derived from the kg VOC flare | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | CO2 emitted from flare | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| **GATE-TO-GATE: BRINE STORAGE – VENTING AND FLARING** | | | | | | | | | | | | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water for disposal | kg | | | | Derived | Included in Gas Processing Ve | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water methane content | kg $CH_4$ / bbl water | | 1.50E-03 | | Literature | DOE NETL (2010a) | 1.50E-03 | 1.50E-03 | 1.50E-03 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water total dissolved solids (TDS) | mg / L | | 200,000 | | Literature | DOE NETL (2010a) | 200,000 | 200,000 | 200,000 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / $m^3$ | | | | Derived | Estimated using the correlati | 1,139 | 1,139 | 1,139 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water density | kg / bbl | | | | Derived | Derived from unit conversion | 181 | 181 | 181 | |
| Gate-to-Gate | e Storage – Venting and Fl | Produced water volume | bbl | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Percent of methane released to atmosphere | % | | 100% | | Literature | Assumed | 100% | 100% | 100% | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CH_4$ | | | | Derived | Derived from the produced w | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | Methane released to atmosphere | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | e Storage – Venting and Fl | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| GATE-TO-GATE: BRINE DISPOSAL – INJECTION WELL ELECTRICITY | | | | | | | | | | | | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity rate | kWh / kg brine disposal injected | | 0.00E+00 | | Literature | Included in Facility Electricity | 0.00E+00 | 0.00E+00 | 0.00E+00 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | kWh | | | | Derived | Derived from the kg of produ | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump electricity | MWh | | | | Derived | Unit conversion from kWh to | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | isposal – Injection Well Ele | Brine disposal pump $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | S |
| GATE-TO-GATE: GAS PROCESSING (RYAN-HOLMES) | | | | | | | | | | | | |
| Gate-to-Gate | Ryan-Holmes) – $CO_2$ Read | $CO_2$ ready for reinjection | kg $CO_2$ | | | | Derived | NA, Derived by the $CO_2$ produ | 100 | 100 | 100 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | esel (purchased) thermal energy rate for backup power generat | MJ diesel / kg $CO_2$ output | | 9.50E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 9.50E-03 | 9.50E-03 | 9.50E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel (purchased) thermal energy for backup power generator | MJ diesel | | | | Derived | Derived from the thermal en | 1 | 1 | 1 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel lower heating value (LHV) | MJ / L diesel | | 39.0 | | Literature | DOE NETL (2015) "Diesel Fire | 39.0 | 39.0 | 39.0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use per MJ of energy | L diesel / MJ | | 2.56E-02 | | Literature | DOE NETL (2015) "Diesel Fire | 2.56E-02 | 2.56E-02 | 2.56E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | L diesel | | | | Derived | Derived from the MJ of diese | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel density | kg diesel / L diesel | | 8.43E-01 | | Literature | DOE NETL (2015) "Diesel Fire | 8.43E-01 | 8.43E-01 | 8.43E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel use | kg diesel | | | | Derived | Derived from the L of diesel r | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions factor | kg $CO_2$ / kg diesel | | 6.26E-01 | | Literature | DOE NETL (2015) "Diesel, Pro | 6.26E-01 | 6.26E-01 | 6.26E-01 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions factor | kg $CH_4$ / kg diesel | | 4.19E-03 | | Literature | DOE NETL (2015) "Diesel, Pro | 4.19E-03 | 4.19E-03 | 4.19E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions factor | kg $N_2O$ / kg diesel | | 1.21E-05 | | Literature | DOE NETL (2015) "Diesel, Pro | 1.21E-05 | 1.21E-05 | 1.21E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 