Overview of Energy Life Cycle Analysis at NETL

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Disclaimer and Attribution

Attribution

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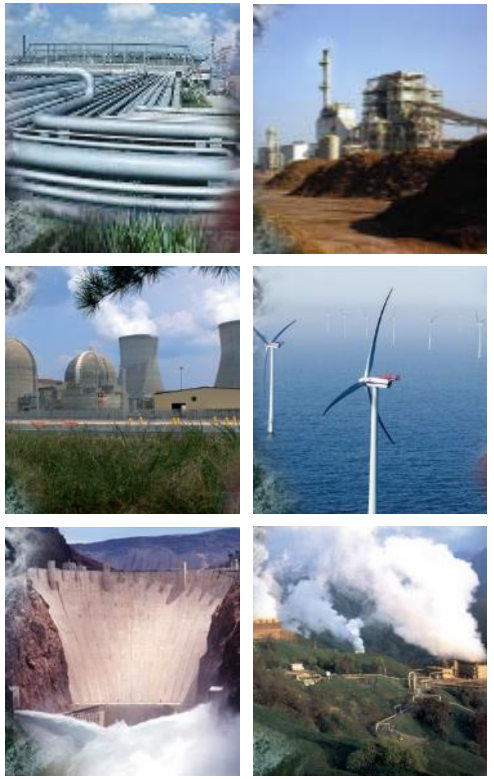
2017 LCA Work

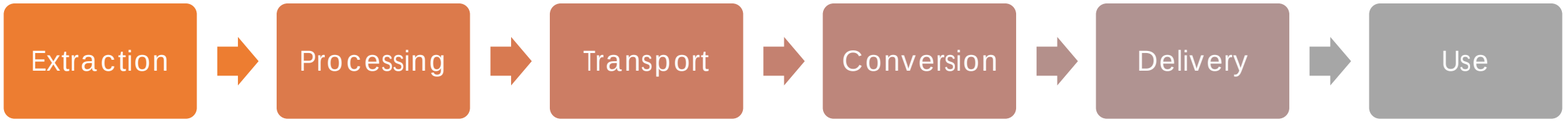
- **Journal Publications**
  - Methane Emission Synthesis (January, 2017)
  - Updated Petroleum Baseline (November, 2016)
  - Low-carbon fuels from EOR (In preparation)
  - Comparison of Industrial & Power CO2 Capture (in preparation)
- **Major Reports & Tools**
  - Update to Natural Gas LCA
  - Baseline Power Updates
  - Solid-oxide fuel-cell Power LCA
  - Life Cycle GHG Model for CO2-EOR Applications
  - Update to Grid Mix Explorer & Upstream Dashboard
- **Ongoing Work**
  - CO_2 Utilization LCA Guidance Documents
  - Environmental Life Cycle Analysis of Algae to Biofuels
  - Support for Federal LCA Commons
  - Support for DOE Loan Program Office
- **Emerging Work**
  - Development of an Electricity Baseline for the U.S.
  - Implementation of Consequential LCA for Energy Systems
  - Development of Energy Sustainability Metrics for Energy Systems
  - Creation of Power System Construction Inventories

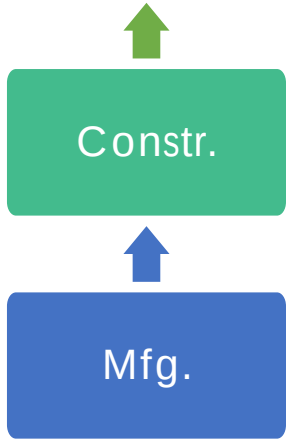


Work can be accessed at:
www.netl.doe.gov/lca

Energy Life Cycle Analysis

Cradle-to-grave environmental footprint of energy systems





Mission

Develop and utilize the LCA framework and methods to support the evaluation of sustainable energy systems both in and outside of the Department of Energy

Vision

A world-class research and analysis team that integrates results which inform and recommend sustainable energy strategy and technology development

Life Cycle Analysis Team

Tim Skone – 18 years
Federal Team Lead
BS Chemical Engineering | P.E. Env. Engr.

Greg Cooney – 10 years
Contractor Team Lead
MS Env. Engr. | BS Chem. Engr.

James Littlefield – 17 years
Natural gas, system & process design
BS Chemical Engineering

Joe Marriott – 12 years
Senior Advisor
PhD Environmental Engr. & Public Policy

Matt Jamieson – 8 years
Power systems, CO_2-enhanced oil recovery
BS Mechanical Engineering

Michele Mutchek – 5 years
Loan program office, federal LCA commons
MS Civil/Env/Sust Engr | BS Env Sciences

Michelle Krynock – 2 years
Natural gas, fuel cells, coal
BS Civil/Env Engr & Public Policy

Derrick Carlson – 7 years
I/O LCA, Energy efficiency
PhD/MS Civ/Env Engr | B.S. Chemistry

Dan Augustine – 1 year
Natural gas, visual analytics
BS Energy Engineering

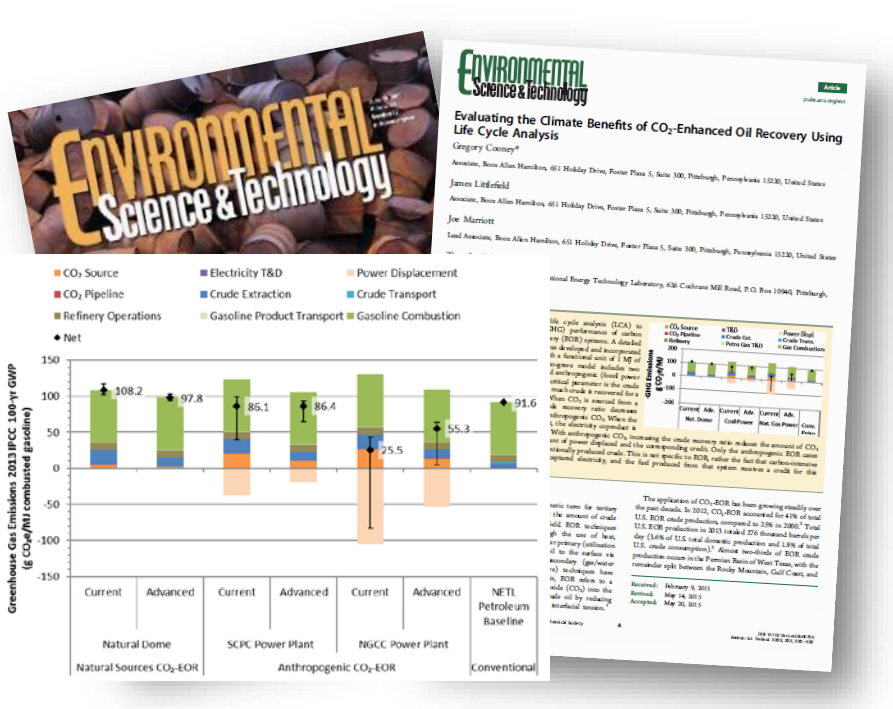
Ambica Pegallapati – 5 years
Biofuels, bioreactor development
PhD Env Engr | B.S. Civil Eng.

