SCOPING STUDIES TO EVALUATE THE BENEFITS OF AN ADVANCED DRY FEED SYSTEM ON THE USE OF LOW-RANK COAL

Topical Report – Task 4.0 "Design of Posimetric Feed System (PFS)"

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DISCLAIMER

ABSTRACT

This report describes the development of the design of an advanced dry feed system that was carried out under Task 4.0 of Cooperative Agreement DE-FE0007902 with the US DOE, "Scoping Studies to Evaluate the Benefits of an Advanced Dry Feed System on the use of Low-Rank Coal." The resulting design will be used for the advanced technology IGCC case with 90% carbon capture for sequestration to be developed under Task 5.0 of the same agreement. The scope of work covered coal preparation and feeding up through the gasifier injector. Subcomponents have been broken down into feed preparation (including grinding and drying), low pressure conveyance, pressurization, high pressure conveyance, and injection. Pressurization of the coal feed is done using Posimetric[1] Feeders sized for the application. In addition, a secondary feed system is described for preparing and feeding slag additive and recycle fines to the gasifier injector. This report includes information on the basis for the design, requirements for down selection of the key technologies used, the down selection methodology and the final, down selected design for the Posimetric Feed System, or PFS.

[1] "Posimetric" is a trademark of General Electric Company and/or its affiliates.

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EXECUTIVE SUMMARY

This report describes the development of the design of an advanced dry feed system utilizing GE's Posimetric[2] Feeder technology. This work was carried out under Task 4.0 of Cooperative Agreement DE-FE0007902 with the US Department of Energy, "Scoping Studies to Evaluate the Benefits of an Advanced Dry Feed System on the use of Low-Rank Coal," and is one of seven tasks to be carried out under the Agreement. The resulting advanced dry feed system, also referred to as the Posimetric Feed System or PFS, is to be used under Task 5.0 in the development and evaluation of an advanced technology IGCC with 90% carbon capture using a U.S. low rank coal from the Powder River Basin.

The work was carried out under three subtasks: (1) Evaluate available and novel technologies for potential use in the PFS, which reports on the key attributes and technologies that comprise the PFS, as well as the basis for down selecting among the available options; (2) Sizing, performance and cost evaluation of equipment for the application, where the focus was on developing design, performance, cost and availability information for the PFS integrated with two key coal grinding and drying options, and (3) Trade-off study to develop an optimized PFS, where further evaluation of the PFS integrated with the two grinding and drying options was completed, focused on determining the relative impact of different heating media.

Based on the work done under Task 4.0, the recommended PFS for the Task 5.0 work is as follows:

- **Grinding and Drying** – Use impact dryer mills where the heat for drying is supplied by high pressure and medium pressure boiler feed water. This configuration was chosen both for CAPEX and efficiency reasons, as it provides a particularly effective way of using readily available low level energy;

- **Low Pressure Conveyance** – Dense phase pneumatic conveyance using nitrogen carrier gas was selected, specifically because of the benefits it provides in reducing CAPEX and OPEX, as well as in reducing equipment size, wear, nitrogen use and power use.

- **Pressurization and Metering** – Use four operating Posimetric Feeders with one spare. Posimetric Feeders are more attractive compared to lockhoppers, especially given the combined pressurization and metering capability of the feeders, ability to handle higher moisture content feeds, and wide pressure capability.

- **High pressure conveyance** – Using high pressure dilute phase conveyance both minimizes equipment sizing and operating costs and ensures uniform solids/gas flow.

- **Solids recycle – Slurry feed** – This integrates particularly well with the quench gasifier technology, eliminating the need to dry the solids prior to recycle, while providing useful gasifier temperature moderation.

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- **Slag Additive – Slurry feed** - A slag additive broadens the temperature operating window for a given coal by modifying the slag viscosity. Like the recycle solids, using a slurry feed also provides a useful gasifier temperature moderator.

- **Injection – Common Gasifier Injector** – Demonstrated as an effective means for mixing feeds with widely varying physical properties.

It should be noted that a cage mill/fluidized bed dryer option using low pressure steam gives essentially equal results to the impact dryer mill using high pressure and medium pressure boiler feed water with respect to performance and CAPEX. The key benefits of the impact dryer mill option are ease of startup and operation, and a reduced foot print and number of transfer points.

REPORT DETAILS

1. Overview and Design Basis

1.1 Introduction

The work in this report was conducted under Cooperative Agreement DE-FE0007902, “Scoping Studies to Evaluate the Benefits of an Advanced Dry Feed System on the use of Low-Rank Coal.” This report describes the work conducted under Task 4.0 of the Cooperative Agreement, which was the development of the design of an advanced dry feed system for an IGCC plant based on the use of GE’s Posimetric Feeder[3] technology with 90% carbon capture for sequestration (CCS) using US low cost low rank coal. It includes information on the basis for design, the various technology options considered, the requirements for the down selection of the key technologies incorporated into the final design and a tradeoff study pertaining to the coal drying and grinding technology to be incorporated in the final preferred advanced dry feed system design.

1.2 Summary Description and Benefits of the Advanced Dry Feed System

The advanced dry feed system, also known as the Posimetric Feed System or PFS, incorporates key features that are particularly advantageous for integration with the GE Gasification Process. The PFS consists of coal drying and grinding, low pressure coal conveying, coal pressurization and metering using GE’s Posimetric Feeder, and high pressure coal conveying to a proprietary feed injector designed for dry feed. There is also a slurry subsystem that is used to feed slag additive slurry and recycled fines slurry to the gasifier via the same feed injector. The slag additive slurry and recycled fines slurries are produced separately and then combined in a single feed line upstream of the feed injector. Following are some of the benefits of this approach:

Reduced Drying Levels – Use of Posimetric Feeder technology allows operation at reduced coal drying levels compared to lockhopper based dry feed systems. This reduces the losses associated with deeper levels of drying, allowing the remaining water in the coal to operate as a temperature moderator while also achieving high coal gas efficiencies, and low specific oxygen and specific coal consumptions.

High Pressure Capability – Posimetric Feeder technology enables operation at much higher pressure than lockhopper based dry feed systems. This can result in significant economy for applications requiring high pressure syngas.

Safe/Reliable Isolation for Carrier Gas – Posimetric Feeder technology provides a safe/reliable means for preventing the loss of carrier gas through the upstream portion of the feed system. This is advantageous for using carrier gases containing reactive or toxic species, including syngas species such as hydrogen, carbon monoxide or hydrogen sulfide.

Simplified Solids Recycle – The slurry feed system used for solids recycle integrates particularly well with GE’s quench configuration, as it eliminates the need to dry the recycle solids before feeding them to the gasifier, while maximizing carbon conversion and minimizing the fines content of the slag.

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Slag Additive Slurry – When desired, slag additive may be used to adjust the viscosity of the slag in the gasifier. This helps optimize conversion and gasifier liner life, while ensuring effective slag removal at the desired operating temperature.

Minimum Stepouts – The Posimetric Feed System technology described here requires a minimum level of stepouts from commercially available technology, substantially limiting the risks associated with its commercial introduction.

1.3 Scope of Work

1.3.1 Project Scope of Work

This focus of this study is on integrating an advanced dry feed system into an IGCC plant for producing power from low rank coals with 90% CO2 capture for sequestration. However, the results should be applicable to other end user applications, including other power generation or chemical production applications.

The Cooperative Agreement calls for conducting the following seven tasks.

Task 1.0 Project Management and Planning

Task 2.0 Establish Key Assumptions and Methodologies

Task 3.0 Evaluate and Analyze Baseline Case

Task 4.0 Design of Posimetric Feed System

Task 5.0 Evaluate and Analyze Advanced Technology Case

Task 6.0 Analyze Results – Compare and Report the Results

Task 7.0 Data to Support Potential Technology Value

The advanced dry feed system design developed during Task 4.0 is being used to develop the design of the Advanced Technology case IGCC under Task 5.0. The results of that work will then be compared to the slurry Base Line Case developed under Task 6.0.

1.3.2 Task 4.0 Scope of Work

The work performed under Task 4.0 consisted of three subtasks:

Subtask 4.1 – Evaluate Available and Novel Technologies for Potential Use in the PFS
This subtask involved developing a shortlist of technologies available for incorporation into the advanced dry feed system, including leveraging the results of internal studies and expertise, as well as searches and analysis of related and advanced technologies.

Subtask 4.2 – Sizing, Performance & Cost Evaluation of Equipment for the Application
This subtask involved developing sizing, cost and performance information for the components identified and down selected in Subtask 4.1. This information was used to develop process flow sketches, sized equipment lists, and performance estimates for two key design options. The

focus of this effort was on the use of different grinding and drying methods, specifically, the use of an impact dryer mill, where the grinding and drying occur simultaneously, or of a cage mill and fluidized bed dryer, where the grinding and drying occur sequentially.

Subtask 4.3 – Trade-off Study to Develop Optimized Dry Feed System
This subtask involved conducting a tradeoff study to evaluate the relative benefits of using different heating media for the two grinding and drying options down selected in Subtask 4.2.

1.4 Advanced IGCC Plant Configuration

The block flow diagram for the advanced technology case IGCC plant is provided in Figure 1. In this plant, the advanced dry feed system is used to feed coal and recycle solids/slag additive slurry to a GE gasifier in sufficient quantity to fully load one GE 7FB gas turbine modified for use with high hydrogen content fuel gas. Upstream of the gas turbine, the syngas will be processed in order to capture 90% of the carbon fed to the gasifier and to produce a high pressure stream of CO2 that can be fed to an enhanced oil recovery (EOR) field as a means of sequestering the CO2 in an economically beneficial manner. The advanced dry feed system includes the Posimetric Feed System and slag additive preparation blocks, as well as portions of the equipment in the quench gasifier and fine slag handling blocks.

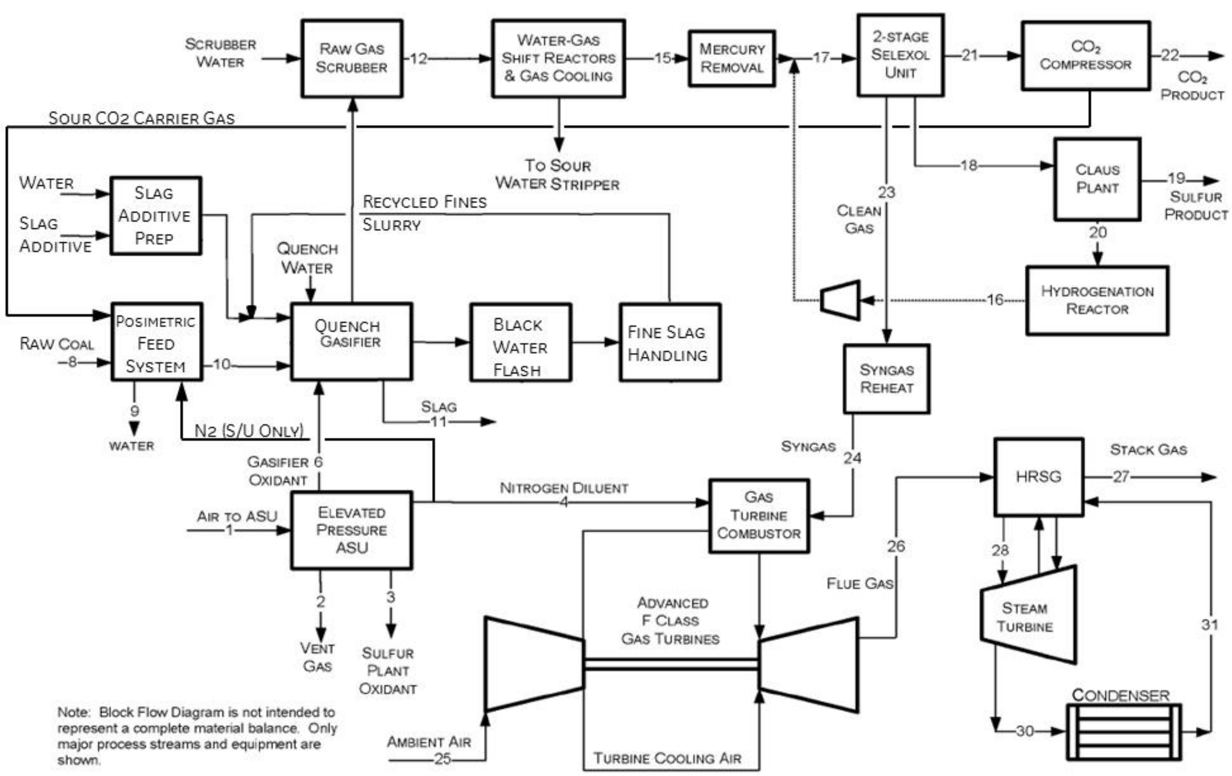


Figure 1. IGCC Block Flow Diagram

1.5 Advanced Dry Feed System Configuration

A block flow diagram of the advanced feed system is given in Figure 2.

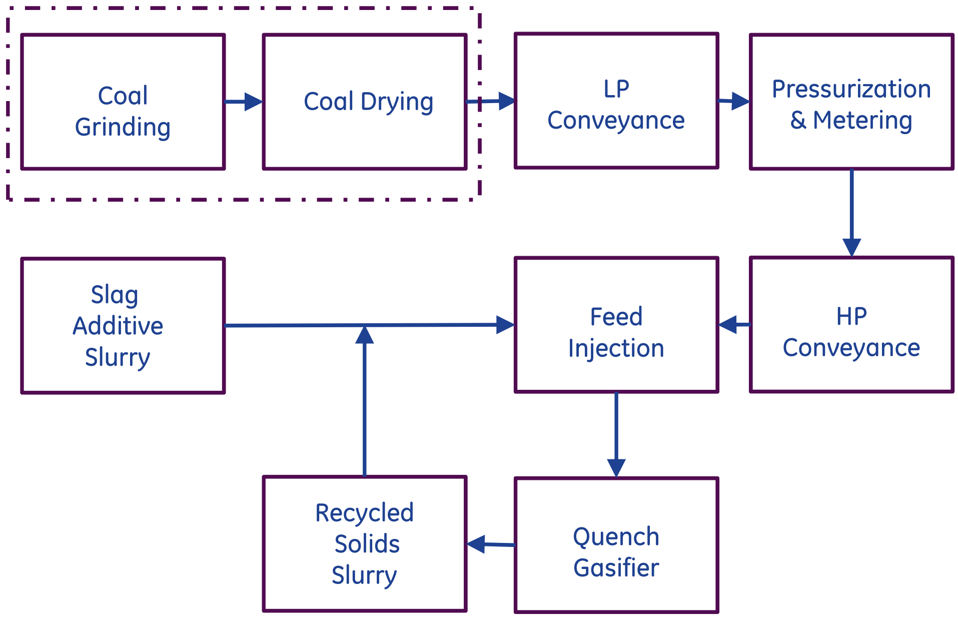


Figure 2. Advanced Dry Feed System Block Flow Diagram

The PFS portion of the advanced dry feed system includes coal drying and grinding, which may be done simultaneously or in sequential steps; low pressure conveyance, which is used for transporting the coal through the feed system prior to pressurization; pressurization and metering using the Posimetric Feeder; high pressure conveyance using a recycle CO2 stream; and injection using a proprietary dry feed injector into the gasifier.