1.29E-02 | 1.29E-02 | 1.29E-02 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 8.59E-05 | 8.59E-05 | 8.59E-05 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 2.49E-07 | 2.49E-07 | 2.49E-07 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Diesel upstream delivered $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | Natural gas combustion $N_2O$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – Dies | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | RH |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions factor | kg $CO_2$ / L diesel | | 2.65E+00 | | Literature | DOE NETL (2015) "Diesel Fire | 2.65E+00 | 2.65E+00 | 2.65E+00 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions factor | kg $CH_4$ / L diesel | | 3.80E-04 | | Literature | DOE NETL (2015) "Diesel Fire | 3.80E-04 | 3.80E-04 | 3.80E-04 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions factor | kg $N_2O$ / L diesel | | 6.87E-05 | | Literature | DOE NETL (2015) "Diesel Fire | 6.87E-05 | 6.87E-05 | 6.87E-05 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the diesel comb | 0 | 0 | 0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the diesel comb | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the diesel comb | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CO_2$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | Diesel combustion $CH_4$ emissions | kg $CO_2$e | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions | kg $CO_2$e | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | ng (Ryan-Holmes) – Diesel | $CO_2$ emissions factor | kg $CO_2$e / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | RH |
| Gate-to-Gate | ) – Natural Gas Combustio | Natural gas use rate (2 turbines + 3 compressors) | g natural gas / kg $CO_2$ for reinjection | | 1.77E-02 | | Literature | DOE NETL (2015) "Ryan Holm | 1.77E-02 | 1.77E-02 | 1.77E-02 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ for reinjection gas | kg $CO_2$ | | | | Derived | Derived from the $CO_2$ produc | 100 | 100 | 100 | |
| Gate-to-Gate | ) – Natural Gas Combustio | kg natural gas used by turbines and compressors | kg natural gas | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy per kg of natural gas | Btu / kg natural gas | | 53,803 | | Literature | EIA (2015) | 53,803 | 53,803 | 53,803 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Btu of energy | Btu | | | | Derived | Derived from the energy cont | 95,442 | 95,442 | 95,442 | |
| Gate-to-Gate | ) – Natural Gas Combustio | Emissions factor for natural gas | lb $CO_2$ / Btu | | 1.17E-04 | | Literature | EIA (2015) | 1.17E-04 | 1.17E-04 | 1.17E-04 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | lb $CO_2$ | | | | Derived | Derived from the emissions fa | 11 | 11 | 11 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions | kg $CO_2$ | | | | Derived | Unit conversion from lb to kg | 5 | 5 | 5 | |
| Gate-to-Gate | ) – Natural Gas Combustio | $CO_2$ emissions factor | kg $CO_2$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | RH |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Purchased natural gas rate | chased natural gas / kg $CO_2$ for reinjection | | 7.29E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.29E-03 | 7.29E-03 | 7.29E-03 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | kg of purchased natural gas | kg purchased natural gas | | | | Derived | Derived from the purchased | 1 | 1 | 1 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 1 | 1 | 1 | |
| Gate-to-Gate | g (Ryan-Holmes) – Natural | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | RH |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovery rate | kg $C_2$ / kg $CO_2$ for reinjection | | 3.90E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 3.90E-03 | 3.90E-03 | 3.90E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovery rate | kg $C_3$ / kg $CO_2$ for reinjection | | 7.28E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.28E-03 | 7.28E-03 | 7.28E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg $CO_2$ for reinjection | | 6.16E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 6.16E-03 | 6.16E-03 | 6.16E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovery rate | kg $iC_5$ / kg $CO_2$ for reinjection | | 7.07E-03 | | Literature | DOE NETL (2015) "Ryan Holm | 7.07E-03 | 7.07E-03 | 7.07E-03 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) recovered | kg $C_2$ | | | | Derived | Derived from the $C_2$ producti | 0 | 0 | 0 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the $C_3$ producti | 1 | 1 | 1 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the $C_4$ producti | 1 | 1 | 1 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) recovered | kg $iC_5$+ | | | | Derived | Derived from the $iC_5$+ produc | 1 | 1 | 1 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL recovered for tank storage | kg NGL | | | | Derived | Derived from the sum of the | 2 | 2 | 2 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Ethane ($C_2H_6$) density | kg / $m^3$ | | 570 | | Literature | The Engineering Toolbox (201 | 570 | 570 | 570 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Propane ($C_3H_8$) density | kg / $m^3$ | | 494 | | Literature | The Engineering Toolbox (201 | 494 | 494 | 494 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Butane ($C_4H_{10}$) density | kg / $m^3$ | | 599 | | Literature | The Engineering Toolbox (201 | 599 | 599 | 599 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | Isopentane ($C_5H_{12}$+) density | kg / $m^3$ | | 625 | | Literature | The Engineering Toolbox (201 | 625 | 625 | 625 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | sing (Ryan-Holmes) – NGL | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 119 | 119 | 119 | |
| GATE-TO-GATE: GAS PROCESSING (REFRIGERATION/FRACTIONATION) | | | | | | | | | | | | |
| Gate-to-Gate | rigeration/Fractionation) – | EOR reinjection gas | kg EOR reinjection gas | | | | Derived | NA, Derived from the sum of | 102 | 102 | 102 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity rate per unit of gas | MWh / kg EOR reinjection gas | | 1.38E-05 | | Literature | Cooney et al. (2015) | 1.38E-05 | 1.38E-05 | 1.38E-05 | |
| Gate-to-Gate | (Refrigeration/Fractionati | Electricity used | MWh | | | | Derived | Derived from the electricity r | 0 | 0 | 0 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1 | 1 | 1 | |
| Gate-to-Gate | (Refrigeration/Fractionati | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | RF |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage rate | kg / kg EOR reinjection gas | | 1.91E-06 | | Literature | DOE NETL (2015) "NGL Extrac | 1.91E-06 | 1.91E-06 | 1.91E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | geration/Fractionation) – | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.000 | 0.000 | 0.000 | RF |
| Gate-to-Gate | Fractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial | 2.75E+00 | 2.75E+00 | 2.75E+00 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial E | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0.00 | 0.00 | 0.00 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | ractionation) – Natural Ga | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 0 | 0 | 0 | |
| Gate-to-Gate | ractionation) – Natural Ga | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.000 | 0.000 | 0.000 | RF |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovery rate | kg C / kg EOR reinjection gas | | 1.32E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 1.32E-03 | 1.32E-03 | 1.32E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovery rate | kg $C_4$ / kg EOR reinjection gas | | 3.60E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 3.60E-03 | 3.60E-03 | 3.60E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovery rate | kg $C_5$ / kg EOR reinjection gas | | 6.29E-03 | | Literature | DOE NETL (2015) "NGL Extrac | 6.29E-03 | 6.29E-03 | 6.29E-03 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) recovered | kg $C_3$ | | | | Derived | Derived from the recovery ra | 0 | 0 | 0 | |