Greg Zaimes – 4 years
Energy analysis; transportation fuels
PhD Civ/Env Eng; B.S. Physics

Mid-level LCA – 2-5 years
Energy/environment
BS/MS Science or Engineering

Junior-level LCA – 1-3 years
Energy/environment
BS Science or Engineering

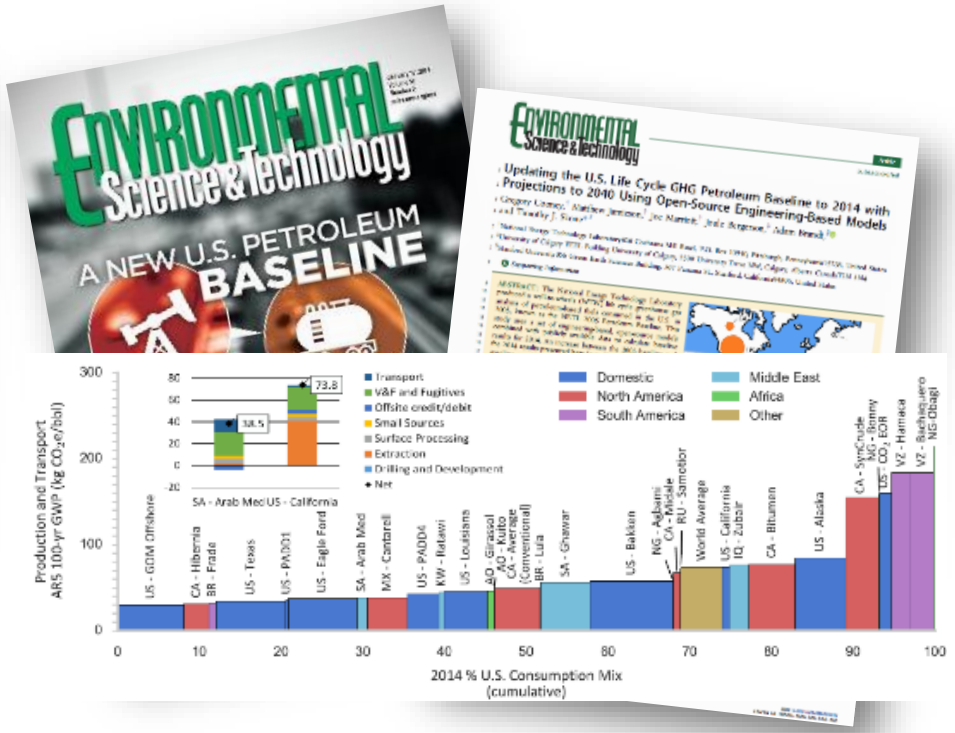
Recent Petroleum-related LCA Work



Evaluating the Climate Benefits of CO_2-Enhanced Oil Recovery Using Life Cycle Analysis (2015)

Cooney, G.; Littlefield, J.; Marriott, J.; & Skone, T. J.

- **CO_2-EOR is a GHG-intensive way of extracting crude compared to conventional extraction methods**
- **Linking EOR with anthropogenic CO_2 yields a benefit due to the displacement of uncaptured electricity**



Updating the U.S. Life Cycle GHG Petroleum Baseline to 2014 with Projections to 2040 Using Open-Source Engineering-Based Models (2016)

Cooney, G., Jamieson, M., Marriott, J., Bergerson, J., Brandt, A., Skone, T.

- **98.1 vs. 96.2 g CO_2e/MJ gasoline (-2%) for 2005 to 2014**
- **Changing baseline values lead to potential compliance challenges with frameworks such as the EISA Section 526**

Ongoing Work

- Adding CO_2 capture to refineries
- Full environmental inventory for the Petroleum Baseline
- Using field EOR data to inform models
- Inclusion of biofuels in U.S. transportation consumption

Collaborators

UNIVERSITY OF CALGARY

Recent Natural gas-related LCA Work

Synthesis of recent ground-level methane emission measurements from the US natural gas supply chain (2017)

Littlefield, J.; Marriott, J.; Schivley, G.; Skone, T. J.

- **Overall Result: 1.7% CH_4 emission rate across the NG life cycle**
- **Emission reduction opportunities: Pneumatic devices – widespread use in production and gathering stages; Unassigned" emissions (observed, but not fully understood); Gathering Systems (new to emissions inventories, but highly aggregated)**

Boundary	Upstream Emissions (g CH) Extraction	Processing	Transmission	Distribution	NG Exiting Boundary (g)	Loss Rate	Emission Rate
Cradle-to-Extraction	4.7				1,086	0.5%	0.43%
Cradle-to-Processing	4.7	2.6			1,020	6.6%	0.71%
Cradle-to-Transmission	4.7	2.6	5.2		1,005	7.9%	1.24%
Cradle-to-Distribution	4.7	2.6	5.2	4.5	1,000	8.4%	1.70%
Processing Only (GtG)		2.6			1,020	6.1%	0.25%
Transmission Only (GtG)			5.2		1,005	1.5%	0.52%
Distribution Only (GtG)				4.5	1,000	0.5%	0.45%
	Numerator				*Denominator*		

Using Common Boundaries to Assess CH_4 Emissions: a Life Cycle Evaluation of Natural Gas & Coal Power Systems (2016)

Littlefield, J.; Marriott, J.; Schivley, G.; Cooney, G.; Skone, T. J.