The slurry subsystem portions of the advanced dry feed system include separate slurry preparation and feeding systems for the slag additive and recycle solids, The separate slag additive and recycle solids slurries are combined upstream of the gasifier feed injector and fed as a single slurry through the feed injector.[4]

[4] This subsystem can be replaced with a water or other moderator system in the event solids recycle and the use of a slag additive is not desired in a given plant design.

1.6 Basis for Design

The basis for design used for Task 4 is provided in Table 1. As shown, the advanced IGCC plant and advanced dry feed system are being designed based on the use of Powder River Basin Montana Rosebud coal, assuming a Texas Gulf Coast location. The coal throughput is based on fully loading a GE Frame 7FB gas turbine modified for use with high hydrogen syngas. Due to the low melting temperature of the Montana Rosebud coal ash, a slag additive is used to increase the ash viscosity and thus facilitate operation at higher temperatures. 100% recycle of the fines collected in the process water is used to maximize carbon conversion and minimize the fines content of the slag.

Table 1. Advanced Dry Feed System - Basis for Design

Item/Variable	Specification	
Site	Texas Gulf Coast	
Elevation, feet	77	
Atmospheric Pressure, psia	14.68	
Average Ambient Temperature, °F	70	
Average Relative Humidity,%	77	
Number of Dry Feed Trains, operating/spare	1/0	
Coal Feed	PRB Montana Rosebud Coal	
Proximate Analysis, wt%	(as-received)	(moisture-free basis)
Volatile Matter	30.34	40.87
Fixed Carbon	35.70	48.09
Ash	8.19	11.04
Moisture	25.77	0
Ultimate Analysis, wt%	(as-received)	(moisture-free basis)
C	50.07	67.45
H	3.38	4.56
N	0.71	0.96
S	0.73	0.98
Ash	8.19	11.03
Cl	0.01	0.01
O (by difference)	11.14	15.01
Heating Value	(as-received)	(moisture-free basis)
HHV, BTU/lb (high)	11,200	11,615
LHV, BTU/lb (low)	8,622	8,314

Item/Variable	Specification	
Ash Composition, wt% oxides		
SiO_2	38.09	
Al203	16.73	
Fe_2O_3	6.46	
TiO_2	0.72	
CaO	16.56	
MgO	4.25	
Na_2O	0.54	
K_2O	0.38	
SO_3	15.08	
P_2O_5	0.35	
BaO	0.00	
SrO	0.00	
Unknown	0.84	
Coal throughput, TPH (moisture-free basis)[5]	126.8	
Coal Top Size, inches	2	
Coal Moisture Content at Dryer Outlet, wt%	20.2	
Gasifier Pressure[6], psig	1,000	
Coal Carrier Gas – Startup	Nitrogen	
Coal Carrier Gas – NOC	Recycle CO_2	
Slag Additive Used, lb additive/lb coal (moisture-free basis)	≤ 0.055	
Cooling Water (CW)	Temperature, °F	Pressure, psia
CW Supply	90	79.7
CW Return	110	39.7
Steam	Temperature, °F	Pressure, psia
LP Steam	328	99.7
MP Steam	489	614
Boiler Feed Water	Temperature, °F	Pressure, psia
LP BFW	228	20
MP BFW	395	800
HP BFW	610	1,793

[5] Throughput set to fully load a GE Frame 7FB gas turbine modified for use with high hydrogen syngas.
[6] Conservative value assumed for Task 4, the pressure may be modified as part of the optimization work under Task 5.

2. Evaluate Available and Novel Technologies for Potential Use in the PFS

The purpose of Subtask 4.1 was to evaluate available technologies, including novel technologies, that may be applicable to the subsystems and components that make up the advanced dry feed system, and to develop a short list of those technologies that might best enable the advanced IGCC to meet its objectives, This process was facilitated by determining what key characteristics the advanced dry feed system, including its subsystems and components, would need to meet, in order to satisfy overall customer requirements for the advanced IGCC plant (what are referred to as critical to quality requirements, or CTQs), and then down selecting among the options by comparing each of the options against its ability to meet those CTQs. This section of the report describes applicable CTQs, key alternatives that were considered, and the short list that resulted from the initial down selection, with much of the basis coming from prior work done by GE in its development of an advanced dry feed system.

2.1 Advanced Dry Feed System CTQs

Key CTQs applicable to the advanced IGCC plant include the following:

- CO2 carbon capture level
- Plant availability
- Net plant efficiency
- Operating costs
- Compliance with emissions regulations
- Operability
- Capital cost

These flow down to the following CTQs for the advanced dry feed system:

- Optimized level of drying
- Optimized carrier gas selection (type and amount)
- Optimized feed system configuration
- Ability to handle transients and system upsets
- Accurate and reliable control
- Reliability and availability equivalent to slurry feed
- Meet turndown requirements
- Use appropriate specifications for wear and life
- Minimize particulate and other emissions

These CTQs for the advanced dry feed system in turn flow down to CTQs for the key subsystems, a number of which are listed in the following sections of the report.

2.2 Alternatives and Initial Evaluation

2.2.1 Grinding and Drying

The coal grinding and drying equipment has significant impact on the system CAPEX and reliability/availability/maintenance (RAM). The following are the list of CTQs for the subsystem:

- Technology readiness
- Ability to meet grind size specification range
- Ability to meet moisture content specification range
- Controllability
- Reliability/Proven Technology
- Operation complexity (ease of use)
- Footprint/Layout
- Electrical Power Requirements
- Drying Gas Flow rate
- Heating Duty
- CAPEX
- OPEX
- RAM
- Ability to handle Transient Scenarios
- Emissions

Key options considered:

- Direct fired impact dryer mill
- Indirect fired/heated impact dryer mill
- Cage mill and fluidized bed dryer

These options were selected as being representative of general classes of milling and drying technology that are available from one or more vendors and that can be readily integrated into an advanced dry feed system. Some newer technologies also were considered, including ultra-high velocity grinding and microwave drying, but these technologies were not considered sufficiently advanced for inclusion in this study.

Direct Fired Impact Dryer Mill – In an impact dryer mill, coal is ground by impact with a series of rotary hammers located at the base of the mill. The ground coal is then swept up a drying column with mill gas that's been heated by mixing it with hot flue gas produced by the combustion of fuel with air. The hot gas dries the coal and carries the ground product out through a rotary classifier. The ground product from the classifier is then recovered from the mill gas using a combination of cyclones and a bag filter, and then stored in the ground coal storage hopper for use in the gasifier. Typically, most of the mill gas is recycled back to the mill, only venting sufficient quantities to keep the moisture content of the gas from becoming too high. Normally, combustor operation and level of recycle are also used to maintain the oxygen content in the mill gas below combustibility limits. Any solids that don't pass through the classifier are batted back to the bottom of the mill for further size reduction.

This configuration provides proven technology that will meet the grind size and moisture content specifications for the study coal. Grind size is controlled by setting the classifier speed, and moisture content is controlled by setting the temperature of the air entering the mill based on the natural gas firing rate. One of the biggest advantages of this technology is the integrated operation of the grinding, drying, and low pressure conveyance systems. This results in a compact footprint and reliable layout with minimum transfer points. Also, the mill is very responsive to operating conditions, and very quick to start up.[7]

Indirect Fired Impact Dryer Mill – Indirect firing or heating provides an alternative way to meet the same specifications. In this case, rather than being heated by the combustion of natural gas, the mill gas is heated by indirect heat exchange with available utility or process streams from within the plant. Consequently, this option requires the use of an inert gas to help keep the oxygen concentration in the mill gas below combustibility limits. However, the lack of combustion products in the mill gas also means that the gas makeup and vent rates can be lower from a dew point control perspective. This option is expected to have minimal impact on the overall footprint of the mill. It's also responsive to operating conditions, and very quick to start up.[7]

Cage Mill and Fluidized Bed Dryer – In this system, the coal is first ground and then dried. The grinding is done using cage mills. This occurs by impacting the coal with the rotating cages located inside the mill. The ground product is then transported from the mill to a fluidized bed dryer, where the coal is dried by indirect heat exchange with low pressure steam. The atmosphere within the fluidized bed dryer is comprised of superheated water vapor, which after particulate separation and heating, is used as the working fluid to fluidize the incoming coal. The coal is discharged from the mill and nitrogen is then used to strip the product coal of water vapor. A small stream of water, equal to the quantity of water dried from the coal, is vented from the fluidized bed dryer to maintain the fluidized bed in water balance.

As with the impact drying mill, this option provides proven technology for grinding and drying the coal that can meet the study specifications. The fluidized bed dryer technology is flexible, and, like the impact drying mill, can be designed to accommodate all levels of drying. However, this system requires individual equipment for grinding, drying, and conveying, which involves more transfer points, and, together with the very large size of the fluidized bed, results in a larger footprint for the same grinding/drying duty. Also, startup is expected to take more time. However, the longer residence times of the fluidized bed dryer may help with maintaining operational stability. The fluidized bed dryer also has a much lower vent rate compared to the impact drying mill, allowing for much lower particulate emissions depending on the particulate removal equipment used. These drop further to the extent that the effluent vapor is condensed for additional heat recovery.

[7] It should be noted that though this study focused on using impact dryer mill technology, should a finer particle sized distribution be desired, or in cases where a feed is to be used that's more difficult to grind than the study feed, pulverizer technology could be used instead while integrating similarly with the plant.

2.2.2 Low Pressure Conveyance

Low pressure conveyance subsystem moves ground and dried coal from the large storage bin to the live wall hopper attached to the inlet of the Posimetric Feeder. The following are the list of CTQs for the subsystem:

- Controllability of conveyance system
- Entrainment of coal solids in carrier gas
- Design layout simplicity
- Processed coal properties
- OPEX
- CAPEX
- RAM

Key options considered:

- Dense Phase
- Dilute Phase

The dense phase conveyance has been selected for the application. The configuration of a dense phase system will be less expensive in comparison to dilute phase due to significantly smaller size requirements and less conveying gas.

2.2.3 Pressurization

The pressurization method will move coal continuously from atmospheric pressure to a pressure high enough to transport the coal into the high pressure gasifier. The CTQs determined to be applicable for the pressurization methods include the following:

- Pressure Capability
- Solids Fuel Flexibility
- Flow Stability / Metering Capability
- Reliability
- Turn down capability
- Minimize Power Consumption
- CAPEX
- OPEX
- RAM

Key options considered:

- GE Posimetric feeder
- Lockhopper System

GE Posimetric Feeder - The GE proprietary Posimetric Feeder has been selected for the application. The Posimetric Feeder provides a continuous flow of solids by creating a dynamic high pressure coal seal. The pump also provides metering capability where throughput is directly proportional to feeder RPM. The Posimetric Feeder is a very simple device with one moving part providing substantially lower maintenance costs compared to lockhopper systems.

Disadvantages:

- Due to the porosity of the coal plug used as the barrier between high and low pressure, there may be some vent leakage back through the pump.

Lockhopper System – Lockhopper systems consist of at least three vessels aligned vertically and separated by valves. The top vessel is always at the source (atmospheric pressure in this case), the bottom always at the destination (higher than gasifier pressure in this case), and the middle alternates between the source pressure (when filling) and the destination pressure (when discharging). Nitrogen, carbon dioxide or another suitable gas can be used as the pressurizing fluid. Energy and gas may be saved by using staged lockhoppers that allow reuse of some of the pressurized gas before the pressure is fully let down. However, this also results in higher costs.

Disadvantages:

- Solids must be kept fluidized during transport to prevent plugging in the vessels
- Large amounts of pressurizing gas are required for operation
- Dusty gases exiting the lockhopper must be cleaned and recycled, or rejected
- Operation is discontinuous
- Vessels are large and require tall structures

2.2.4 High Pressure Conveyance

The high pressure conveyance system includes the portion of the advanced dry feed system from the discharge of the Posimetric Feeder to the inlet of the gasifier feed injector. The CTQs determined to be applicable to this subsystem include the following:

- Compliance of design with conveyance design map
- Requirements for startup, shutdown and turndown
- Controllability of conveyance system
- Entrainment of coal solids in carrier gas
- Design layout simplicity
- HP conveyance gas properties
- Processed coal properties
- Maintenance

Key options for the HP conveyance system that were considered included:

- Conveyance mode
  - Dilute phase
  - Dense phase
- Carrier gas type
  - Startup (nitrogen)
  - Normal operation (nitrogen or recycle carbon dioxide)
- Entrainment of coal solids in carrier gas
  - Store and meter coal downstream of pumps
  - Manifold to combine metered feed downstream of pumps

Conveyance Mode – Dilute phase pneumatic transport occurs when the solids/gas ratio is such that the velocities are maintained above the saltation velocity, and dense phase pneumatic transport occurs when the solids/gas ratio (SLR) are maintained below the saltation velocity, where the saltation velocity is the minimum velocity for free stream flow (the solids are fully entrained with the gas flow). The key advantages of using dense phase transport are associated with lower carrier gas requirements and velocities, which reduces power requirements and potential for erosion in the conveyance system. However, these advantages were outweighed by the advantages of using dilute phase, specifically, the greater flow uniformity (carrier gas and solids fluxes) and increased wider range of operability with throughput, especially if the SLRs are maintained near the high end of the dilute phase transport range.

Carrier Gas Type – Potential carrier gases considered for the advanced dry feed system included nitrogen and recycle CO2. Recycle CO2 was selected as the preferred choice for normal operation, because it more readily integrates with the CO2 recovery for CO2 capture and sequestration, and because it ensures that the gas turbine has sufficient quantities of diluent nitrogen available. However, nitrogen was selected as the carrier gas during startup because the method adopted for startup of the gasifier used in the advanced dry feed system involves establishing the feed flows before sequentially introducing them into the gasifier. This ensures carrier gas will be available during startup, as well as simplifies the handling and treatment requirements of the carrier gas, limiting the treatment requirements to particulate removal only.

Combination and Entrainment of Coal Solids in Carrier Gas – The pressurized coal from the Posimetric Feeder is entrained in the carrier gas so that the coal can be transported to the feed injector One method of entraining the pressurized solids involves collecting the solids in a high pressure feed vessel, fluidizing the solids using a small stream of carrier gas and then discharging the solids from the feed vessel into the main flow of carrier gas either through a valve or a high pressure rotary feeder. The other method takes advantage of the metering capability of the Posimetric Feeder, entraining the metered coal with carrier gas and producing a single stream of feed. The latter option was selected for simplicity, reliability, operability and CAPEX reasons.