| Gate-to-Gate | eration/Fractionation) – C | *n*- Butane ($C_4H_{10}$) recovered | kg $C_4$ | | | | Derived | Derived from the recovery ra | 0 | 0 | 0 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) recovered | kg $C_5$ | | | | Derived | Derived from the recovery ra | 1 | 1 | 1 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy content | MJ / kg $C_3$ | | 50.3 | | Literature | Cooney et al. (2015) | 50.3 | 50.3 | 50.3 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy content | MJ / kg $C_4$ | | 48.6 | | Literature | Cooney et al. (2015) | 48.6 | 48.6 | 48.6 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy content | MJ / kg $C_5$ | | 50.2 | | Literature | Cooney et al. (2015) | 50.2 | 50.2 | 50.2 | |
| Gate-to-Gate | eration/Fractionation) – C | Propane ($C_3H_8$) energy | MJ | | | | Derived | Derived from the energy cont | 7 | 7 | 7 | |
| Gate-to-Gate | eration/Fractionation) – C | Butane ($C_4H_{10}$) energy | MJ | | | | Derived | Derived from the energy cont | 18 | 18 | 18 | |
| Gate-to-Gate | eration/Fractionation) – C | Pentane ($C_5H_{12}$) energy | MJ | | | | Derived | Derived from the energy cont | 32 | 32 | 32 | |
| **GATE-TO-GATE: GAS PROCESSING (MEMBRANE)** | | | | | | | | | | | | |
| Gate-to-Gate | g (Membrane) – Fluid for | Mass of fluid for compression | luid (recycled $CO_2$ + hydrocarbon gas) | | | | Derived | NA, Derived from the sum of | 102 | 102 | 102 | |
| Gate-to-Gate | embrane) – Compressor El | Energy usage per kg of fluid compressed | MWh / kg fluid | | 1.99E-05 | | Literature | DOE NETL (2015) "Compresso | 1.99E-05 | 1.99E-05 | 1.99E-05 | |
| Gate-to-Gate | embrane) – Compressor El | Energy use | MWh | | | | Derived | Derived from the mass of flui | 0 | 0 | 0 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 1 | 1 | 1 | |
| Gate-to-Gate | embrane) – Compressor El | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.0 | 0.0 | 0.0 | M |
| Gate-to-Gate | Membrane) – Compressor I | Compressor fugitive emissions rate | kg $CO_2$ / kg fluid | | 3.29E-05 | | Literature | DOE NETL (2015) "Compresso | 3.29E-05 | 3.29E-05 | 3.29E-05 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the compressor | 0 | 0 | 0 | |
| Gate-to-Gate | Membrane) – Compressor I | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.00 | 0.00 | 0.00 | M |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage per kg of $CO_2$ dehydrated | kWh / kg $CO_2$ dehydrated | | 1.93E-04 | | Literature | DOE NETL (2015) "Carbon Dio | 1.93E-04 | 1.93E-04 | 1.93E-04 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | kWh | | | | Derived | Derived from the energy usag | 0 | 0 | 0 | |
| Gate-to-Gate | embrane) – Dehydration E | Energy usage | MWh | | | | Derived | Unit conversion from kWh to | 0.0 | 0.0 | 0.0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | embrane) – Dehydration E | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.00 | 0.00 | 0.00 | M |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity rate per unit of gas | / kg gas (recycled $CO_2$ + hydrocarbon gas) | | 1.67E-06 | | Literature | DOE NETL (2015) "Gas Strean | 1.67E-06 | 1.67E-06 | 1.67E-06 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | Electricity used | MWh | | | | Derived | Derived from the electricity r | 0 | 0 | 0 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the MWh and t | 0 | 0 | 0 | |
| Gate-to-Gate | (Membrane) – Chiller Elec | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissio | 0.00 | 0.00 | 0.00 | M |
| Gate-to-Gate | g (Membrane) – Membra | Product hydrocarbon stream from membrane separation | g hydrocarbon stream / kg inlet flow | | 3.51E-01 | | Literature | Derived from DOE NETL (201 | 3.51E-01 | 3.51E-01 | 3.51E-01 | |
| Gate-to-Gate | g (Membrane) – Membra | Inflow stream for post-membrane amine separation | kg feed gas for amine system | | | | Derived | Derived from the mass of flui | 36 | 36 | 36 | |
| Gate-to-Gate | ane) – Post-Membrane An | stream for post-membrane amine separation per unit of $CO_2$ rec | kg inflow / kg $CO_2$ recovered | | 1.089 | | Literature | DOE NETL (2015) "Membrane | 1.089 | 1.089 | 1.089 | |
| Gate-to-Gate | ) – Post-Membrane Amine | kg of $CO_2$ recovered from post-membrane amine system | kg $CO_2$ recovered | | | | Derived | Derived from the kg feed gas | 33 | 33 | 33 | |
| Gate-to-Gate | Post-Membrane Amine C | Amine solvent makeup rate | kg solvent / kg $CO_2$ recovered | | 1.00E-04 | | Literature | DOE NETL (2015) "Post Mem | 1.00E-04 | 1.00E-04 | 1.00E-04 | |