- **Emphasizes the importance of boundary selection when expressing CH_4 emission rates and comparing NG to other energy sources**
- **Includes use of technology warming potential as a method for comparing cumulative radiative forcing**

Ongoing Work

- Creating a 2016 baseline for natural gas produced in the U.S.
- Collaboration with ONE Future
- Improved uncertainty characterization

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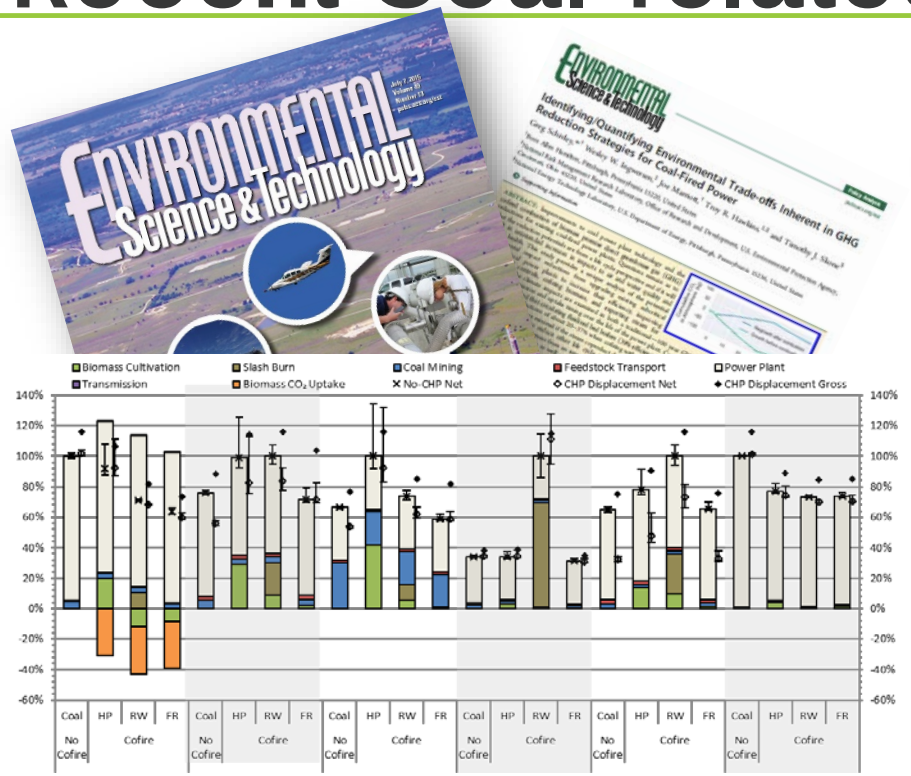
EDF ENVIRONMENTAL DEFENSE FUND Finding the ways that work

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

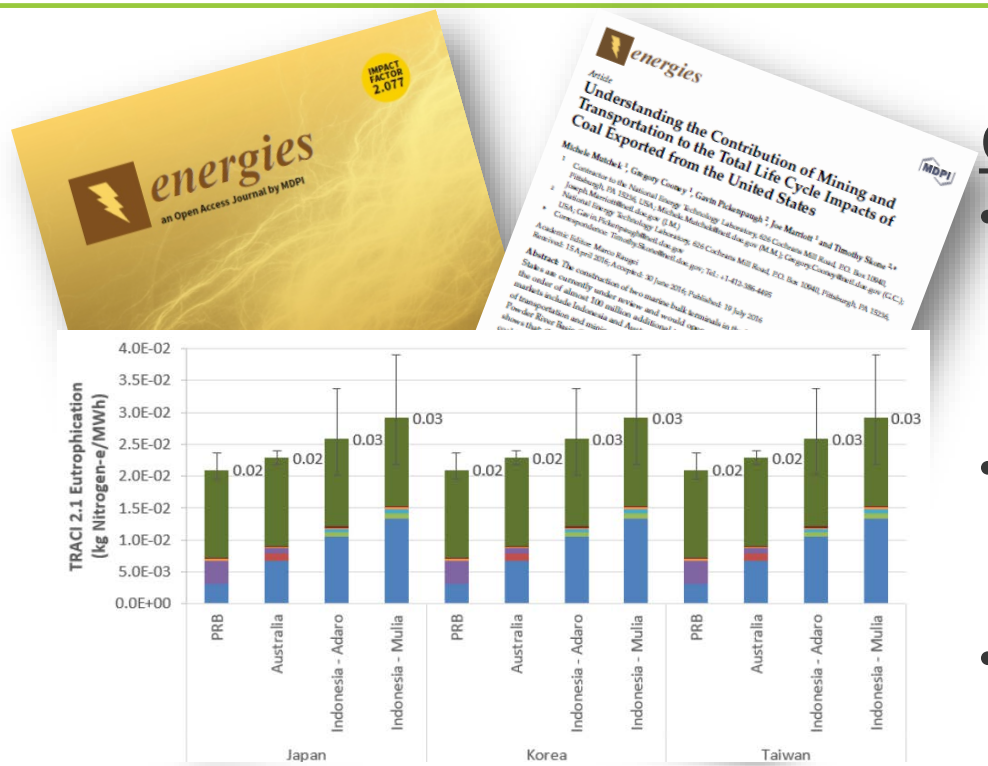
Recent Coal-related LCA Work



Identifying/Quantifying Environmental Trade-offs Inherent in GHG Reduction Strategies for Coal-Fired Power (2015)

Schivley, G.; Ingwersen, W.; Marriott, J.; Hawkins, T.; Skone, T. J.

- **Upgrading boiler & environmental controls reduces all impacts**
- **Intensive biomass (hybrid poplar) can increase some impacts**
- **Modeling decisions (growth before or after burning) makes a difference for climate impacts when accounting for emission timing**



Understanding the Contribution of Mining and Transportation to the Total Life Cycle Impacts of Coal Exported from the United States (2016)

Mutchek, M.; Cooney, G.; Pickenpaugh, G.; Marriott, J.; Skone, T. J.