2.2.5 Recycle Solids

The advanced IGCC incorporates recycle solids both to help maximize carbon conversion and minimize the fines content of the slag effluent solids. The key CTQs for this system include:

- Layout
- Flowability of the dry solids
- Feed preparation requirements
- Mechanical design
- Gasifier equivalent feed moisture content
- Controllability of the gasifier (inputs/outputs)
- Inventory
- Fines properties

With GE's full-quench gasifier technology, the unconverted carbon and fine ash are separated from the syngas with water, and for this study, are assumed to be recovered from the gasification unit as a 20 wt% solids/water slurry. The solids can be recycled by at least two different processes: (1) by filtering and drying the recycle solids to the point where they can be fed dry and then combining them with the coal either upstream or downstream of the coal drying and grinding system; or (2) feeding the recycle solids as a separate slurry stream to the gasifier feed injector with or without a pre-concentrating step. Option 2 was selected in this case because it represents a much lower CAPEX and OPEX operation than Option 1. Also, because the water in the recycle slurry serves as a useful a temperature moderator in the gasifier, the slurry option eliminates the unnecessary steps of removing the water from the recycle solids slurry by drying and then adding it back in as a separate moderator stream.

2.2.6 Slag Additive

Because of the low melting temperature of PRB Montana Rosebud coal, a slag additive system has been included. The slag additive mixes with the coal ash to increase its viscosity, and thereby allow operation at higher gasifier temperatures. The CTQs for this system are nearly the same as for the recycle solids system, except that the CTQ on fines properties is replaced by two new CTQs, one for the coal ash properties, and the other for the slag additive properties.

As with the recycle solids, there are two key options for feeding the slag additive to the gasifier: (1) Feed the slag additive with the coal, or (2) feed the additive as a solids slurry in water through a separate passage in the injector. The key concern with feeding the slag additive dry is that differences between the physical properties of the slag additive particles and the coal particles may result in some degree of segregation of the two materials within the feed system. If so, this could result in chronic dosing problems, impacting RAM. Using a separate slurry feed helps ensure that the dosing is consistent. It also provides additional necessary temperature moderator. Consequently, the slurry option was down selected for the advanced dry feed, where the slag additive slurry, at 60 wt% solids, and recycle solids slurry, at 20 wt% solids, are pressurized separately, and then combined into a single feed upstream of the feed injector.

Because of the properties of the slag additive, it's necessary to use a slurry stabilizing agent, and it's preferable not to wet grind the slag additive. Also, in evaluating dry grinding options during a previous study, a conventional dry ball mill was found to be preferred to a stirred ball mill because the conventional ball mill option was lower cost. Thus, the process for making the slag additive slurry requires three separate steps: (1) grinding the slag additive in a conventional dry ball mill, (2) preparation of an aqueous solution containing the slurry stabilizing agent, and (3) completing the process by combining the slag additive with the slurry stabilizing agent solution to produce the slag additive slurry.

2.2.7 Feed Injection

The design of the advanced dry feed system requires the use of an injector that receives, mixes and injects the pneumatically conveyed coal, slurry streams, and oxygen into the gasifier. The feed injector is a proprietary design that includes separate dedicated inlets for the pneumatically conveyed coal, and for the slag additive and recycle solids slurry mixture.

2.3 Sizing, Performance & Cost Evaluation of Equipment for the Application

This section of the report provides the deliverables required under Subtask 4.2. These include process flow sketches, sizing, costing and performance information for the representative advanced dry feed subsystems down selected under Subtask 4.1. The down selection process resulted in two key options that differ only with respect to the drying and grinding subsystems used:

> ***Case 1*** represents the advanced dry feed system where the drying and grinding of the coal is done simultaneously using two impact dryer mills; and
>
> ***Case 2*** represents the advanced dry feed system where the grinding of the coal is done using two cage mills, and the drying of the coal is done in a separate sequential step using a fluidized bed dryer that uses low pressure steam as the drying source.

2.3.1 Methodology

The data for Cases 1 and 2 developed under this subtask were based primarily on prior work related to dry feed by GE, and included: confirmation of CTQs, development and updating of a basis for design and a block flow diagram, updating the list of options, solicitation of quotes, development of process flow sketches, calculation of performance estimates using a combination of hand calculations, Aspen for the dry feed system, GE proprietary software, Pro/II for the rest of the gasification island, and Thermoflow for the power block, development of CAPEX using vendor data, internal GE data and Icarus, and evaluation of availability using Visual SPAR software by Clockwork, a Monte Carlo-based RAM model, that was used along with a combination of industry and in-house mean time between failures (MTBF) and mean time to repair (MTTR) data.

2.3.2 Case 1 – Impact dryer mill – Steam

Process Flow Sketches

The Case 1 advanced dry feed system grinds and dries the coal in two impact dryer mills that use heat from medium and low pressure steam to provide the drying energy. The process configuration for Case 1 is illustrated in three process flow sketches, one of the coal grinding and drying subsystem shown in Figure 3, one of the pressurization and metering subsystem shown in Figure 4, and one of the slag additive and slag recycle solids slurry feed subsystems shown in Figure 5.

Note: The process flow sketches shown in Figure 4 and Figure 5 and equipment lists in Table 3 and Table 4 are common to all of the cases described in this report. So, to avoid unnecessary repetition, the description, process flow sketches and equipment lists for these two the subsystems will be provided with the Case 1 information only.

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 1 coal grinding and drying subsystem is shown in Figure 3. There are two grinding/drying trains included. This description will refer to one train only, except where common equipment is identified.

Maximum 2" top size coal from raw coal receiving and handling is supplied to raw coal feed hopper, 02-T-0001A. From the outlet of the hopper, weigh belt feeder, 02-W-0001A, meters and transfers the coal to screw conveyor, 02-L-0001A, and into impact dryer mill, 02-H-0001A, where the coal is ground by rotating hammers in the bottom portion of the mill.

The drying/carrier gas used in the mill is produced by combining low pressure nitrogen, and air supplied via air filter, 02-X-0006A, and blowers, 02-B-0001A/B (one operating and one spare). The makeup rates for the nitrogen and air are used to control dew point temperatures within the mill, as well as to ensure the oxygen content of the gases within the mill are maintained below combustibility limits.

The makeup air and nitrogen are combined with mill recycle gas from recycle blowers, 02-B-0002A/B, and heated in exchangers, 02-E-00001A and 02-E-0002A, using low pressure and medium pressure steam, respectively. The heated gas is introduced into the mill where it is used to dry and carry the ground coal up through the drying portion of the mill, and then through a built-in classifier just upstream of the mill outlet.

The classifier returns oversize material back to the grinding portion of the mill, while the ground coal and now cooler gas pass out of the classifier and on to cyclones, 02-V-0001A/B[8], and baghouse, 02-X-0002A, to recover the dry ground coal from the gas. Blowers, 02-B-0002A/B, (one operating and one spare) are used to draw the mill gas through the baghouse and recycle it back to the mill. A portion of the gas is vented to allow elimination of the water removed from the coal from the mill. The product coal separated from the gas by the cyclones and the baghouse is collected in the ground coal storage bin, 02-T-0003, which in turn supplies the coal for use by the gasifier as shown in Figure 4.

Figure 3 also shows a portion of the recycle system used for gasifier startup. This includes startup cyclone, 02-V-0002, startup recycle solids hopper, 02-T-0002, and baghouse, 02-X-0004. These are used to establish the startup flow of coal and carrier gas prior to gasifier lightoff.

Pressurization and Feeding Subsystem – The process flow sketch for the pressurization and feeding subsystem (which includes low pressure conveyance, pressurization, metering, and high pressure conveyance) is provided in Figure 4, and is applicable to all of the cases in this study. As shown, this subsystem is comprised of a single train that uses four operating and one spare Posimetric Feeders to pressurize and meter the coal to the gasifier.

The ground coal is supplied from the ground coal storage bin, 02-T-0003, via low pressure dense phase pneumatic transport using nitrogen as the carrier gas. This is done using five dedicated coal feed lines (four operating and one spare), that includes one each of

[8] The mill system was quoted by the vendor assuming a single larger cyclone per train. However, two cyclones are shown here to ensure the cyclones do not exceed shipping limits. The sizing and costing were adjusted accordingly.

metering/pickup devices, 02-X-0007A/B/C/D/E, Posimetric Feeder cyclones, 02-V-0003A/B/C/D/E, Posimetric Feeder feed hoppers, 02-T-0004A/B/C/D/E, and Posimetric Feeders, 02-P-0001A/B/C/D/E. The metering/pickup devices both meter the coal and provide the necessary isolation between the ground coal storage bin and the five coal feed lines. After low pressure conveyance, the coal is separated from the nitrogen using the cyclones, and drops into the feeder hoppers which include live bottoms to facilitate the transfer of coal into the Posimetric Feeders. The overhead from the cyclones are combined and any fines remaining in the low pressure carrier gas are recovered in baghouse, 02-X-0008. The carrier gas is recycled back to the pickup devices to continue delivery of the coal to the Posimetric Feeder hoppers.

The Posimetric Feeders meter and pressurize the coal, which is entrained in recycle CO2 carrier gas at the outlet of the Posimetric Feeders. The coal and carrier gas from the active Posimetric Feeders are combined in special mixing manifold, 02-X-0009, and conveyed to the gasifier feed injector. Prior to startup, high pressure nitrogen is used to establish the startup flow of the coal feed, recirculating the coal back through the startup cyclone shown in Figure 3. The nitrogen is heated using HP N2 startup heater, 02-E-0004, prior to entraining the coal solids exiting the Posimetric Feeders.

High pressure buffer nitrogen is used at the outlet of the Posimetric Feeders to create an inert gas barrier between the pump discharge and the upstream system. The buffer gas is heated using HP nitrogen heater, 02-E-0003.

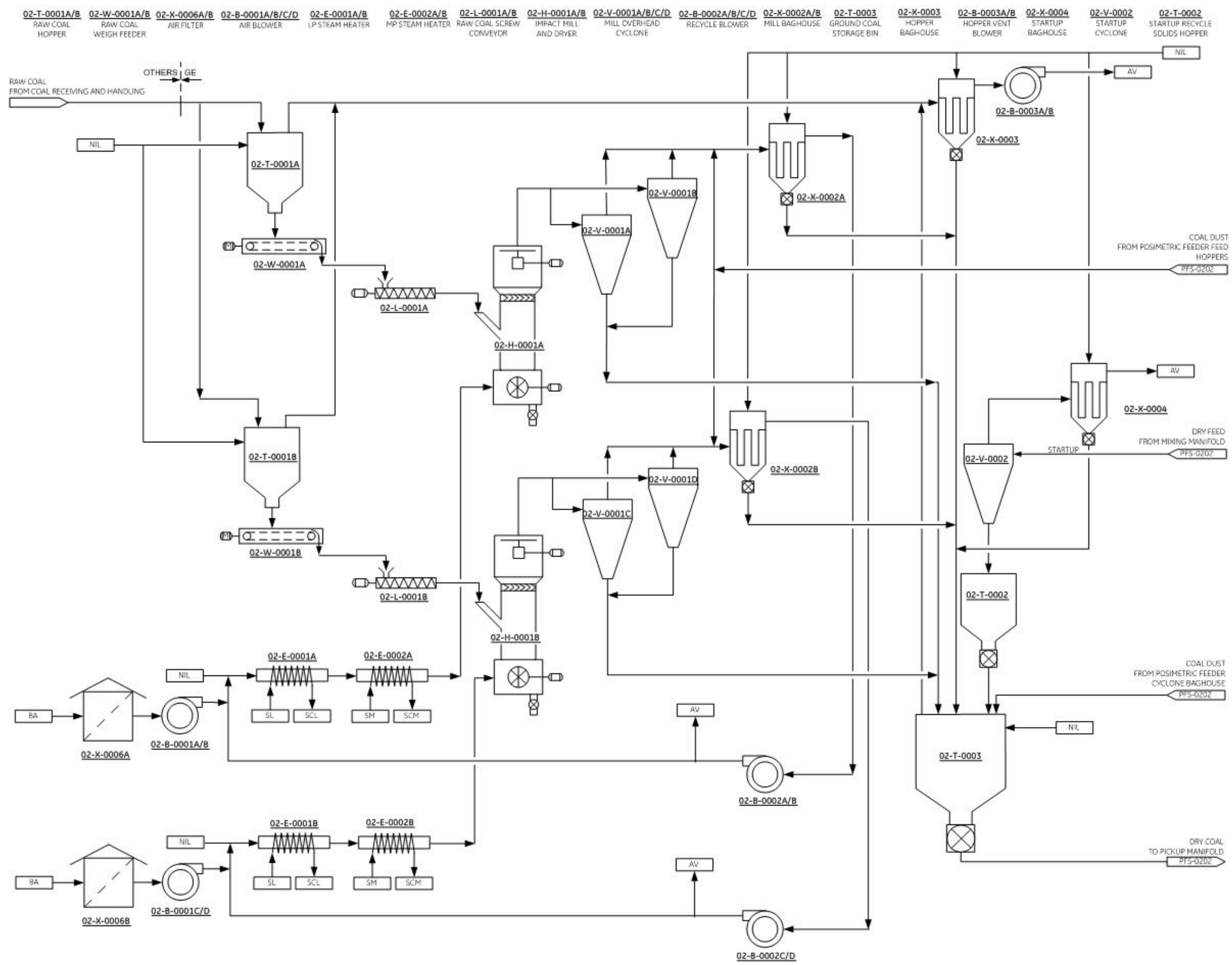


Figure 3. Case 1 Process Flow Sketch – Coal Grinding and Drying Subsystem – Impact Dryer Mill - Steam