| Gate-to-Gate | Post-Membrane Amine C | kg of amine solvent used | kg solvent | | | | Derived | Derived from the amine solve | 0 | 0 | 0 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT | | | | | | | | | | | | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage rate for amine capture | kg natural gas / kg $CO_2$ recovered | 6.33E-02 | 6.64E-02 | 6.95E-02 | Literature | DOE NETL (2015) "Post Mem | 6.64E-02 | 6.33E-02 | 6.95E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas usage | kg natural gas | | | | Derived | Derived from the natural gas | 2 | 2 | 2 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions factor | kg $CO_2$ / kg natural gas | | 1.68E-01 | | Literature | DOE NETL (2015) "Natural Ga | 1.68E-01 | 1.68E-01 | 1.68E-01 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions factor | kg $CH_4$ / kg natural gas | | 1.81E-02 | | Literature | DOE NETL (2015) "Natural Ga | 1.81E-02 | 1.81E-02 | 1.81E-02 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions factor | kg $N_2O$ / kg natural gas | | 4.60E-06 | | Literature | DOE NETL (2015) "Natural Ga | 4.60E-06 | 4.60E-06 | 4.60E-06 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CH_2$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 1 | 1 | 1 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Natural gas delivered $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 2 | 2 | 2 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.0 | 0.0 | 0.0 | M |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions factor | kg $CO_2$ / kg natural gas combusted | | 2.75E+00 | | Literature | DOE NETL (2015) "Industrial I | 2.75E+00 | 2.75E+00 | 2.75E+00 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions factor | kg $CH_4$ / kg natural gas combusted | | 5.26E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.26E-05 | 5.26E-05 | 5.26E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions factor | kg $N_2O$ / kg natural gas combusted | | 5.03E-05 | | Literature | DOE NETL (2015) "Industrial I | 5.03E-05 | 5.03E-05 | 5.03E-05 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CO_2$ emissions | kg $CO_2$ | | | | Derived | Derived from the natural gas | 6 | 6 | 6 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CH_4$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $N_2O$ | | | | Derived | Derived from the natural gas | 0 | 0 | 0 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $CH_4$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | Natural gas combustion $N_2O$ emissions | kg $CO_2e$ | | | | Derived | Applying IPCC 100-year GWP | 0 | 0 | 0 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions | kg $CO_2e$ | | | | Derived | Derived from the sum of $CO_2$ | 6 | 6 | 6 | |
| Gate-to-Gate | st-Membrane Amine $CO_2$ ( | $CO_2$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Derived from the $CO_2$ emissic | 0.1 | 0.1 | 0.1 | M |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Sales gas (NGLs) generated | kg sales gas (NGL) | | | | Derived | Derived from the kg of inflow | 3 | 3 | 3 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | $CO_2$ | % | | 10% | | Literature | DOE NETL (2015) "Post Mem | 10% | 10% | 10% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | % | | 8% | | Literature | DOE NETL (2015) "Post Mem | 8% | 8% | 8% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | % | | 24% | | Literature | DOE NETL (2015) "Post Mem | 24% | 24% | 24% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | % | | 6% | | Literature | DOE NETL (2015) "Post Mem | 6% | 6% | 6% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | % | | 14% | | Literature | DOE NETL (2015) "Post Mem | 14% | 14% | 14% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | % | | 20% | | Literature | DOE NETL (2015) "Post Mem | 20% | 20% | 20% | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Methane ($CH_4$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Ethane ($C_2H_6$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Propane ($C_3H_8$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1 | 1 | 1 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isobutane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Butane ($C_4H_{10}$) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 0 | 0 | 0 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | Isopentane ($C_5H_{12}$+) | kg | | | | Derived | DOE NETL (2015) "Post Mem | 1 | 1 | 1 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy content | MJ / kg NGL | | 48.8 | | Literature | Cooney et al. (2015) | 48.8 | 48.8 | 48.8 | |