- **Emissions from coal mining activities are more significant in Australia and Indonesia than PRB**
- **PRB disadvantages: longer transport distance, lower heating value**
- **Non-GWP impact categories are driven by emissions from diesel combustion (transport and mining) and affected by differences in diesel regulations between exporting countries**

Ongoing Work

- Creating a regionalized 2017 baseline for coal produced in the U.S.
- Options for energy in the North Slope of Alaska
- Updated advanced power plant design LCAs

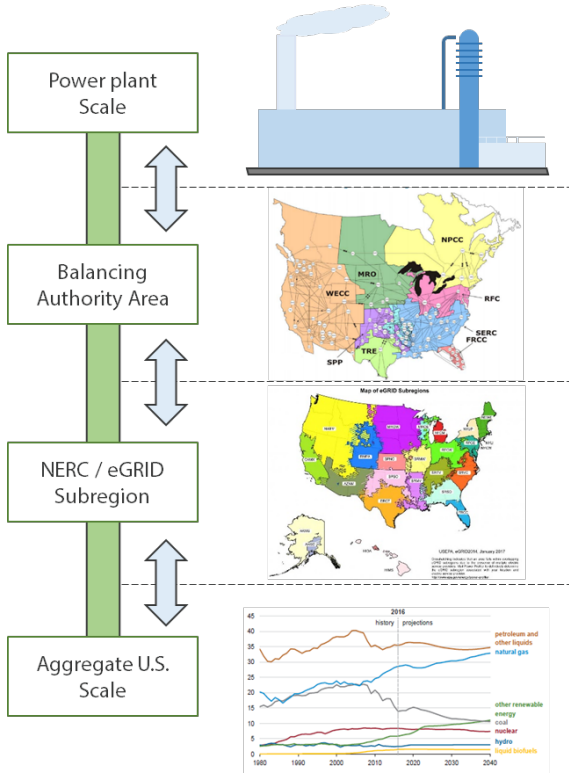
Collaborators

Life Cycle Baseline for Electricity in the U.S.

- **Bottom-up, regional and multi-scale full environmental characterization of power generation and consumption in the U.S.**
  - Builds on expertise used to develop the 2005 and 2014 baselines for petroleum fuels
  - Collaboration with EPA, NREL, USDA as part of the Federal Interoperability Workgroup
- **Development occurring in two phases:**
  - Phase 1: September, 2017
  - Phase 2: FY18 into FY19

Energy/ Fuel Source	GHG		Energy Use		Water use & Quality		Land Area		Land Use Change (GHG)		Infrastructure		Other Air Pollutants		TRACI Categories	
	Inc	R&D	Inc	R&D	Inc	R&D	Inc	R&D	Inc	R&D	Inc	R&D	Inc	R&D	Inc	R&D
Coal	X		X		X								X			
Natural Gas	X		X		X		X		X				X			
Petroleum	X				X								X			
Nuclear	X		X		X		X		X				X			
Hydropower	X		X		X		X		X		X		X			
Biomass	X						X		X				X			
Geothermal	X		X		X		X		X		X		X			
Solar	X				X		X		X		X		X			
Wind	X				X		X		X		X		X			

X Included in Current NETL Models ☐ Not Included in Current NETL Models ☐ Model Development ☐ Under Development ☐ Revisions Necessary



Category: Petroleum, Natural Gas, Coal, Nuclear, Hydro, Wind, Solar, Geothermal, Biomass

Function: Baseload, Cycling, Load Following, Peaking

Interregional Electricity Trade: Mapping of electricity imports/exports, accounting for international trade with Mexico and Canada, as well as transmissions losses.

NERC & eGRID Subregion: Environmental impacts of electricity generation and consumption for North American Electricity Reliabiltiy Corporation (NERC) and eGRID subregions

U.S. Electricity Baseline: A static description of the environmental footprint of U.S. electricity in the current year.

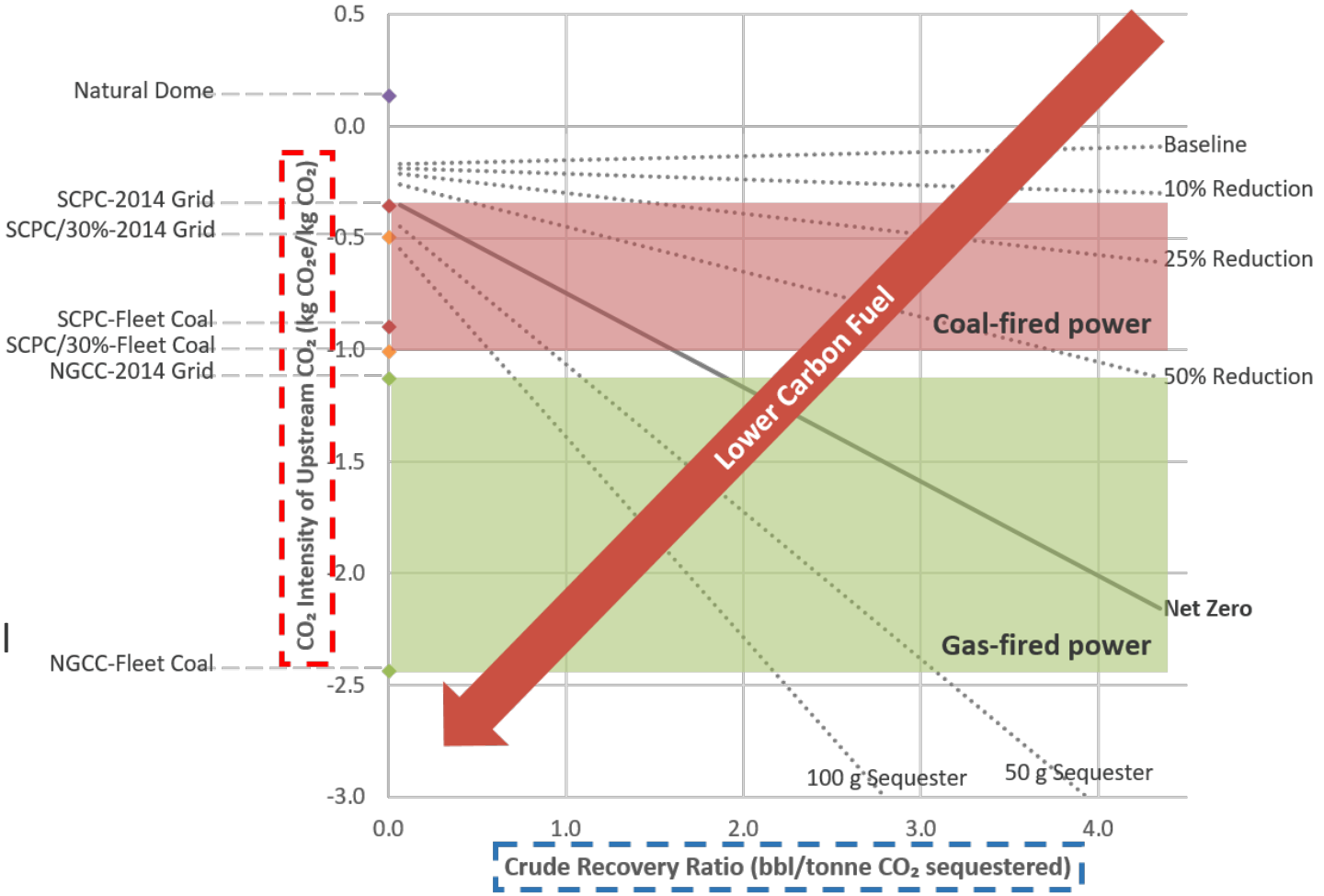
LCA of CO_2 Storage via Enhanced Oil & Gas Recovery