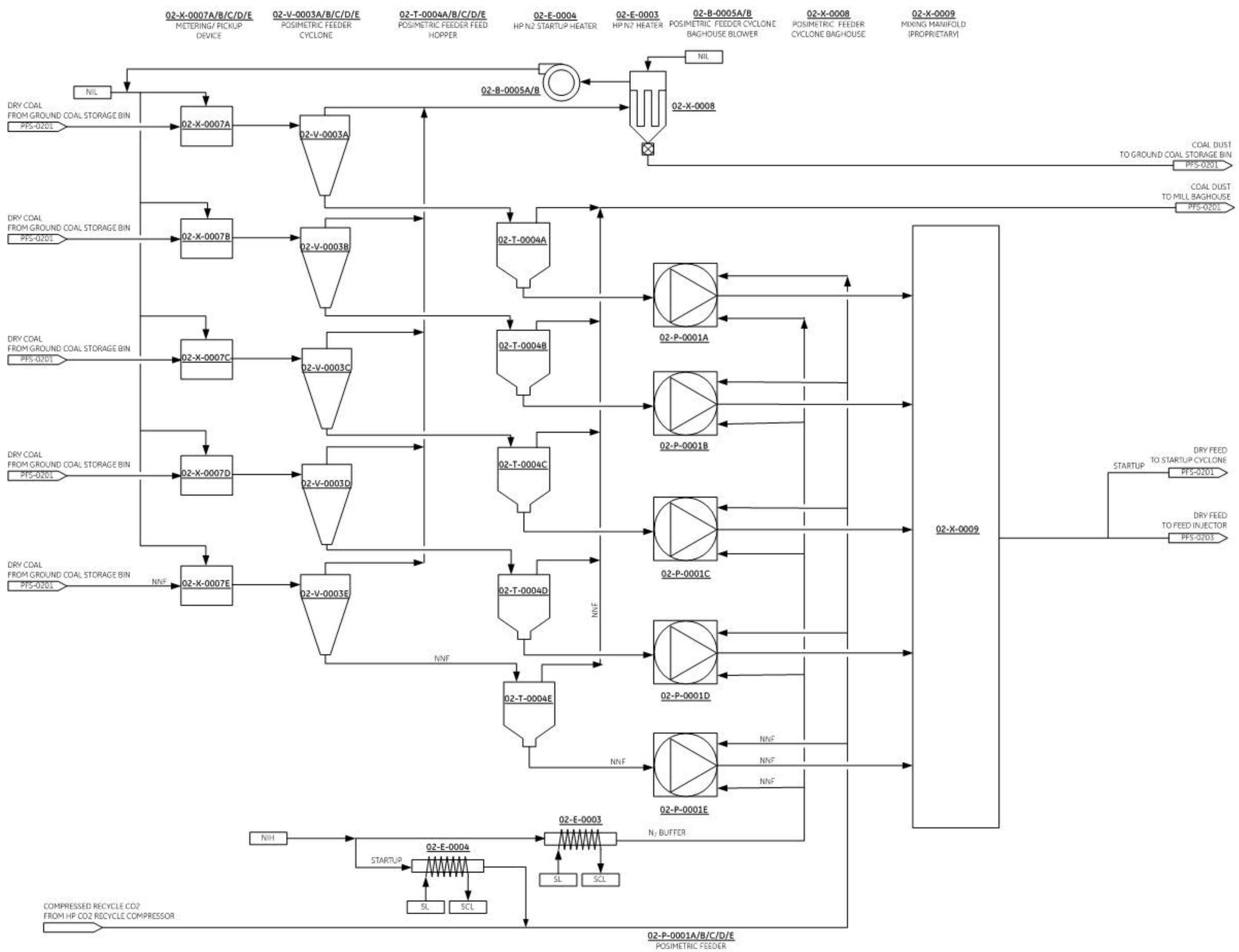


Figure 4. All Cases Process Flow Sketch – Low Pressure Conveyance, Pressurization and Metering Subsystems

Slag Additive and Slag Recycle Solids Slurry Feed Subsystem – The process flow sketch for the slag additive and slag recycle solids slurry subsystem is provided in Figure 5, and is applicable to all of the cases in this study. This subsystem is used to prepare and feed both slag additive and recycle solids slurries to the gasifier.

The slag additive slurry is comprised of slag additive, water and a slurry stabilizing (or, simply, slurrying) agent. Both the slag additive and slurrying agent are received as dry materials. The slurrying agent is transferred from on-site storage to slurrying agent feed bin, 02-T-0006, from where it is metered using weigh feeder, 02-W-0006, into slurrying agent mixing tank, 02-T-0008, and then mixed with water to produce the slurry agent solution using agitator, 02-A-0002. The slag additive is dry ground in slag additive mill, 02-H-0002. From the mill, the ground slag additive is blended with slurrying agent solution transferred from the slurrying agent mix tank by pump, 02-P-0004A/B, (one operating and one spare) into slag additive slurry mix tank, 02-T-0009. The slurry in the slag additive mix tank is blended using agitator, 02-A-0003. The slurry is then transferred to the slag additive run tank using pump, 02-P-0005 A/B (one operating and one spare). Agitator, 02-A-0004 is used to keep the slurry mixed and in suspension.

Recycle fines from the black water settler are received and stored in recycle fines tank, 02-T-0007, where the fines are maintained as a homogenous slurry using agitator, 02-A-0001. The recycle fines slurry and slag additive slurry are fed to the gasifier as a single stream to the gasifier feed injector. This is done by combining the two streams after they have been metered and pressurized using recycle fines charge pump, 02-P-0003A/B (one operating and one spare) and slag additive charge pump, 02-P-0006A/B (one operating and one spare), respectively.

Sized Equipment List

A sized equipment list for the Case 1 coal preparation and feed system from Figure 3, Figure 4, and Figure 5 are provided in Table 2, Table 3 and Table 4, respectively. As noted earlier, the equipment from Figure 4 and Figure 5 are common to all cases, so, as with Figure 4 and Figure 5, Table 3 and Table 4 will not be repeated in subsequent case descriptions.

Auxiliaries

A list of the auxiliaries required to operate the Case 1 coal preparation and feed system is provided in Table 5.

Low and medium pressure steam are required to provide the heating and drying energy to the mill/dryer. Low purity nitrogen is used to ensure the oxygen concentration in the drying gas is maintained below combustibility limits.

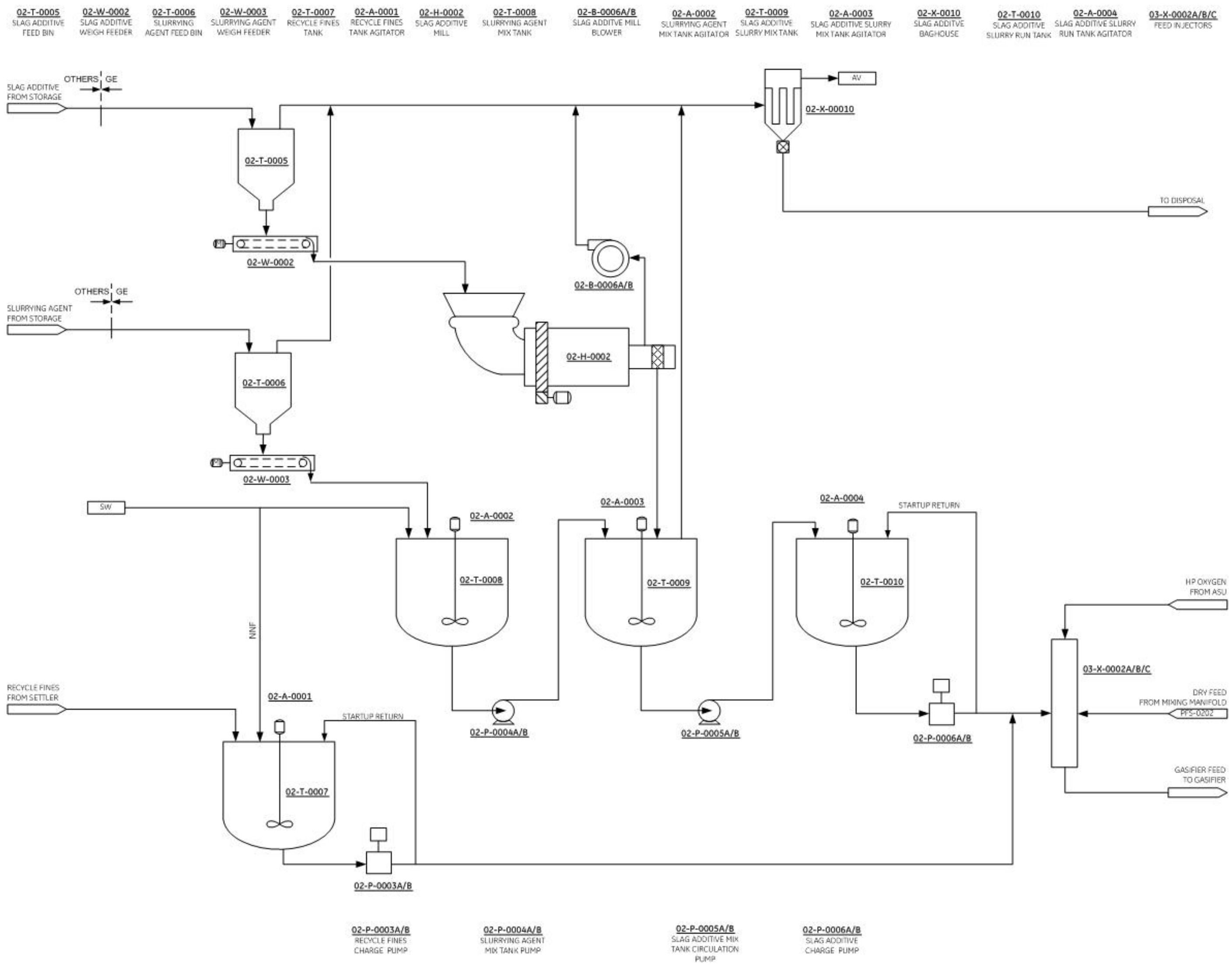


Figure 5. All Process Flow Sketch – Slag Additive and Recycle Solids Slurry Feed Subsystems

Table 2. Case 1 Equipment List – Impact Dryer Mill - Steam

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001 A/B/C/D	Air Blower	Fan	22,000 scfm	2 op / 2 sp
02-B-0002 A/B/C/D	Recycle Blower	Fan	110,000 scfm	2 op / 2 sp
02-B-0003 A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-E-0001 A/B	LP Steam Heater	Coil	40 MM Btu/h;1 26 mscfm	2 op / 0 sp
02-E-0002 A/B	MP Steam Heater	Coil	40 MM Btu/h; 126 mscfm	2 op / 0 sp
02-H-0001 A/B	Grinding Impact Dryer Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001 A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001 A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0001 A/B/C/D	Mill Overhead Cyclone	Vert. Separator	60000 acfm;87400 lb/h	4 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001 A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0002 A/B	Mill Baghouse	Filter	111,000 acfm, 4371 lb/h	2 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0006 A/B	Air filters	Filter	22,000 cfm	2 op / 0 sp

Table 3. All Cases Equipment List – Pressurization and Feeding

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0005A/B	PF Cyclone Baghouse Blower	Filter	1500 ccfm	1 op / 1 sp
02-P-0001A/B/C/D/E	Posimetric Feeder (Dry Feed Pump)	Dry feed	41 tph	4 op / 1 sp
02-T-0004	Posimetric Feeder Hopper	Vertical Hopper	7.5'IDx15'TTL	4 op / 1 sp
02-V-0003A/B/C/D/E	Posimetric Feeder Cyclone	Separator	70,000lb/h; 460 cfm	4 op/ 1 sp
02-X-0007A/B/C/D/E	Metering/PU Device	Metering	11,500 cfm	1 op / 0 sp
02-X-0008	Posimetric Feeder Cyclone Baghouse	Filter	11,500 cfm, 15,280 lb/h	1 op / 0 sp
02-X-0009	Mixing Manifold	Proprietary	166.3 tph	1 op / 0 sp

Table 4. All Cases Equipment List – Slag Additive and Recycle Fines

Item No.	Description	Type	Design Condition	Operating/Spare
02-A-0001	Recycle Fines Tank Agitator	Agitator	36,500 gal; 10 Hp	1 op / 0 sp
02-A-0002	Slurry Agent Mix Tank Agitator	Agitator	2500 gal; 1 Hp	1 op / 0 sp
02-A-0003	Slag Additive Mix Tank Agitator	Agitator	10,000 gal; 8 Hp	1 op / 0 sp
02-A-0004	Slag Additive Slurry Run Tank Agitator	Agitator	20,000 gal; 15 Hp	1 op / 0 sp
02-B-0006A/B	Slag Additive Mill Blower	Fan	11,500 acfm	1 op / 1 sp
02-H-0002	Slag Additive Mill	Ball mill	15,300 lb/h	1 op / 0 sp
02-P-0003	Recycle Fines Charge Pump	Recip	100 gpm, 120 Hp	1 op / 0 sp
02-P-0004A/B	Slurry Agent Mix Tank Pump	Centrifugal	40 gpm, 8Hp	1 op / 1 sp
02-P-0005A/B	Slag Additive Mix Tank Circulation Pump	Centrifugal	40 gpm, 8Hp	1 op / 1 sp
02-P-0006	Slag Additive Charge Pump	Recip	40 gpm, 40Hp	1 op / 0 sp
02-T-0005	Slag Additive Feed Bin	Vertical Hopper	15 tons	1 op / 0 sp
02-T-0006	Slurrying Agent Feed Bin	Vertical Hopper	150 lb	1 op / 0 sp
02-T-0007	Recycle Fines Tank	Semi-elliptical	26,000 gal	1 op / 0 sp
02-T-0008	Slurrying Agent Mix Tank	Semi-elliptical	2,000 gal	1 op / 0 sp
02-T-0009	Slag Additive Slurry Mix Tank	Semi-elliptical	8,000 gal	1 op / 0 sp
02-T-0010	Slag Additive Slurry Run Tank	Semi-elliptical	14,000 gal	1 op / 0 sp
02-W-0002	Slag Additive Weigh Feeder	Conveyor	20,000 lb/h	1 op / 0 sp
02-W-0003	Slurrying Agent Weigh Feeder	Conveyor	200 lb/h	1 op / 0 sp
02-X-0010	Slag Additive Bag House	Filter	11,500 cfm	1 op / 0 sp

Table 5. Case 1 Auxiliaries – Impact Dryer Mill - Steam

Utility Stream	Value
MP steam	35,700 lb/hr
LP steam	45,700 lb/hr
Mill nitrogen	96,000 lb/hr

Case Summary

Key advantages and drawbacks of using the Case 1 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- No impact on CO2 capture level, as no additional fuel is consumed for drying
- Uses readily available thermal energy generated within the plant
- Use of nitrogen/air mixture as mill makeup gas facilitates control of both the oxygen content and dew point of the mill gas
- Cost of nitrogen minimized by using ASU low purity nitrogen stream
- Short residence time increases responsiveness to controls
- High steam-side heat transfer coefficients in the heat exchangers

Drawbacks

- High required drying gas temperatures necessitate use of both MP and LP steam
- Requires steam and nitrogen to be available to operate the mill/dryer
- Approach of temperature-enthalpy curve between the heat exchangers and the steam is less favorable than for boiler feed water (BFW)

2.3.3 Case 2 – Cage Mill/Fluidized Bed Dryer – Steam

The Case 2 advanced dry feed system grinds the coal using two cage mills, and then dries the coal in a separate step using a single fluidized bed dryer that employs low pressure steam as the heating medium. And though the coal grinding and drying subsystem portion of the coal preparation and feed system is different, the balance of the coal preparation and feed system (Figure 4 and Figure 5) is identical to that for Case 1.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the coal grinding and drying subsystem is provided in Figure 6. As with Case 1, maximum 2" top size coal from raw coal receiving and handling is supplied to raw coal feed hopper, 02-T-0001A. From the outlet of the hopper, weigh belt feeder, 02-W-0001A, meters and transfers the coal to cage mill, 02-H-0001A, where the coal is ground by impact with the rotating cages inside the mill. The ground coal is discharged from the mill onto vibrating screen, 02-X-0005A. The ground coal passes through the screen and is fed by raw coal screw conveyor, 02-L-0001A, to fluidized bed dryer, 02-X-0001.

The ground coal is fluidized in the dryer using recycle steam that is heated in fluidizing gas heater, 02-E-0001, after being extracted from the dryer bed and passing through baghouse, 02-X-0002, using recycle blower, 02-B-0001A/B. Though the fluidizing gas provides a portion of the heat needed by the dryer, it's done primarily to facility operation of the fluidized bed. The majority of the heat required for heating and drying the coal is supplied by indirect heat exchange with low pressure steam through an in-bed heat exchanger.