| Gate-to-Gate | ost-Membrane Amine $CO_2$ | NGL energy | MJ | | | | Derived | Derived from the NGL energy | 144 | 144 | 144 | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): EXCLUDES GAS SEPARATION STEP** | | | **kg $CO_2e$ / bbl** | | | | | | **71,657.8** | **71,597.3** | **71,844.3** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): RYAN-HOLMES** | | | **kg $CO_2e$ / bbl** | | | | | | **0.1** | **0.1** | **0.1** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): REFRIGERATION/FRACTIONATION** | | | **kg $CO_2e$ / bbl** | | | | | | **0.0** | **0.0** | **0.0** | |
| **GATE-TO-GATE: TOTAL (SUM OF EACH SUB-SEGMENT): MEMBRANE** | | | **kg $CO_2e$ / bbl** | | | | | | **0.1** | **0.1** | **0.1** | |
| **GATE-TO-GATE: $CO_2$ STORED IN RESERVOIR** | | | **kg $CO_2e$ / bbl** | | | | | | **1,390,370.0** | **1,390,370.0** | **1,390,370.0** | |
| **GATE-TO-GATE: FUGITIVE SURFACE LOSSES OF PURCHASED $CO_2$** | | | **kg $CO_2e$ / bbl** | | | | | | **################** | **################** | **################** | |
| **GATE-TO-GATE: $CO_2$ LEAKAGE FROM STORAGE OVER 100-YEAR TIMEFRAME** | | | **kg $CO_2e$ / bbl** | | | | | | **13.9** | **0.0** | **69.5** | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Note: This portion of the model is taken largely from DOE-NETL (2008), with exceptions noted in the text. | | | | | | | | | | | | |
| **DOWNSTREAM: CRUDE OIL TRANSPORT BY PIPELINE TO REFINERY** | | | | | | | | | | | | |
| Downstream | il transport by pipeline to | One-way energy intensity | Btu / ton-mile | | 260 | | Literature | DOE NETL (2008); Wang (200 | 260 | 260 | 260 | |
| Downstream | il transport by pipeline to | One-way energy intensity | kWh / kg-km | | | | Derived | Unit conversion from Btu/tor | 5.22E-05 | 5.22E-05 | 5.22E-05 | |
| Downstream | il transport by pipeline to | Pipeline distance | km | 800 | 900 | 1000 | Literature | Assumes pipeline distances fr | 900 | 800 | 1000 | |
| Downstream | il transport by pipeline to | Crude oil density | degrees API | 37.5 | 35.0 | 32.5 | Literature | DOE NETL (2010b) | 35 | 35 | 35 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / $m^3$ | 837 | 850 | 863 | Derived | Unit conversion from degree | 850 | 850 | 850 | |
| Downstream | il transport by pipeline to | Crude oil density | kg / bbl | 133 | 135 | 137 | Derived | Unit conversion from kg/$m^3$ t | 135 | 135 | 135 | |
| Downstream | il transport by pipeline to | Mass of crude oil transported | kg | | | | | Derived from the barrels of o | 100,052 | 100,052 | 100,052 | |
| Downstream | il transport by pipeline to | One-way energy use | kWh | | | | | Derived from the one-way en | 4,700 | 4,177 | 5,222 | |
| Downstream | il transport by pipeline to | One-way energy use | MWh | | | | | Unit conversion from kWh to | 5 | 4 | 5 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for electricity | kg $CO_2$ / MWh | | 660 | | Literature | 2010 U.S. mix, delivered | 660 | 660 | 660 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions for crude oil transport by pipeline | kg $CO_2$ | | | | | Derived from the one-way en | 3,102 | 2,757 | 3,446 | |
| Downstream | il transport by pipeline to | $CO_2$ emissions factor for crude oil transport by pipeline | kg $CO_2$ / bbl | | | | | Derived from the $CO_2$ emissic | 4 | 4 | 5 | |