Educating scientific community on the environmental value of CO_2-EOR and geologic storage opportunities

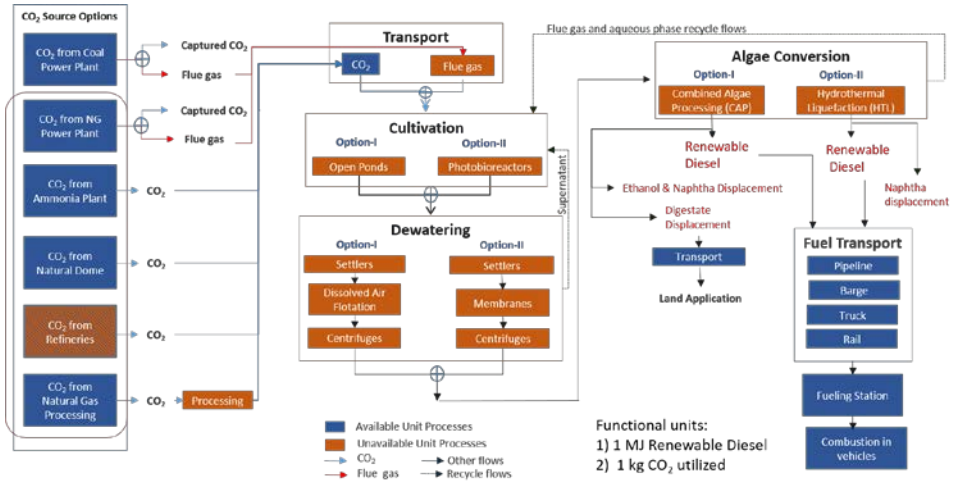
- LCA Conference, October 2016
- RIC Technical Seminar, March 2017
- Energy Modeling Forum, April 2017
- LCA Conference, September 2017

New NETL Reports and Models for 2017

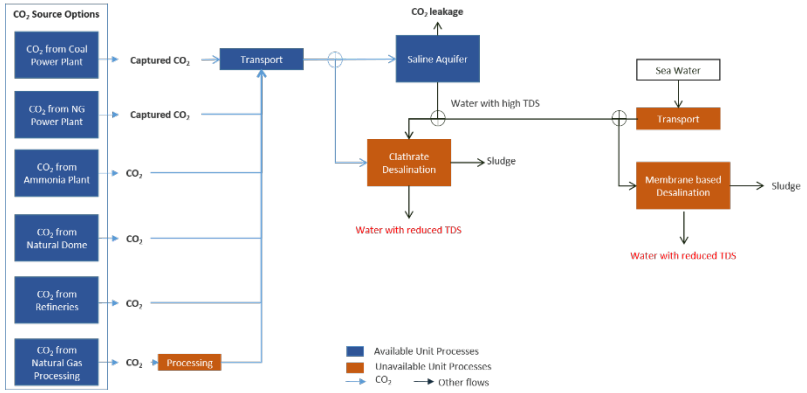
- *Public* CO_2-EOR LCA Model (Winter 2017)
- Enhanced Hydrocarbon Assessment Journal Article (pending)