The dried coal exiting the dryer is stripped of the surrounding water vapor using low pressure nitrogen heated in 02-E-0002. It is then conveyed using dry coal screw conveyor, 02-L-0002, to the ground coal storage bin, 02-T-0003, which in turn supplies the coal for use by the gasifier as shown in Figure 4.

Sized Equipment List

The sized equipment list for the Case 2 coal preparation and feed system is provided in Table 6. It includes the equipment from Figure 6, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of the auxiliaries required to operate the Case 2 coal preparation and feed system is provided in Table 7.

Although Case 2 is estimated to use more low pressure steam than Case 1, it uses less total steam than Case 1, and it does not require any medium pressure steam because of the lower drying temperatures used in the fluidized bed. It also does not require nitrogen for inerting, and is estimated to use less power than Case 1.

Case Summary

Key advantages and drawbacks of using the Case 2 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- No impact on CO2 capture level, as no fuel is consumed for drying
- Uses readily available thermal energy generated within the plant
- Able to dry using low pressure steam only
- Inerting is provided by steam generated within the dryer
- Capacitance of the system helps ensure stable operations
- High steam-side heat transfer coefficients in the heat exchangers
- Approach of temperature-enthalpy curve between the steam and in-bed heater is more favorable than for BFW

Drawbacks

- Requires steam be available to operate the dryer
- Need to strip water vapor from coal upon exiting the dryer or maintain the coal under heated conditions to avoid condensation of water on the dryer product.

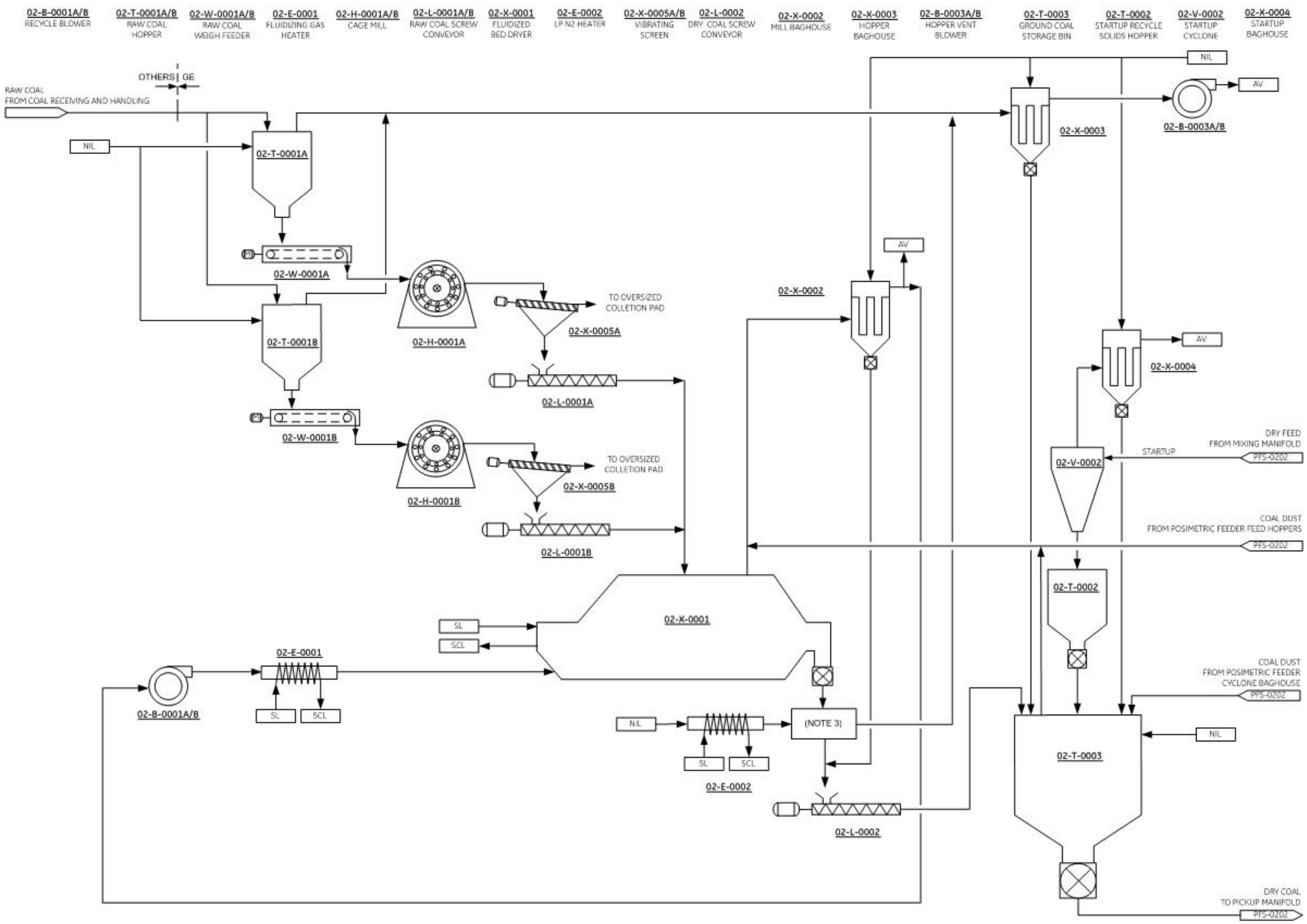


Figure 6. Case 2 Process Flow Sketch – Coal Grinding and Drying Subsystem – Cage Mill/Fluidized Bed Dryer - Steam

Table 6. Case 2 Equipment List – Cage Mill/Fluidized Bed Dryer - Steam

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001A/B	Recycle Blower	Fan	61,000 scfm	1 op / 1 sp
02-B-0003A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-E-0001	LP Steam Heater	Coil	4.0 MM Btu/h; 61 mscfm	2 op / 0 sp
02-E-0002	LP Nitrogen Heater	Coil	1.5 MMBtu/h, 1700 lb/h	1 op / 0 sp
02-H-0001A/B	Grinding (Cage) Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-L-0002A/B	Dry Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0001	Fluidized Bed Dryer	Steam-Gas	75,000 acfm; 188 tph Coal	1 op / 0 sp
02-X-0002	Mill Baghouse	Filter	111,000 acfm; 4371 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0005A/B	Vibrating Screens	Classifier	200,000 lb/h	2 op / 0 sp

Table 7. Case 2 Auxiliaries – Cage Mill/Fluidized Bed - Steam

Utility Stream	Value
LP steam	62,000 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	-15%

2.3.4 Case 1 and Case 2 Efficiency Deltas

Based on the configurations assumed for Cases 1 (impact dryer mill – steam) and 2 (cage mill/fluidized bed dryer – steam), the nominal plant heat rate is expected to be approximately 1.0% less for Case 2 than for Case 1. The difference appears to be largely driven by the need to use both low and medium pressure steam in the Case 1 system, compared with only low pressure steam in the Case 2 system.

2.3.5 Case 1 and Case 2 CAPEX Deltas

In contrast to the efficiency deltas, the relative CAPEX for the coal preparation and feeding system for Case 1 came out to be about 2.4% lower than for Case 2. Given the relative uncertainty in the CAPEX values, however, this difference is too small to be considered significant, especially given the differences in the two milling and drying systems.

2.3.6 Availability

Availability calculations were completed for Cases 1 and 2 configured as shown in Figure 3, Figure 4, Figure 5, and Figure 6, using a combination of Visual SPAR software by Clockwork, which employs a Monte Carlo-based RAM model, and industry and in-house MTBF and MTTR data. Based on the results of those calculations, the RAM was found to be equivalent for the two cases, with both able to achieve the target IGCC availability of 85%.

2.3.7 Conclusions

The Case 1 and 2 options both represent viable equivalent options for integration with the Advanced IGCC System. Though Case 2 offers a potential efficiency benefit over Case 1, the two cases are reasonably balanced when it comes to meeting CTQs, and essentially indistinguishable from CAPEX and RAM perspectives. Consequently, both base technologies were recommended for further consideration during Subtask 4.3 of this project, where the effort was focused on understanding how differences in the potential heat sources might affect the ranking.

3. Trade-off Study to Develop Optimized Dry Feed System

Based on the results of the comparison between Cases 1 and 2 under Subtask 4.2 of this study, both cases were carried forward for further evaluation under Subtask 4.3, where the intent was to determine the relative impact of using different heat sources, as shown in Table 8.

Table 8. Cases for Study

Case	Description
1	Impact Dryer Mill – MP and LP Steam (Steam)
2	Cage Mill/Fluidized Bed Dryer – LP Steam (Steam)
3	Impact Dryer Mill – Natural Gas (NG)
4	Impact Dryer Mill – Syngas (SG)
5	Impact Dryer Mill – HP and MP Boiler Feed Water (BFW)
6	Impact Dryer Mill – Heated HRSG Flue Gas (HRSG)
7	Cage Mill/Fluidized Bed Dryer – HP and MP Boiler Feed Water (BFW)
8	Cage Mill/Fluidized Bed Dryer – Vapor Recompression (VRC)

The following sections of this report describe the additional cases and associated results.

3.1 Methodology

The methodology, procedures and software used for this portion of the study were similar to that described under 4.2.2, except that this portion of the study relied on the earlier developed basis for design, coal preparation and feed system block flow diagram, and the Case 1 and 2 results. Consequently, the work during this portion of the study involved identifying and down selecting the cases to be evaluated, development of process flow sketches, calculation of performance estimates, development of CAPEX, and evaluation of availability.

3.2 Case 3 – Impact Dryer Mill – Natural Gas

Case 3 is similar to Case 1 and employs two impact dryer mills to grind and dry the coal. However, for Case 3, natural gas is used to provide the required heat for drying.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 3 coal grinding and drying subsystem is shown in Figure 7. It is largely the same the one for Case 1, except as follows:

(1) The hot gas that's combined with the mill recycle gas to dry and carry the coal through the mill is produced by combusting natural gas in combustor, 02-E-0001A, with a mixture of air supplied via air filter, 02-X-0006A, and a portion of the mill recycle gas from mill

recycle blowers, 02-B-0002A/B. The latter is combined with the air in order to keep the oxygen content of the mill gas below combustibility limits.

(2) Rather than sending all of the overhead gas from the mill cyclones, 02-V-0001A/B to the mill baghouse, 02-B-0002A, only the portion of the mill gas that's vented is sent through the baghouse. This reduces CAPEX, and can be done because of the Case 3 configuration is more tolerant of fines in the mill gas than the heat exchangers in Case 1.

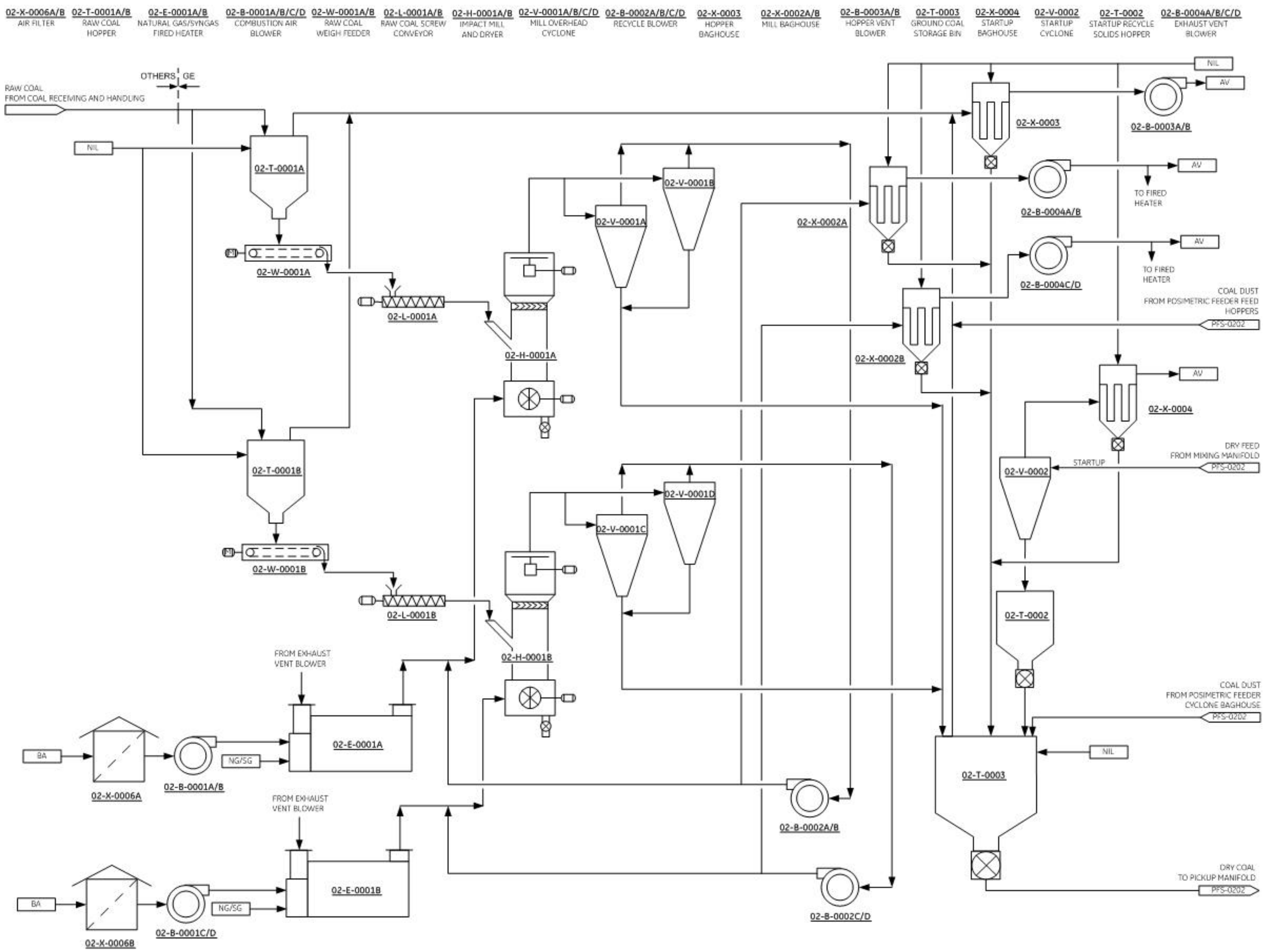


Figure 7. Cases 3 & 4 Process Flow Sketch – Coal Grinding and Drying Subsystem – Impact Dryer Mill – NG/Syngas

Sized Equipment List

The sized equipment list for the Case 2 coal preparation and feed system is provided in Table 9. It includes the equipment from Figure 7, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of the auxiliaries required to operate the Case 3 coal preparation and feed system is provided in Table 10.

The natural gas used for Case 3 replaces the medium and low pressure steam used for Case 1, and the consumption of oxygen in the make-up air to the mill and associated combustion products, combined with rebalancing the mill recycle gas, eliminate the need for inerting nitrogen. Also, the electrical power requirements were estimated to be essentially the same as for Case 1.