| **DOWNSTREAM: CRUDE OIL REFINING** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2$ / bbl refined product | | 46.0 | | Literature | DOE NETL (2008) | 46.0 | 46.0 | 46.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2$ / bbl refined product | | 50.8 | | Literature | DOE NETL (2008) | 50.8 | 50.8 | 50.8 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$ / bbl refined product | | 30.5 | | Literature | DOE NETL (2008) | 30.5 | 30.5 | 30.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2$ / bbl refined product | | 35.7 | | Literature | DOE NETL (2008) | 35.7 | 35.7 | 35.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2$ / bbl refined product | | 42.4 | | Literature | DOE NETL (2008) | 42.4 | 42.4 | 42.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2$ / bbl refined product | | 28.9 | | Literature | DOE NETL (2008) | 28.9 | 28.9 | 28.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2$ / bbl refined product | | 67.0 | | Literature | DOE NETL (2008) | 67.0 | 67.0 | 67.0 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CH_4$ / bbl refined product | | 5.620E-02 | | Literature | DOE NETL (2008) | 5.62E-02 | 5.62E-02 | 5.62E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CH_4$ / bbl refined product | | 6.270E-02 | | Literature | DOE NETL (2008) | 6.27E-02 | 6.27E-02 | 6.27E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CH_4$ / bbl refined product | | 3.760E-02 | | Literature | DOE NETL (2008) | 3.76E-02 | 3.76E-02 | 3.76E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CH_4$ / bbl refined product | | 4.380E-02 | | Literature | DOE NETL (2008) | 4.38E-02 | 4.38E-02 | 4.38E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CH_4$ / bbl refined product | | 5.100E-02 | | Literature | DOE NETL (2008) | 5.10E-02 | 5.10E-02 | 5.10E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CH_4$ / bbl refined product | | 3.500E-02 | | Literature | DOE NETL (2008) | 3.50E-02 | 3.50E-02 | 3.50E-02 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CH_4$ / bbl refined product | | 8.090E-02 | | Literature | DOE NETL (2008) | 8.09E-02 | 8.09E-02 | 8.09E-02 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $N_2O$ / bbl refined product | | 7.450E-04 | | Literature | DOE NETL (2008) | 7.45E-04 | 7.45E-04 | 7.45E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $N_2O$ / bbl refined product | | 7.850E-04 | | Literature | DOE NETL (2008) | 7.85E-04 | 7.85E-04 | 7.85E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $N_2O$ / bbl refined product | | 4.720E-04 | | Literature | DOE NETL (2008) | 4.72E-04 | 4.72E-04 | 4.72E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $N_2O$ / bbl refined product | | 5.640E-04 | | Literature | DOE NETL (2008) | 5.64E-04 | 5.64E-04 | 5.64E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $N_2O$ / bbl refined product | | 7.280E-04 | | Literature | DOE NETL (2008) | 7.28E-04 | 7.28E-04 | 7.28E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $N_2O$ / bbl refined product | | 4.840E-04 | | Literature | DOE NETL (2008) | 4.84E-04 | 4.84E-04 | 4.84E-04 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $N_2O$ / bbl refined product | | 1.130E-03 | | Literature | DOE NETL (2008) | 1.13E-03 | 1.13E-03 | 1.13E-03 | |
| Downstream | Crude oil refining | $CH_4$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.9 | 1.9 | 1.9 | |
| Downstream | Crude oil refining | $CH_4$ emissions (diesel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.1 | 2.1 | 2.1 | |
| Downstream | Crude oil refining | $CH_4$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.3 | 1.3 | 1.3 | |
| Downstream | Crude oil refining | $CH_4$ emissions (residual fuel oil) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CH_4$ emissions (coke) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.7 | 1.7 | 1.7 | |
| Downstream | Crude oil refining | $CH_4$ emissions (light ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 1.2 | 1.2 | 1.2 | |
| Downstream | Crude oil refining | $CH_4$ emissions (heavy ends) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | $N_2O$ emissions (gasoline) | kg $CO_2$e / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |

| SEGMENT | SUB-SEGMENT | PARAMETER DESCRIPTION | UNITS | LOW VALUE | EXPECTED | HIGH VALUE | SOURCE | NOTES | BASE CASE | LOW-EMISSION | HIGH-EMISSION | PROCESS SUM IDENTIFIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **UPSTREAM: COAL MINING, PROCESSING, AND TRANSPORT** | | | | | | | | | | | | |
| Downstream | Crude oil refining | $N_2O$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.2 | 0.2 | 0.2 | |
| Downstream | Crude oil refining | $N_2O$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.1 | 0.1 | 0.1 | |