LCA Support of CO_2 Utilization



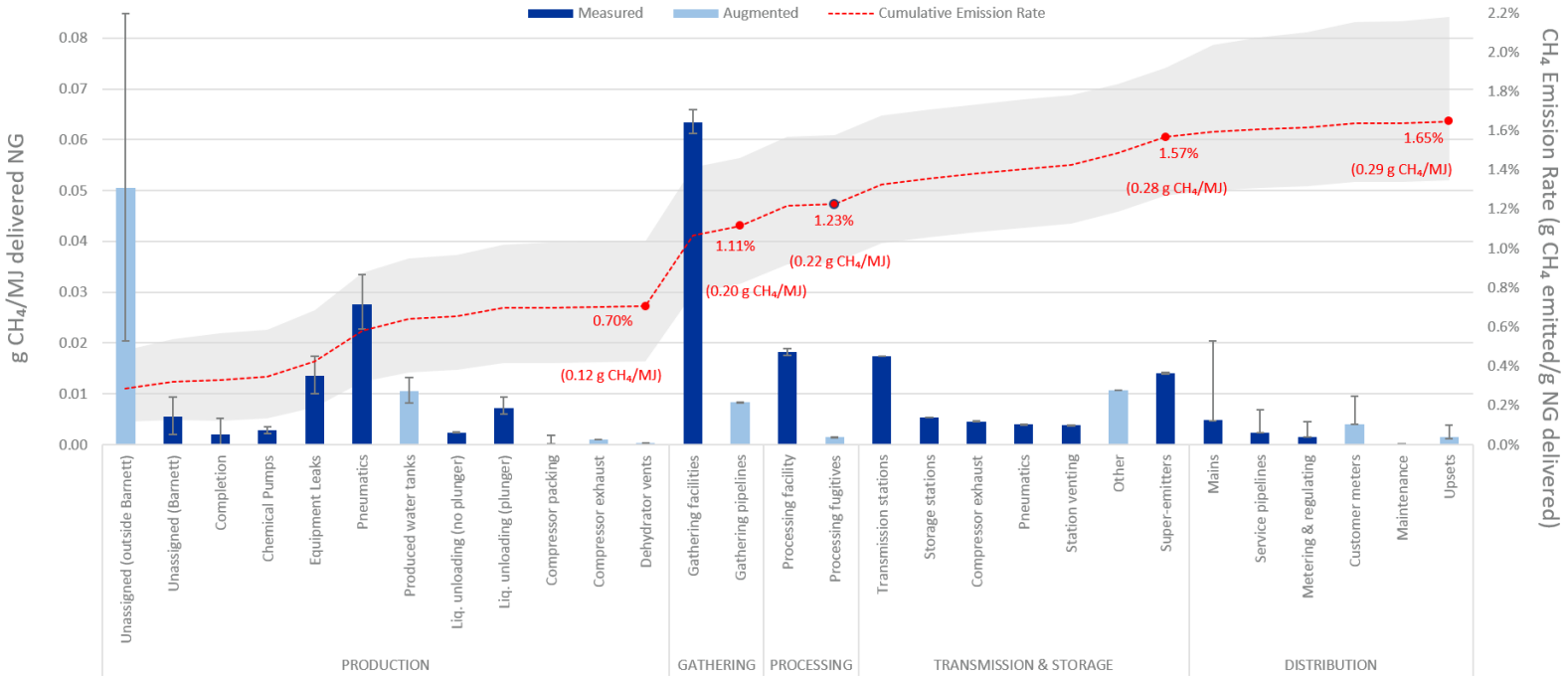
Design Basis for CO_2-enhanced Algal Biofuels



Design Basis for Clathrate-based Industrial Desalination

Guidance documents for designing, performing, and interpreting LCAs for CO_2 utilization projects

Recent & Ongoing Natural Gas LCA Work



- **<u>Overall</u> result: 1.7% CH_4 emission rate across NG life cycle**
- **<u>Emission reduction</u> opportunities**
  - Pneumatic devices – widespread use in production and gathering stages
  - "Unassigned" emissions (observed, but not fully understood)
  - Gathering Systems (new to emissions inventories, but highly aggregated)
- **<u>Research</u> opportunities**
  - Improve activity data on pneumatic devices throughout supply chain
  - Identify drivers and regional variability for unassigned emissions
  - Disaggregate gathering emissions at the category level to individual system components

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Finding the ways that work

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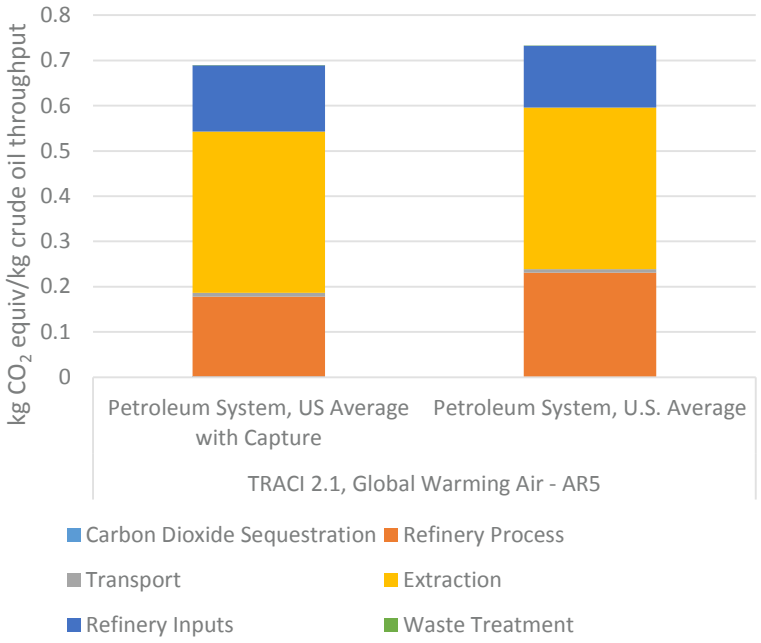
Collaboration with ONE Future

1. Leverage ONE Future's best management practices
2. Emphasize the value of industry participation in identifying emission reduction opportunities
3. Establish benchmarks for assessing the value of CH_4 reduction opportunities and what they mean at the national scale