Case Summary

Key advantages and drawbacks of using the Case 3 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- Relatively low fuel requirement allows CO2 capture level to be met via minor modification of the AGR operation
- Nitrogen injection not required for inerting; the combination of oxygen consumption from the combustion of the natural gas, the combustion products themselves, and mill gas recycle are sufficient to maintain oxygen below combustibility limits
- Can be started up and operated independent of other plant operations
- Mill overhead baghouses are smaller compared to equivalent steam and BFW cases
- Short residence time increases responsiveness to controls

Drawbacks

- Dew point elevation due to using combustion products and mill gas recycle to the combustor for inerting
- High levels of mill gas internal recycle to the combustor are required for oxygen control

3.3 Case 4 – Impact Dryer Mill – Syngas

Case 4 is similar to Case 3, except that syngas is used as the fuel for coal drying instead of natural gas.

Process Flow

Coal Grinding and Drying Subsystem – Case 4 shares the same process flow sketch as Case 3 (Figure 7), except that syngas is used instead of natural gas as the fuel for coal drying,

Table 9. Cases 3 & 4 Equipment List – Impact Dryer Mill – NG/Syngas

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001 A/B/C/D	Air Blower	Fan	22,000 scfm	2 op / 2 sp
02-B-0002 A/B/C/D	Recycle Blower	Fan	110,000 scfm	2 op / 2 sp
02-B-0003 A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-H-0001 A/B	Grinding Impact Drying Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001 A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001 A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0001 A/B/C/D	Mill Overhead Cyclone	Vertical Separator	60,000 acfm; 87,400 lb/h	4 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001 A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0002 A/B	Mill Baghouse	Filter	26200 acfm; 4369 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0006 A/B	Air Filters	Filter	22,000 cfm	2 op / 0 sp

Table 10. Case 3 Auxiliaries – Impact Dryer Mill – NG

Utility Stream	Value
Natural gas	3090 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	~ Same

Sized Equipment List

The sized equipment list for the Case 4 coal preparation and feed system is the same as for Case 3, and is provided in Table 9. It includes the equipment from Figure 7, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of auxiliaries required to operate the Case 4 coal preparation and feed system is provided in Table 11.

Table 11. Case 4 Auxiliaries – Impact Dryer Mill – Syngas

Utility Stream	Value
Syngas	3740 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	~ Same

The syngas used for Case 4 replaces the medium and low pressure steam used for Case 1, and the consumption of oxygen in the make-up air to the mill and associated combustion products, combined with rebalancing the mill recycle gas, eliminate the need for inerting nitrogen. Also, the electrical power requirements were estimated to be essentially the same as for Case 1.

Case Summary

Key advantages and drawbacks of using the Case 4 technology for the Advanced IGCC plant include:

Advantages

- Technology is similar to equivalent natural gas option
- No impact on CO2 capture level (capture occurs pre-combustion)
- Nitrogen injection not required for inerting; the combination of oxygen consumption from the combustion of the natural gas, the combustion products themselves are sufficient to maintain oxygen below combustibility limits (less internal recycle of mill gas than for natural gas)
- Mill overhead baghouses are smaller compared to equivalent steam and BFW cases.
- Short residence time increases responsiveness to controls

Drawbacks

- Requires gasification island be in operation or the mill/dryer be designed for operation on both syngas and a backup fuel
- May require development of burners and safety measures specific to syngas operation
- CAPEX associated with designing and building the gasification island so that it can generate the additional required syngas could more than overwhelm any potential benefits
- Dew point elevation due to using combustion products from high hydrogen fuel gas for inerting
- Dual fuel injector development may be required (syngas and startup/backup fuel)

3.4 Case 5 – Impact Dryer Mill – Boiler Feed Water

Case 5 is similar to Case 1, except that it uses high pressure and medium pressure boiler feed water instead of medium pressure and low pressure steam for heating.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 5 coal grinding and drying subsystem is provided in Figure 8, and is similar to that for Case 1 (Figure 3), except that medium pressure boiler feed water and high pressure boiler feed water are used in exchangers 02-E-0001A and 02-E-0002A, respectively, for heating the nitrogen-air makeup to the mill/dryer instead of low pressure and medium pressure steam.

Sized Equipment List

The sized equipment list for the Case 5 coal preparation and feed system is provided in Table 12. It includes the equipment from Figure 8, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of auxiliaries required to operate the Case 5 coal preparation and feed system is provided in Table 13.

High pressure and medium pressure boiler feed water were used to replace the medium and low pressure steam used in Case 1. Nitrogen and power consumption remained the same.

Case Summary

Key advantages and drawbacks of using the Case 5 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- No impact on CO_2 capture level, as no fuel is consumed for drying
- Uses readily available thermal energy generated within the plant
- Lower thermal value of BFW, and closer approach of temperature-enthalpy curves of mill gas with BFW enhances efficiency compared to steam
- Cost of nitrogen minimized by using ASU low purity nitrogen stream
- Short residence time increases responsiveness to controls
- Short residence time minimizes potential for devolatilization

Drawbacks

- Higher drying gas temperatures requires use of HP boiler feed water to reach required operating temperatures for drying
- Requires steam and nitrogen to be available to operate the mill/dryer
- To minimize exchanger fouling, mill overhead baghouses are much larger compared to the equivalent natural gas and syngas cases.
- Heat transfer coefficient on the BFW side of exchangers is lower than for steam

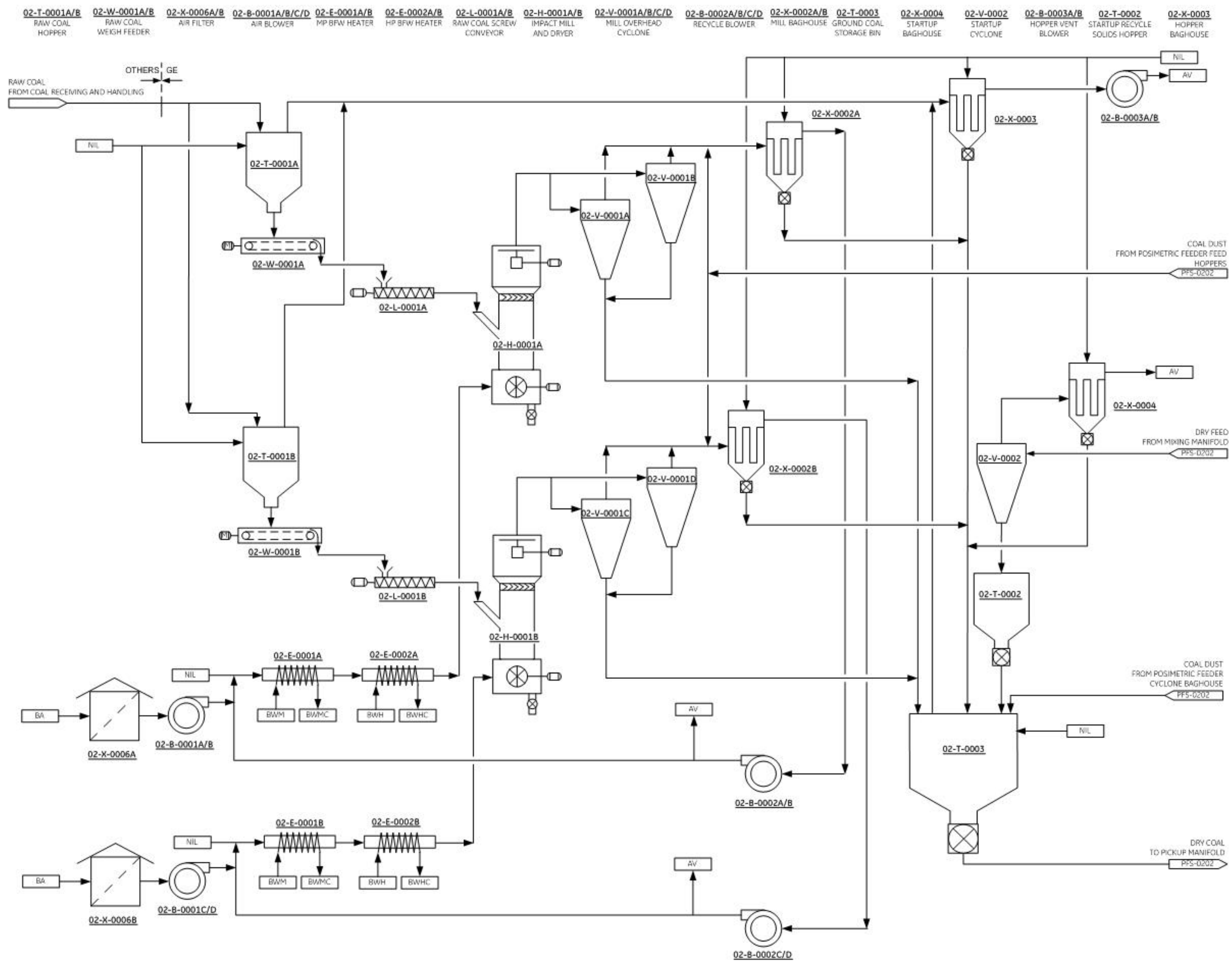


Figure 8. Case 5 Process Flow Sketch – Coal Grinding and Drying Subsystem – Impact Dryer Mill – BFW

Table 12. Case 5 Equipment List – Impact Dryer Mill – BFW

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001 A/B/C/D	Air Blower	Fan	22,000 scfm	2 op / 2 sp
02-B-0002 A/B/C/D	Recycle Blower	Fan	110,000 scfm	2 op / 2 sp
02-B-0003 A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-E-0001 A/B	MP Heater	Coil	40 MM Btu/h; 126000 acfm	2 op / 0 sp
02-E-0002 A/B	HP BFW Heater	Coil	40 MM Btu/h; 126000 acfm	2 op / 0 sp
02-H-0001 A/B	Grinding Impact Dryer Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001 A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001 A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0001 A/B/C/D	Mill Overhead Cyclone	Vertical Separator	60000 acfm; 87400 lb/h	4 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001 A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0002	Mill Baghouse	Filter	111000 acfm; 4371 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0006 A/B	Air Filters	Filter	22,000 cfm	2 op / 0 sp

Table 13. Case 5 Auxiliaries – Impact Dryer Mill – BFW

Utility Stream	Value
HP boiler feed water	145,000 lb/hr
MP boiler feed water	360,000 lb/hr
Mill nitrogen	96,000 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	~Same

3.5 Case 6 – Impact Dryer Mill – Heated HRSG Flue Gas

Similar to Case 1, Case 6 employs two impact dryer mills to grind and dry the coal. However, for Case 6, flue gas from the HRSG, heated with medium pressure steam and used to dry and carry the coal through the mills.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 6 coal grinding and drying subsystem is provided in Figure 9, and is similar to that for Case 1 (Figure 3), except that the mill gas make up source has been altered to be HRSG flue gas supplied by blower, 02-B-0001A/B, and is used on a once through basis only. Further, after removal of the coal solids in cyclones, 02-V-0001A/B, and baghouse, 02-X-0002A, is vented through flue gas stack, 02-X-0011.

Sized Equipment List

The sized equipment list for the Case 6 coal preparation and feed system is provided in Table 14. It includes the equipment from Figure 9, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of auxiliaries required to operate the Case 6 coal preparation and feed system is provided in Table 15.

Case 6 has a lower steam requirement, including no need for low pressure steam, because of the elevated temperature of the HRSG flue gas. Electrical power requirements increased due to the need to transport the HRSG flue gas to the mill. The actual amount will depend at least in part on the proximity of the HRSG stack to the mill.

Case Summary

Key advantages and drawbacks of using the Case 6 technology for the Advanced IGCC plant include:

Advantages

- Uses combined heat available in HRSG flue gas and thermal energy in the form of steam to provide required heat
- No impact on CO2 capture level during normal operation, as no additional fuel is consumed for drying
- Flue gas is anticipated to be sufficiently low in oxygen content to avoid combustibility problem with the coal
- No mill gas recycle[9]
- Short residence time increases responsiveness to controls

Drawbacks

- Requires gas turbine to be operating in order to run the mill, although this should not be a problem, as the combustion turbine is always started before the gasifier
- Additional power and ducting is required to transport the flue gas from the HRSG
- Stack is assumed necessary for discharge of HRSG flue gas post drying – this would be in lieu of the normal gas vent for the impact drying mill
- Composition and temperature of flue gas may vary with plant operating conditions

[9] Mill gas recycle may be required if oxygen content is too high. If dew point becomes an issue, then nitrogen addition may be an effective alternative.

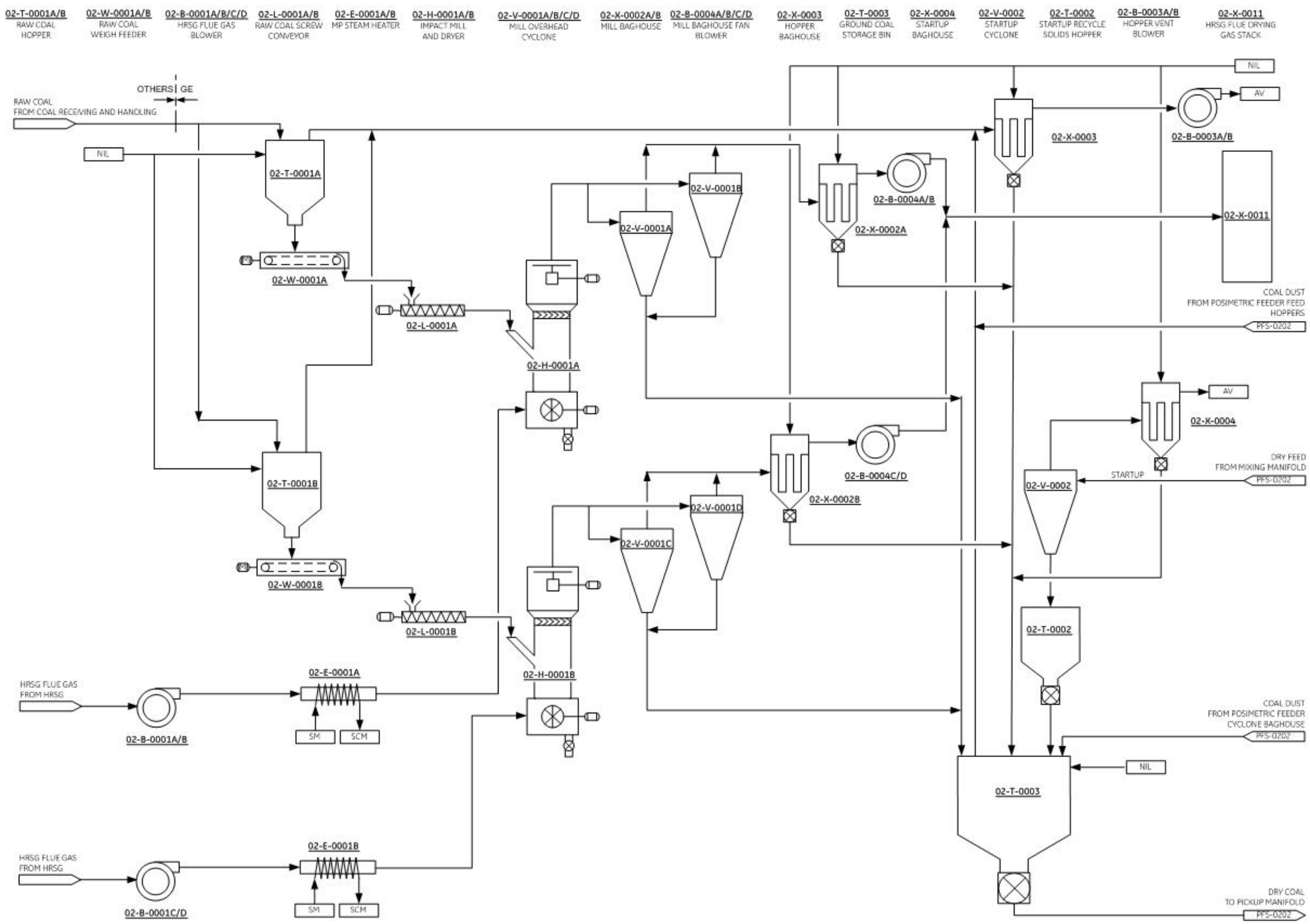


Figure 9. Case 6 Process Flow Sketch – Coal Grinding and Drying Subsystem – Impact Dryer Mill – HRSG