| Downstream | Crude oil refining | $N_2O$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Applying IPCC 100-year GWP | 0.3 | 0.3 | 0.3 | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 48.1 | 48.1 | 48.1 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 53.2 | 53.2 | 53.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 31.9 | 31.9 | 31.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 37.4 | 37.4 | 37.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 44.4 | 44.4 | 44.4 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 30.2 | 30.2 | 30.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl refined product | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 70.1 | 70.1 | 70.1 | |
| Downstream | Crude oil refining | Fraction of total refinery production (gasoline) | % | | 45% | | Literature | DOE NETL (2008) | 45% | 45% | 45% | |
| Downstream | Crude oil refining | Fraction of total refinery production (diesel) | % | | 23% | | Literature | DOE NETL (2008) | 23% | 23% | 23% | |
| Downstream | Crude oil refining | on of total refinery production (kerosene and kerosene-based je | % | | 9% | | Literature | DOE NETL (2008) | 9% | 9% | 9% | |
| Downstream | Crude oil refining | Fraction of total refinery production (residual fuel oil) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | Fraction of total refinery production (coke) | % | | 5% | | Literature | DOE NETL (2008) | 5% | 5% | 5% | |
| Downstream | Crude oil refining | Fraction of total refinery production (light ends) | % | | 10% | | Literature | DOE NETL (2008) | 10% | 10% | 10% | |
| Downstream | Crude oil refining | Fraction of total refinery production (heavy ends) | % | | 4% | | Literature | DOE NETL (2008) | 4% | 4% | 4% | |
| Downstream | Crude oil refining | $CO_2$ emissions (gasoline) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 21.7 | 21.7 | 21.7 | |
| Downstream | Crude oil refining | $CO_2$ emissions (diesel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 12.2 | 12.2 | 12.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (kerosene and kerosene-based jet fuel) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.9 | 2.9 | 2.9 | |
| Downstream | Crude oil refining | $CO_2$ emissions (residual fuel oil) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 1.5 | 1.5 | 1.5 | |
| Downstream | Crude oil refining | $CO_2$ emissions (coke) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.2 | 2.2 | 2.2 | |
| Downstream | Crude oil refining | $CO_2$ emissions (light ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 3.0 | 3.0 | 3.0 | |
| Downstream | Crude oil refining | $CO_2$ emissions (heavy ends) | kg $CO_2e$ / bbl crude | | | | Derived | Product emissions factor × fra | 2.8 | 2.8 | 2.8 | |
| Downstream | Crude oil refining | Product-weighted average emissions factor | kg $CO_2e$ / bbl crude | | | | Derived | Product-weighted average en | 46 | 46 | 46 | |
| **DOWNSTREAM: FUEL TRANSPORT TO POINT-OF-SALE** | | | | | | | | | | | | |
| Downstream | uel transport to point-of-sa | $CO_2$ emissions factor | kg $CO_2$ / bbl | | 4.54 | | Literature | DOE NETL (2008) | 4.54 | 4.54 | 4.54 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CH_4$ / bbl | | 2.81E-03 | | Literature | DOE NETL (2008) | 2.81E-03 | 2.81E-03 | 2.81E-03 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $N_2O$ / bbl | | 8.93E-05 | | Literature | DOE NETL (2008) | 8.93E-05 | 8.93E-05 | 8.93E-05 | |
| Downstream | uel transport to point-of-sa | $CH_4$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 9.55E-02 | 9.55E-02 | 9.55E-02 | |
| Downstream | uel transport to point-of-sa | $N_2O$ emissions factor | kg $CO_2e$ / bbl | | | | Derived | Applying IPCC 100-year GWP | 2.66E-02 | 2.66E-02 | 2.66E-02 | |
| Downstream | uel transport to point-of-sa | Transport-weighted average emissions factor | kg $CO_2e$ / bbl | | | | Derived | Sum of $CO_2$, $CH_4$, and $N_2O$ | 5 | 5 | 5 | |
| **DOWNSTREAM: FUEL COMBUSTION** | | | | | | | | | | | | |
| Downstream | Fuel combustion | Fuel combustion emissions factor | kg $CO_2$/bbl | 400 | 415 | 430 | | Jaramillo et al. (2009); EPA (2 | 415 | 400 | 430 | |
| **DOWNSTREAM: TOTAL (SUM OF EACH SUB-SEGMENT)** | | | **kg $CO_2e$ / bbl** | | | | | | **470** | **455** | **486** | |

BATTELLE

It can be done