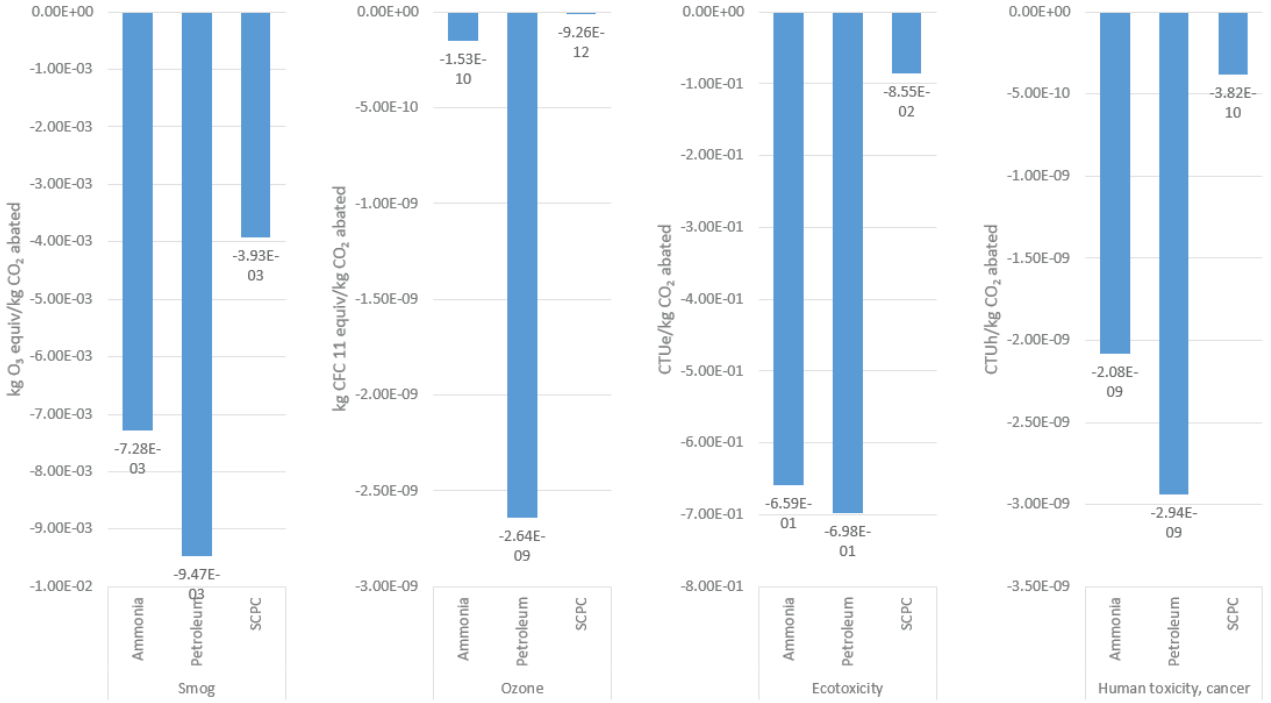
LCA of Carbon Capture Systems

Large scale thermoelectric power generation to small scale industrial CO_2 sources

- **Comparative analysis of carbon capture for ammonia production and petroleum refining**
  - Compared on a carbon dioxide abated functional unit as products are not comparable
  - Carbon capture from each industry is compared with carbon capture for electric power production
  - Next phase will include cement and steel



Functional unit is **1kg carbon dioxide abated**. SCPC results from NETL baseline.

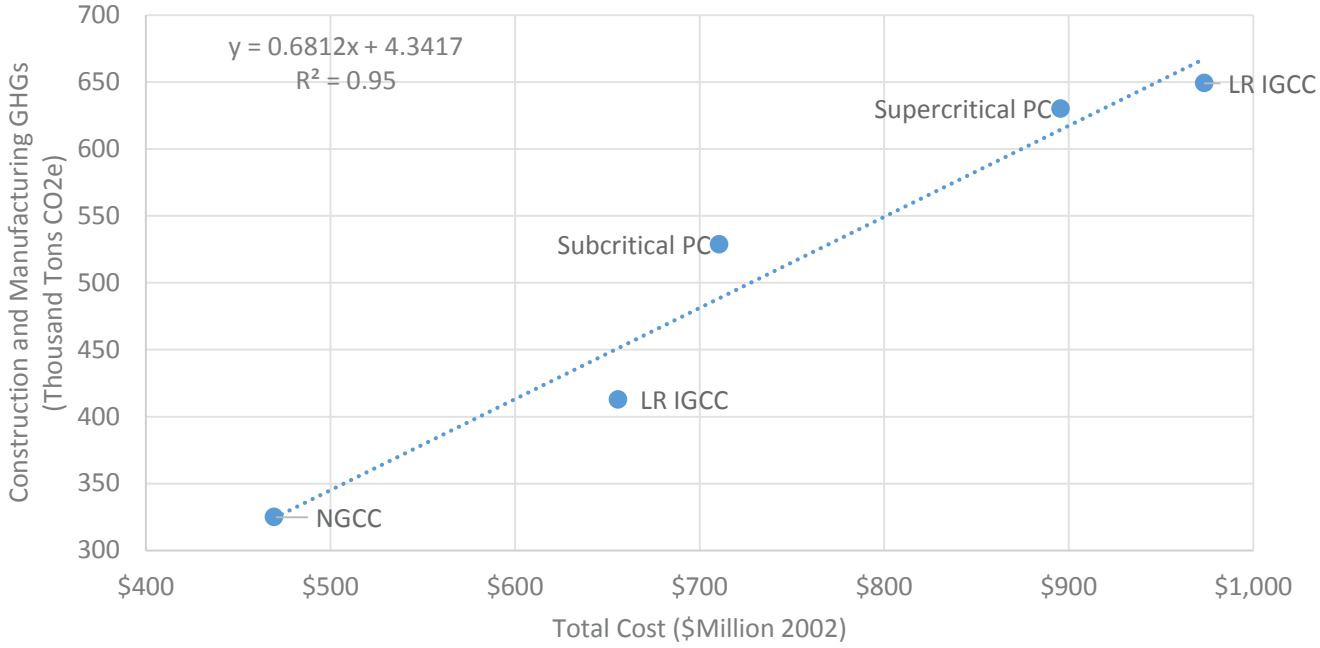


Economic Input-Output LCA Modeling

Power Plant Construction Profiles

- EIO-LCA offers an easy and reliable method to estimate construction emissions for power plants and expand inventory
- Construction, design, processing, and other services are included
- While construction represents <1% of many impacts for a fossil power plant, this is unlikely to be true with the adoption of CCS & renewables
  - For SCPC w/ CCS – construction is ~5% of the operational CO_2 emissions

Case:		B11A – Supercritical PC w/o CO_2					
Plant Size (MW,net):		550					
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O.& Fee
				Direct	Indirect		
7						HRSG, Ducting, & Stack	
7.3	Ductwork	$10,663	$0	$6,731	$0	$17,394	$1,739
7.4	Stack	$10,604	$0	$6,162	$0	$16,766	$1,677
7.9	Duct & Stack Foundations	$0	$1,156	$1,373	$0	$2,528	$253
	Subtotal	$21,267	$1,156	$14,266	$0	$36,689	$3,669
8						Steam Turbine Generator	
8.1	Steam TG & Accessories	$75,300	$0	$8,211	$0	$83,511	$8,351
8.2	Turbine Plant Auxiliaries	$418	$0	$890	$0	$1,308	$131
8.3	Condenser & Auxiliaries	$7,830	$0	$2,737	$0	$10,567	$1,057
8.4	Steam Piping	$26,525	$0	$10,751	$0	$37,276	$3,728
8.9	TG Foundations	$0	$1,247	$2,059	$0	$3,305	$331
	Subtotal	$110,073	$1,247	$24,647	$0	$135,967	$13,597

