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# Front End Engineering Design of Linde-BASF Advanced Post-Combustion $CO_2$ Capture Technology at a Southern Company Natural Gas-Fired Power Plant


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Final Scientific/Technical Report


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## 0.0 EXECUTIVE SUMMARY

This document details the execution of Cooperative Agreement DE-FE0031847, "Front End Engineering Design of Linde-BASF Advanced Post-Combustion Carbon Dioxide ($CO_2$) Capture Technology at a Southern Company Natural Gas-Fired Power Plant" during the period of 10/1/2019 to 6/30/2022. The project was funded by the U.S. Department of Energy's Office of Fossil Energy and Carbon Management (FECM) and managed by the National Energy Technology Laboratory (NETL). Southern Company Services, Inc. (SCS) is the prime recipient and leads the project team. Other members of the project team include Linde, Inc. (Linde), Linde Engineering – Dresden (LED), and BASF.

The overall goal of the proposed project was to complete a front-end engineering design (FEED) study for installing the Linde-BASF post-combustion capture (PCC) technology at an existing domestic natural gas-fired combined cycle (NGCC) power plant within Southern Company's portfolio of assets. The $CO_2$ capture plant was to be of commercial scale (at least 375 MWe) and include process units for pre-conditioning of the flue gas system, the $CO_2$ capture plant island, storage vessels, the $CO_2$ compression train, and any necessary components for integration into the NGCC plant. Southern Company was the prime contractor to NETL and the NGCC plant host site owner. Their scope included project management, scope definition, design and engineering of components required for the integration of the PCC plant with the host site, and overall cost estimation for the facility. BASF provided the basic design package for the PCC solvent technology. Linde designed the $CO_2$ capture and compression plant and supported the cost estimation of process equipment.

The project was broken into five major tasks: (1) Project Management and Planning, (2) Scope Definition and Design Basis, (3) Conceptual Design, (4) Front End Engineering Design Study, and (5) Cost and Schedule Estimation. Task 1 spanned the entirety of the project's period of performance whereas the other tasks occurred generally in sequence over the course of the project.

Site selection was the first technical milestone achieved by the project team, as Mississippi Power's Plant Daniel Unit #4 was chosen. A design basis was then developed based on site-specific conditions and with the target of 90% capture from the existing combustion turbines. The flue gas and steam conditions established as part of this design basis informed the conceptual design efforts by Linde and BASF, which included basic equipment sizing and the development of a heat and material balance for the carbon capture system. Piping and instrumentation diagrams and process flow diagrams were also developed, which allowed the project team to conduct a hazard and operability review. The basic design information plus the findings of this review informed the FEED efforts.

The FEED study produced engineering design drawings and information required to estimate the cost and schedule to retrofit Plant Daniel Unit 4 with carbon capture. A collection of engineering disciplines across both SCS and Linde participated. Major products of the effort included identifying potential permitting requirements, drafting process area descriptions, sizing major equipment, laying out the capture island plot plan, developing the new foundation design, accounting for process chemical containment and stormwater collection, quantifying and accounting for necessary utility additions, and developing a plan for the carbon capture control system. Plant personnel were consulted to identify modifications needed on site. Engineers also worked with vendors to obtain budgetary quotes for major equipment items. Material takeoff quantities were determined and provided to estimators.

The information produced by the FEED was used to develop a cost estimate of +/- 15% accuracy. Project estimators worked with engineering and construction resources to identify labor requirements and task sequencing. Bulk material takeoffs were priced based on recent projects and market pricing. Major equipment was priced based on vendor budgetary quotes. Resources were allotted according to the developed project schedule and internal tools were applied to estimate project cash flow and escalation. The execution of a project based on this FEED study has an estimated duration of almost five years. Capital costs, excluding financing, are estimated at approximately $752 million dollars (2021$).

These results were detailed in a FEED package provided to NETL. A non-proprietary summary of these results is detailed in the following report.

## 1.0 PROJECT BACKGROUND

Southern Company and a team of project partners has executed United States Department of Energy (DOE) project DE-FE0031847. The overall goal of the project was to complete a FEED study for installing the Linde-BASF PCC technology at an existing domestic NGCC power plant within Southern Company's portfolio of assets. The Linde-BASF technology is a mature and well-tested technology for capturing $CO_2$ from flue gas using the BASF OASE® blue solvent. The technology was tested from 2009 until 2017 in two pilot plants with different flue gas sources covering a wide variety of flue gas compositions and impurities. For this FEED, the PCC unit was of commercial scale (at least 375 MWe) and included process steps for pre-conditioning of the flue gas system, the $CO_2$ capture equipment, storage vessels, the $CO_2$ compression train, and any necessary components for integration into the NGCC plant. Southern Company was the prime contractor to DOE and the NGCC plant host site owner. Their scope included project management, scope definition, design and engineering of components required for the integration of the PCC plant with the host site, and overall cost estimation for the facility. BASF provided the basic design package for the PCC solvent technology. Linde designed the $CO_2$ capture and compression process and supported the cost estimation of process equipment.

The project was divided into five major tasks: (1) Project Management and Planning, (2) Scope Definition and Design Basis, (3) Conceptual Design, (4) Front End Engineering Design Study, and (5) Cost and Schedule Estimation. A key impediment to the wide-scale adaptation of this technology and other $CO_2$ capture systems is the high cost of capital required for implementation at scale. Through execution of this FEED study for an actual site, the project team endeavored to provide a reference case for a more detailed understanding of $CO_2$ capture costs in a commercial application that will support the development of cost effective, environmentally sound, and high performing technologies for the reduction of $CO_2$ emissions from NGCC plants.