Table 14. Case 6 Equipment List – Impact Dryer Mill – HRSG

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001 A/B/C/D	HRSG Flue Gas Blower	Fan	22,000 scfm	2 op / 2 sp
02-B-0002 A/B/C/D	Recycle Blower	Fan	110,000 scfm	2 op / 2 sp
02-B-0003 A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-E-0001 A/B	MP Steam Heater	Coil	40 MM Btu/h; 126000 acfm	1 op / 0 sp
02-H-0001 A/B	Grinding Impact Drying Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001 A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001 A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0001 A/B/C/D	Mill Overhead Cyclone	Vert. Separator	60000 acfm;87400 lb/h	4 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001 A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0002	Mill Baghouse	Filter	111,000 acfm; 74,300 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp

Table 15. Case 6 Auxiliaries – Impact Dryer Mill – HRSG

Utility Stream	Rate
MP steam	72,000 lb/hr
HRSG flue gas	660,000 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	10%

3.6 Case 7 – Cage Mill/Fluidized Bed Dryer – Boiler Feed Water

Similar to Case 2, Case 7 employs two cage mills and one fluidized bed dryer to grind and dry the coal. However, for Case 7, high pressure and medium pressure boiler feed water are used to provide the required energy to heat and dry the coal.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 7 coal grinding and drying subsystem is provided in Figure 10, and is similar to that for Case 2 (Figure 6), except that blended medium pressure boiler feed water and high pressure boiler feed water are used to provide the required heat in fluidizing gas heater, 02-E-0001, and the fluidized bed dryer, 02-X-0001, instead of low pressure steam. Blended boiler feed water was used to ensure that temperature of the heat transfer tubing would be below that which would cause devolatilization of the coal, while allowing the use of the same heat exchange surface Case 2.

Sized Equipment List

The sized equipment list for the Case 7 coal preparation and feed system is provided in Table 16. It includes the equipment from Figure 10, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of auxiliaries required to operate the Case 7 coal preparation and feed system is provided in Table 17.

Case 7 replaces the medium and low pressure steam of Case 2 with high pressure and medium pressure boiler feed water. The boiler feed water rates, however are substantially higher than those for Case 5 (impact dryer mill – BFW). The higher rates are primarily due to an effort to keep the size of the fluidized bed dryer the same size as for Case 2, while also trying to avoid high heat transfer fluid temperatures in the fluidized bed dryer.

Case Summary

Key advantages and drawbacks of using the Case 7 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- No impact on CO2 capture level, as no fuel is consumed for drying
- Uses readily available thermal energy generated within the plant
- Inerting is provided by steam generated within the dryer
- Capacitance of the system helps ensure stable operations

Drawbacks

- Requires boiler feed water be available to operate the dryer
- Approach of temperature-enthalpy curve between the in-bed heater and boiler feed water is less favorable than for steam in the in-bed heater
- Lower BFW-side heat transfer coefficient
- Need to strip water vapor from coal upon exiting the dryer or maintain the coal under heated conditions to avoid condensation of water on the dryer product

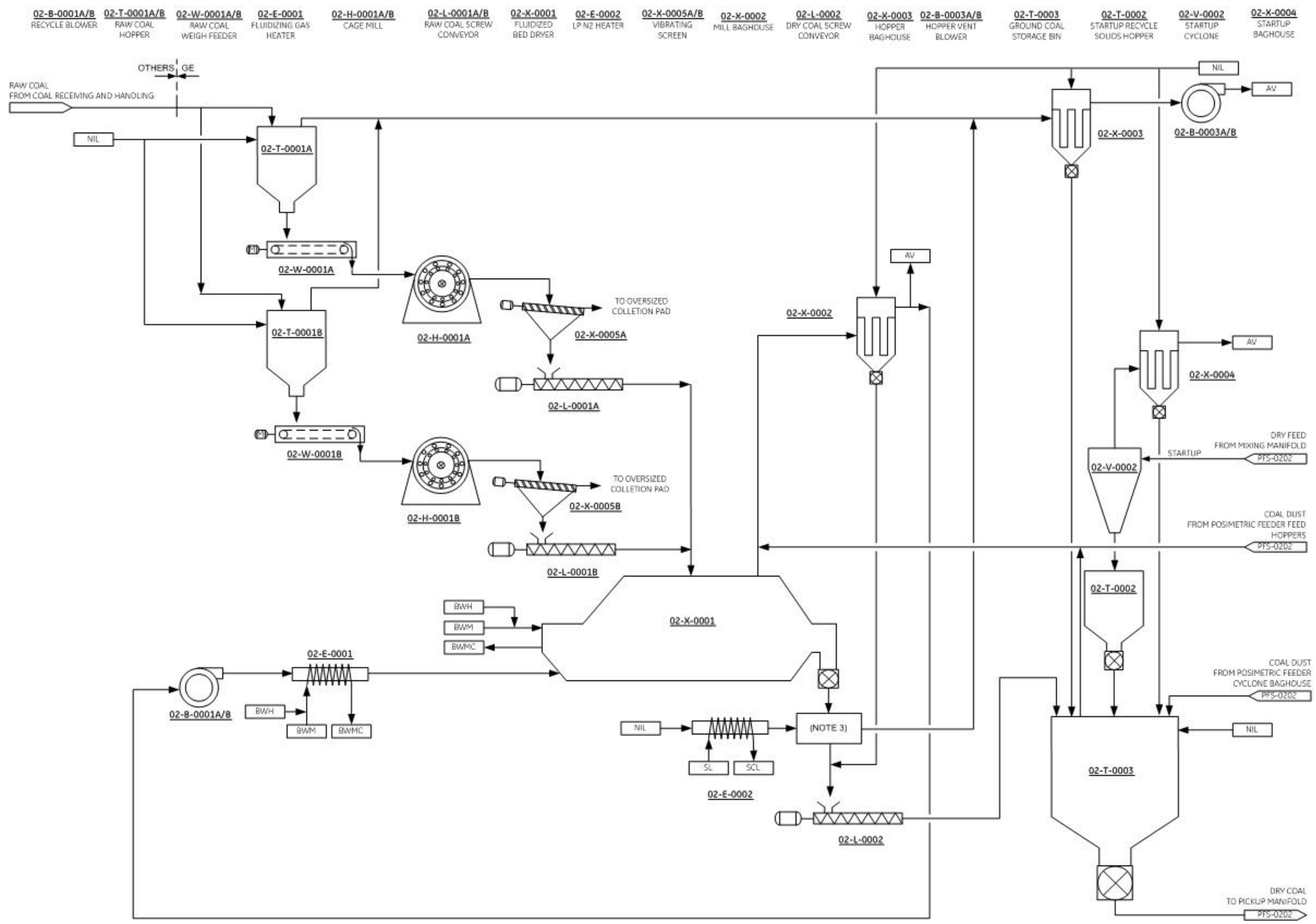


Figure 10. Case 7 Process Flow Sketch – Coal Grinding and Drying Subsystem – Cage Mil/Fluidized Bed Dryer – BFW

Table 16. Case 7 Equipment List – Cage Mill/Fluidized Bed Dryer – BFW

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001A/B	Recycle Blower	Fan	61,000 acfm	1 op / 1 sp
02-B-0003A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-E-0001	BFW Heater	Coil	4.8 MMBtu/h; 61,000 acfm	2 op / 0 sp
02-E-0002	LP Nitrogen Heater	Coil	1.5 MMBtu/h, 1700 lb/h	1 op / 0 sp
02-H-0001A/B	Grinding (Cage) Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-L-0002A/B	Dry Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0001	Fluidized Bed Dryer	Steam-Gas	75,000 acfm; 188 tph Coal	1 op / 0 sp
02-X-0002	Mill Baghouse	Filter	111000 acfm; 4371 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0005A/B	Vibrating Screens	Classifier	200,000 lb/h	2 op / 0 sp

Table 17. Case 7 Auxiliaries – Cage Mill/Fluidized Bed Dryer – BFW

Stream	Value
HP boiler feed water	310,000 lb/hr
MP boiler feed water	510,000 lb/hr
LP Steam	1,700 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	-15%

3.7 Case 8 – Cage Mill/Fluidized Bed Dryer – Vapor Recompression

Case 8 is similar to Case 2, except that vapor recompression is used to provide energy for heating and drying the coal, analogous to the WTA process. However, because of the low level of coal drying assumed in this study, vapor recompression is unable to provide sufficient heat for both the heating and drying of the coal, so low pressure steam is used to make up for the difference.

Process Flow

Coal Grinding and Drying Subsystem – The process flow sketch for the Case 8 coal grinding and drying subsystem is provided in Figure 11, and is similar to that for Case 2 (Figure 6). However, it differs in that part of the energy used for heating and drying the coal in the dryer, 02-X-0001, as well as the energy used to heat the fluidizing gas in fluidizing gas heater, 02-E-0001, is supplied via vapor recompression using vapor compressor, 02-C-0001, which like the recycle blower, 02-B-0001A/B, draws steam vapor from the fluidized bed dryer, through mill baghouse, 02-X-0002. The balance of the energy required for heating and drying the coal in the fluidized bed is provided by low pressure steam, which runs through a dedicated portion of the heat exchange surface within the dryer.

Sized Equipment List

The sized equipment list for the Case 8 coal preparation and feed system is provided in Table 18. It includes the equipment from Figure 11, as well as the common equipment from Figure 4 and Figure 5.

Auxiliaries

A list of auxiliaries required to operate the Case 8 coal preparation and feed system is provided in Table 19.

The use of vapor recompression is estimated to substantially reduce the amount of low pressure steam required compared to Case 2, with an electrical power consumption falling between that of Case 1 and Case 2. Together, these result in Case 8 leading the other cases from an energy efficiency standpoint.

Case Summary

Key advantages and drawbacks of using the Case 8 technology for the Advanced IGCC plant include:

Advantages

- No major stepouts, as process uses well-known, commercially available equipment
- No impact on CO2 capture level, as no fuel is consumed for drying
- Able to dry using low pressure steam and recompressor only
- Inerting is provided by steam generated in the fluidized bed
- Capacitance of the system helps ensure stable operations
- Approach of temperature-enthalpy curve between the in-bed heater is more favorable than for BFW
- Bed can operate on steam if recompressor not available

Drawbacks

- Requires additional equipment (vapor recompressor)
- Potentially higher solids separation specification on vapor-solids separator than for conventional fluidized bed to protect vapor recompressor
- Condensate from vapor recompression adds to process waste water load
- Surface area of in-bed dryer higher than Case 2 and Case 7 due to less favorable log-mean delta temperature assumed with recompressed steam
- Requires steam be available to operate the dryer (for startup and to augment the duty that the recompression doesn't provide)
- Need to strip water vapor from coal upon exiting the dryer or maintain the coal under heated conditions to avoid condensation of water on the dryer product

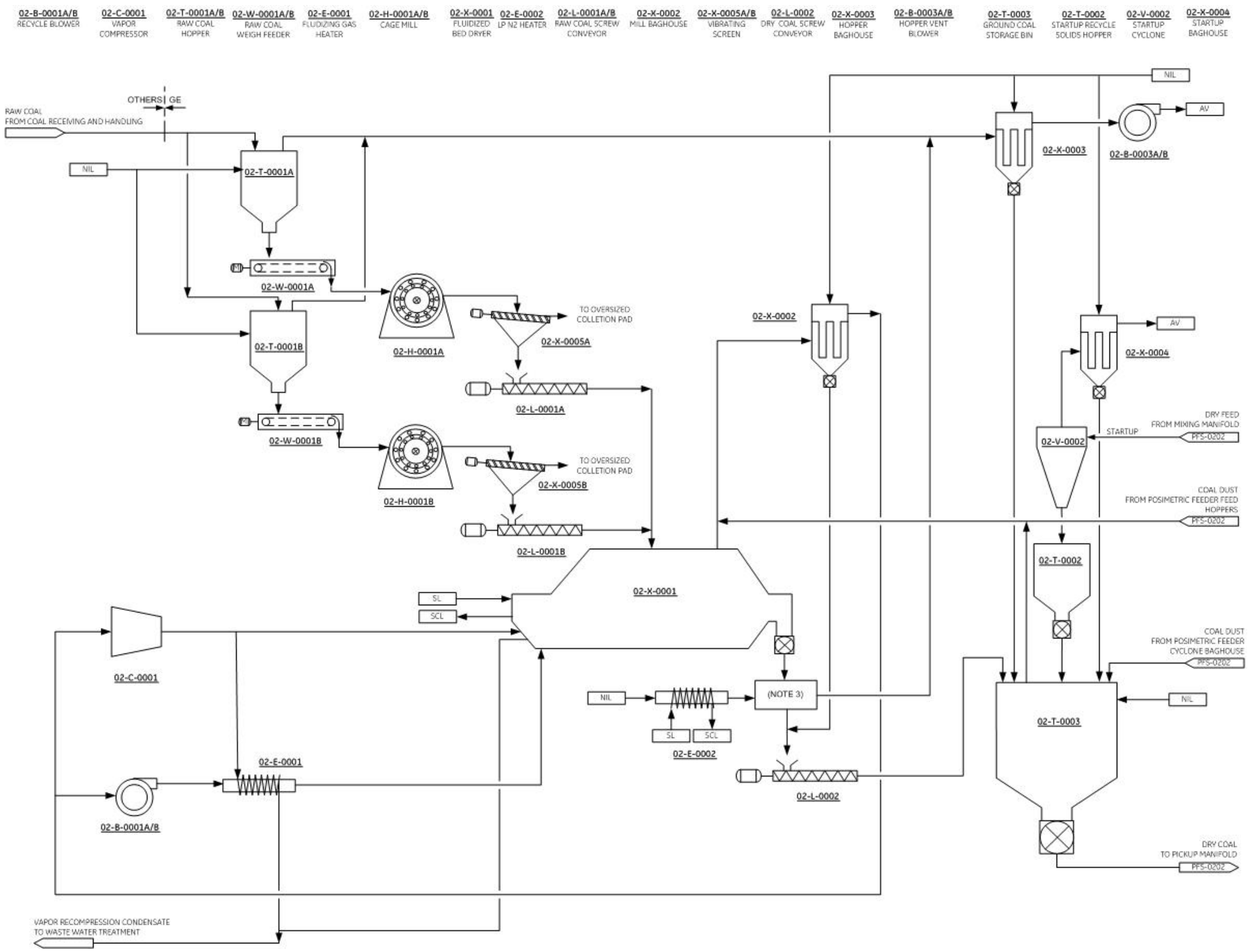


Figure 11. Case 8 Process Flow Sketch - Coal Grinding and Drying Subsystem – Cage Mill/Fluidized Bed Dryer – VRC