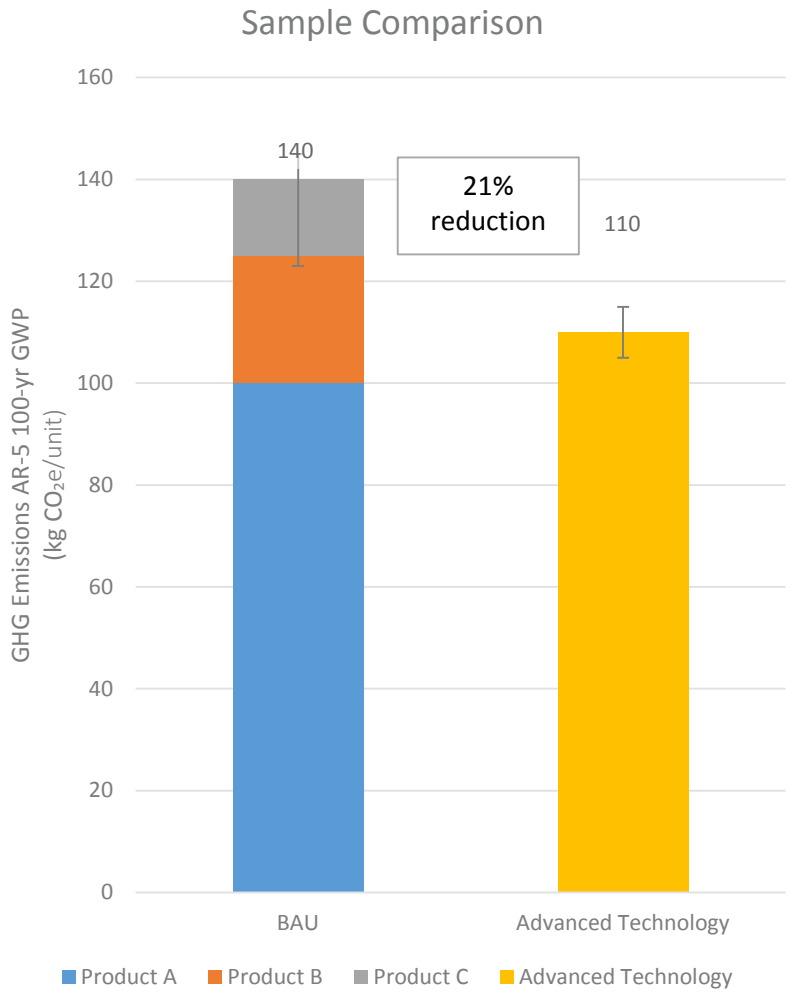


Item No.	Description	EIO-LCA Sector
	HRSG, Ducting, & Stacks	
7.3	Ductwork	Air purification and ventilation equipment manufacturing
7.4	Stack	Air purification and ventilation equipment manufacturing
7.9	HRSG, Duct & Stack Foundations	Ready-mix concrete manufacturing
	Steam Turbine Generator	
8.1	Steam TG & Accessories	Turbine and turbine generator set units manufacturing
8.2	Turbine Plant Auxiliaries	Turbine and Turbine generator set units manufacturing
8.3	Condenser & Auxiliaries	Turbine and Turbine generator set units manufacturing
8.4	Steam Piping	Iron, steel pipe and tube manufacturing from purchased steel
8.9	TG Foundations	Ready-mix concrete manufacturing

DOE Loan Program Office GHG Analysis

http://energy.gov/lpo/innovative-clean-energy-projects-title-xvii-loan-program

- **Background:**
  - Applicants must "avoid, reduce, or sequester" GHG emissions
    - Advanced Fossil
    - Renewable Energy and Efficient Energy
  - Compares GHG emissions to a business-as-usual (BAU) scenario
- **Analysis:**
  - Suggest BAU product or technology
  - Calculate life cycle GHG emissions for the applicant and BAU
  - Include all products in the comparison
- **NETL provided analysis for over a dozen projects in the past year**



Citations and Links to Recent Work

Cooney, G., Littlefield, J., Marriott, J., & Skone, T. J. (2015). Evaluating the Climate Benefits of CO2-Enhanced Oil Recovery Using Life Cycle Analysis. *Environmental Science & Technology, 49*(12), 7491-7500. doi: 10.1021/acs.est.5b00700.
http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00700

Cooney, G., Jamieson, M., Marriott, J., Bergerson, J., Brandt, A., & Skone, T. J. (2016). Updating the U.S. Life Cycle GHG Petroleum Baseline to 2014 with Projections to 2040 Using Open-Source Engineering-Based Models. *Environmental Science & Technology*. doi: 10.1021/acs.est.6b02819
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Littlefield, J. A., Marriott, J., Schivley, G. A., & Skone, T. J. (2017). Synthesis of recent ground-level methane emission measurements from the U.S. natural gas supply chain. *Journal of Cleaner Production, 148*, 118-126. doi: 10.1016/j.jclepro.2017.01.101
http://www.sciencedirect.com/science/article/pii/S0959652617301166

Littlefield, J. A., Marriott, J., Schivley, G. A., Cooney, G., & Skone, T. J. (2016). Using Common Boundaries to Assess Methane Emissions: A Life Cycle Evaluation of Natural Gas and Coal Power Systems. *Journal of Industrial Ecology, 20*(6), 1360-1369. doi: 10.1111/jiec.12394
http://onlinelibrary.wiley.com/doi/10.1111/jiec.12394/full

Mutchek, M., Cooney, G., Pickenpaugh, G., Marriott, J., & Skone, T. (2016). Understanding the Contribution of Mining and Transportation to the Total Life Cycle Impacts of Coal Exported from the United States. *Energies, 9*(7). doi: 10.3390/en9070559
http://www.mdpi.com/1996-1073/9/7/559

Schivley, G., Ingwersen, W. W., Marriott, J., Hawkins, T. R., & Skone, T. J. (2015). Identifying/Quantifying Environmental Trade-offs Inherent in GHG Reduction Strategies for Coal-Fired Power. *Environmental Science & Technology, 49*(13), 7562-7570. doi: 10.1021/acs.est.5b01118
http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b01118

Contact Information

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