Table 18. Case 8 Equipment List – Cage Mill/Fluidized Bed Dryer – VRC

Item No.	Description	Type	Design Condition	Operating/Spare
02-B-0001A/B	Recycle Blower	Fan	61,000 acfm	1 op / 1 sp
02-B-0003A/B	Hopper Vent Blower	Fan	3,000 acfm	1 op / 1 sp
02-C-0001A/B	Vapor Compressor	Compressor	10,000 acfm; 23,200 lb/h	1 op / 1 sp
02-E-0001	LP Steam Heater	Coil	4.8 MM Btu/h; 61,000 acfm	1 op / 0 sp
02-E-0002	LP Nitrogen Heater	Coil	1.5 MMBtu/h, 1700 lb/h	1 op / 0 sp
02-H-0001A/B	Grinding (Cage) Mill	Mill	178,600 lb/h per mill	2 op / 0 sp
02-L-0001A/B	Raw Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-L-0002A/B	Dry Coal Screw Conveyor	Conveyor	200,000 lb/h per mill	1 op / 1 sp
02-T-0001A/B	Raw Coal Hopper	Vertical Hopper	376 tons	2 op / 0 sp
02-T-0002	S/U Recycle Solids Hopper	HP Vertical Hopper	66 tons	1 op / 0 sp
02-T-0003	Ground Coal Storage Bin	Vertical Hopper	350 tons	1 op / 0 sp
02-V-0002	Start Up Cyclone	HP Vert. Separator	460 acfm; 69900 lb/h	1 op / 0 sp
02-W-0001A/B	Raw Coal Weigh Feeder	Conveyor	200,000 lb/h	2 op / 0 sp
02-X-0001	Fluidized Bed Dryer	Steam-Gas	75,000 acfm; 188 tph Coal	1 op / 0 sp
02-X-0002	Mill Baghouse	Filter	111000 acfm; 25,370 lb/h	1 op / 0 sp
02-X-0003	Vent Hopper Baghouse	Filter	3000 cfm	1 op / 0 sp
02-X-0004	Start Up Baghouse	Filter	7000 cfm	1 op / 0 sp
02-X-0005A/B	Vibrating Screens	Classifier	200,000 lb/h	2 op / 0 sp

Table 19. Case 8 Auxiliaries – Cage Mill/Fluidized Bed Dryer - VRC

Utility Stream	Value
LP steam, lb/hr	35,700 lb/hr
Change in coal preparation and feeding system power consumption relative to Case 1	-5%

3.8 Efficiency Deltas

The estimated deltas in nominal heat rate for each of the cases relative to Case 1, impact dryer mill – steam are shown in Figure 12.

Four cases are more efficient than Case 1, impact dryer mill – steam:

- Case 2, cage mill/fluidized bed dryer – steam,
- Case 5, impact dryer mill – BFW,
- Case 7, cage mill/fluidized bed dryer – BFW, and
- Case 8, cage mill/fluidized bed dryer – vapor recompression.

Two cases are essentially the same efficiency as Case 1:

- Case 3, impact dryer mill – natural gas, and
- Case 6, impact dryer mill – HRSG.

The remaining case, Case 4, impact dryer mill – syngas, is less efficient than Case 1.

This ranking is consistent with the levels of energy used to for drying. Like Case 1, Cases 2, 5 and 7 all rely on heat from lower level thermal energy to dry the coal. Case 8 uses a combination of lower level thermal energy and vapor recompression which provides a way of using low-level thermal energy more efficiently. Case 6 is also utilizing low level energy, however, as configured, the additional power required to transport the HRSG flue gas to the impact dryer mill overtakes the savings available from using the low level heat in the HRSG flue gas and the steam used for heating the gas to the required temperature for the mill. Finally, Cases 3 and 4 both use the fuel to dry the coal, with Case 4 having the highest heat rate because of the energy required to produce the syngas.

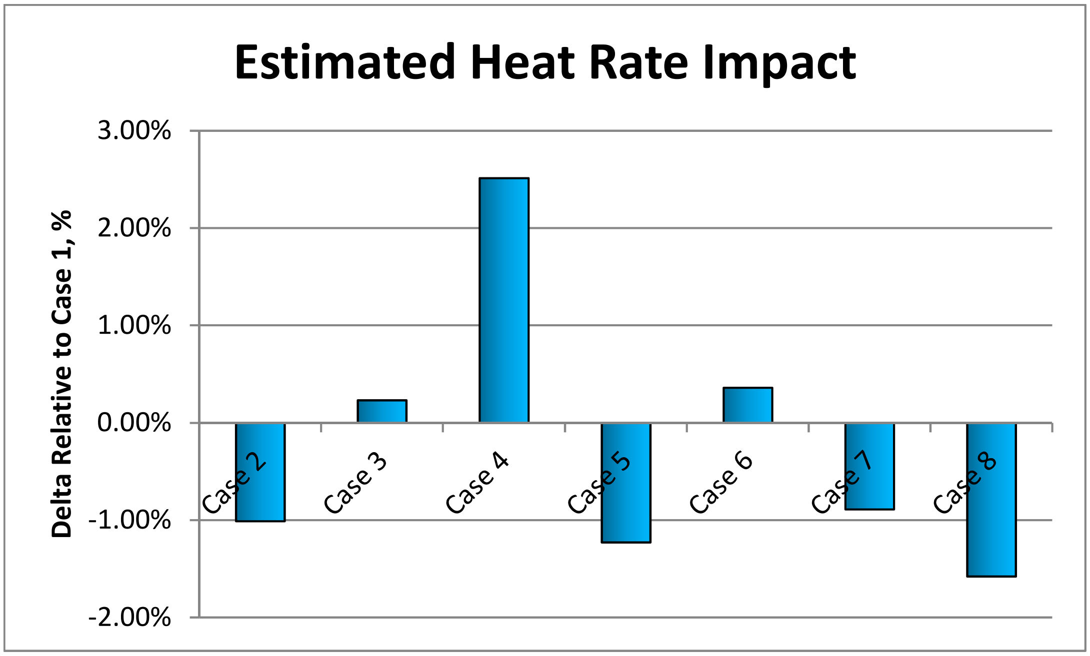


Figure 12. Estimated Plant Heat Rate Impact Relative to Case 1

3.9 CAPEX Deltas

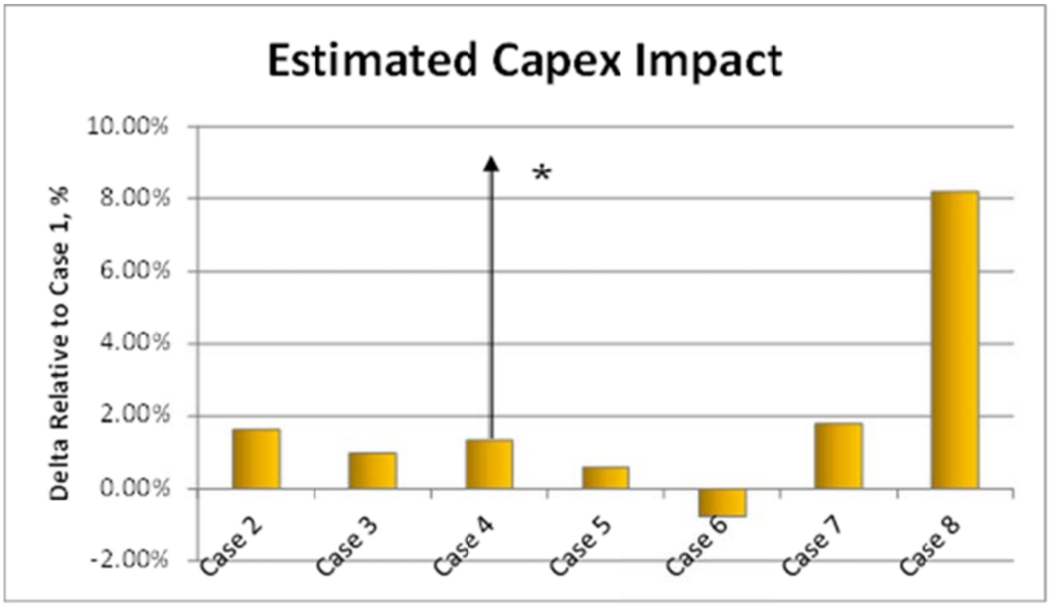
The estimated deltas in coal preparation and feed system CAPEX relative to Case 1, impact dryer mill – steam, are shown in Figure 13.

Four cases have CAPEX similar to Case 1:

- Case 2, cage mill/fluidized bed dryer – steam
- Case 5, impact dryer mill – BFW
- Case 6, impact dryer mill – HRSG
- Case 7, cage mill/fluidized bed dryer - BFW

The other three cases have higher CAPEX than Case 1:

- Case 3, impact dryer mill – natural gas
- Case 4, impact mill – syngas
- Case 8, cage mill/fluidized bed dryer - VRC



* Does not include costs for additional required syngas production capability.

Figure 13. Estimated Coal Preparation and Feeding CAPEX Impact Relative to Case 1

As shown in Figure 13, the relative CAPEX for coal preparation and feeding for Cases 1 through 7 are essentially indistinguishable, given the uncertainties in the estimates, particularly when it comes to distinguishing between the impact drying mill and cage mill/fluidized bed dryer cases. However, the higher relative CAPEX for Case 8, at least as a delta to Cases 2 and 7, is assumed to be meaningful, occurring as a direct result of (1) adding a compressor for compressing water vapor from the fluidized bed, and (2) increasing the size of the fluidized bed dryer due to the lower thermal driving force associated with using the compressed steam compared to higher pressure low pressure steam. Case 4 incurs additional CAPEX outside of coal preparation and feeding because of the need to generate additional syngas for the coal drying. And even though the additional incremental syngas rate may be small, spread across all of the equipment in the gasification island and portions of the power block, the additional CAPEX could be significant in comparison to the CAPEX for coal preparation and feeding.

3.10 Availability

The availability results described in section 4.2.3 for Cases 1 and 2 are considered equally applicable to Cases 5 and 7. In addition, availability calculations were completed for Case 3, which was assumed to be equally applicable to Case 4, and for Cases 6 and 8, all of which had similar results to those of the other cases. Consequently, all of the cases as configured under this study had high enough availabilities that the overall IGCC plant was able to achieve the availability target of 85%.

3.11 Conclusions and Recommendations

The results of this portion of the study show that the leading options for coal preparation and feeding from both an efficiency and CAPEX standpoint are Case 1, Case 2, Case 5, Case 6, and Case 7. However, given the uncertainties in these estimates, and taking into account the other CTQs identified for the coal grinding and drying subsystem (Figure 14), the two leading options at the level of drying considered under this study are Case 5and Case 2. And though going with either technology would be expected to give similar overall results, because of the benefits of overall smaller footprint and ease of operation, the Case 5 technology, impact dryer mill – BFW is recommended for incorporation in the Advanced IGCC evaluation to be carried out under Task 5.

CTQ	Case 1 - Impact Mill - MP and LP Steam (Steam)	Case 2 - Cage Mill/Fluidized Bed Dryer - LP Steam (Steam)	Case 3 - Impact Mill/Dryer - Natural Gas (NG)	Case 4 - Impact Mill/Dryer - Syngas	Case 5 - Impact Mill/Dryer - HP and MP Boiler Feed Water (BFW)	Case 6 - Impact Mill/Dryer - Heated HRSG Flue Gas (HRSG)	Case 7 - Cage Mill/Fluidized Bed Dryer - HP and MP Boiler Feed Water (BFW)	Case 8 - Cage Mill/Fluidized Bed Dryer - Vapor Recompression (VRC)
Technology readiness	■	■	■		■		■	
Ability to meet grind size spec range	■	■	■	■	■	■	■	■
Ability to meet moisture content spec range	■	■	■	■	■	■	■	■
Controllability		■					■	
Reliability/Proven Technology	■	■	■		■		■	
Operation complexity	■		■		■			
Footprint/Layout	■		■		■			
Electrical Power Requirements		■					■	
Drying Gas Flow rate		■					■	
Heating Duty		■					■	
CAPEX					■	■		
OPEX (case 8 not optimal because of water treatment)	■	■			■			
RAM	■	■	■	■	■	■	■	■
Ability to handle Transient Scenarios	■	■	■	■	■	■	■	■
Emissions		■					■	■

Figure 14. Case Comparison Matrix

APPENDICES

GRAPHICAL MATERIALS LISTS

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REFERENCES

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LIST OF ACRONYMS AND ABBREVIATIONS

ACFM	Actual cubic feet per minute
ASU	Air Separation Unit
BFW	Boiler Feed Water
CAPEX	Capital Expenditure
CCS	Carbon capture for sequestration
CF-BFW	Cage Mill/Fluidized Bed Dryer – HP and MP Boiler Feed Water (BFW)
CF-STM	Cage Mill/Fluidized Bed Dryer – LP Steam (Steam)
CF-VRC	Cage Mill/Fluidized Bed Dryer – Vapor Recompression (VRC)
CFM	Cubic feet per minute
CTQ	Critical to Quality measurement as viewed by the customer.
EOR	Enhanced oil recovery
FBD	Fluidized Bed Dryer
HP	High pressure
HRSG	Heat recovery steam generator
IGCC	Integrated Gasification Combined Cycle
IMD-BFW	Impact Mill/Dryer – HP and MP Boiler Feed Water (BFW)
IMD-HRSG	Impact Mill/Dryer – Heated HRSG Flue Gas (HRSG)
IMD-NG	Impact Mill/Dryer – Natural Gas (NG)
IMD-SG	Impact Mill/Dryer – Syngas
IMD-STM	Impact Mill – MP and LP Steam (Steam)
LP	Low pressure
MP	Medium pressure
MTBF	Mean time between failures
MTTR	Mean time to repair
NG	Natural gas
OPEX	Operational Expenditure
PFS	Posimetric Feed System
PRB	Powder River Basin
RAM	Reliability, Availability and Maintainability
SG	Syngas
SLR	Solids Loading Ratio
VRC	Vapor Recompression