## 2.0 PROJECT EXECUTION

This report section and all subsections will detail the process by which the project team executed the FEED study. These tasks and subtasks were identified during the original proposal development process and were organized in accordance with the expectations set out in the Funding Opportunity Announcement.

### 2.1 Project Management and Planning

SCS was the applicant to the funding opportunity and the recipient of funding for the project. As such, SCS was responsible for overall project management for the team. SCS and the NETL agreed to contract terms and established the project in January 2020. With this in place, SCS established internal cost tracking mechanisms, a project schedule, and a subrecipient agreement with technology partner Linde.

As part of project execution, SCS held biweekly update meetings with Linde to update project progress and plan future work along with topic-specific meetings as needed. DOE-NETL was provided the prescribed quarterly Research Performance Progress Reports and SF-425 financial reports throughout the project. While the original period of performance for the award was 10/1/2019 through 9/30/2021, the project was extended at no-cost to DOE-NETL through 6/30/2022 due to time required for contract negotiation, COVID-19 pandemic disruptions, and time for DOE-NETL to review the FEED package during the performance period.

## 2.2 Scope Definition and Design Basis

While the original funding opportunity announcement provided the general guidelines for what should be produced, the first step for the project team was to further refine the scope and expectations for the product. SCS and Linde collaborated to clearly establish project requirements for design, documentation, operation, and more. Site-specification considerations were also identified and recorded into a *Basis of Design* document.

### *2.2.1 Requirements Definition*

Achieving consensus and mutual understanding of the project requirements began immediately in the first quarter of 2020. Linde initially provided SCS with a list of parameters and operating conditions that would be required to determine how to retrofit the existing NGCC with post-combustion carbon capture equipment. In turn, SCS provided Linde with the expectations for the retrofitted plant's operating profile and performance. These requirements were recorded in the *Basis of Design* that informed engineering design throughout the project.

### *2.2.2 Host Site Evaluation and Selection*

In addition to identifying the engineering and operational requirements for the retrofit, the project team evaluated two potential combined cycle sites within the Southern Company Operations fleet: Alabama Power's Plant Barry and Mississippi Power's Plant Daniel. These two sites were selected for evaluation due to several factors: (1) proximity to known, favorable geology for carbon sequestration; (2) availability of onsite land with minimal impediments to allow for the addition of carbon capture equipment; and (3) both sites featured 2-on-1, F-class natural gas turbine combined cycle units, which represent a large number of the operating combined cycle units across the world. Using either of these sites as the basis for the FEED study would provide an excellent example of the current costs to add carbon capture to a NGCC power plant.

SCS was responsible for choosing one site of these two to serve as the basis for the study. Since the NGCC units at these sites are practically sister units that began operation within a year of each other, the decision was based on ancillary details. Information collected and evaluated for each site included specific available space, potential obstructions in the proposed plot space, the existing and potential capacity of necessary utilities, and any site-specific or local laws and regulations. While both sites showed great potential for a carbon capture retrofit, SCS determined that Plant Daniel Unit 4 was the best choice for this study due to more available unimpeded space in proximity to the NGCC unit and higher availability of utilities. This choice was confirmed to DOE-NETL via a host site letter from Plant Daniel's manager in May 2020. More details on Plant Daniel can be found in Section 3 of this report.

## 2.3 Conceptual Design

Conceptual design is the process of refining the project scope so that the front-end engineering is focused on the relevant application. For this carbon capture retrofit, that involved determining the major parameters required for carbon capture system performance and then identifying the necessary equipment and instrumentation to execute that system. SCS-provided host plant data informed this process, but most of this scope fell to Linde and their solvent technology partner, BASF.

### *2.3.1 Basic Design*

Once Plant Daniel Unit 4 was identified as the host site for the FEED study and its flue gas parameters were collected, Linde worked with solvent partner BASF in the summer of 2020 to evaluate the required surface areas for absorption/regeneration and the heat of regeneration required which helped define the major equipment sizing and began to establish the heat and material balance (HMB). A block flow diagram summarized this work.

### *2.3.2 Basic Engineering*

The basic design information produced with BASF allowed Linde to transition the simple block diagram into a process flow diagram (PFD), complete the HMB, establish piping & instrumentation diagrams (P&IDs), and create the process data sheets for major equipment. This also began to highlight the interconnections that SCS would need to account for during the FEED design phase. Linde completed this work early in the fourth quarter of 2020, setting the stage to move into the next phase of the project.

## 2.4 Front End Engineering Study

Front End Engineering Design (FEED) is the process by which a process or system design is refined and detailed to a sufficient level to create an estimate with enough confidence to make capital project decisions. These efforts require a multi-disciplinary team of engineers, estimators, schedulers, and more. The following sections detail the efforts and collaborations between different groups across SCS and Linde to create the engineering documentation, identify the resources required for project execution, and estimate the costs and time required to do so. In general, Linde engineers were responsible for producing the FEED information needed for the inside-battery-limits (ISBL) scope while SCS engineers were responsible for the outside-battery-limits (OSBL) scope.

### *2.4.1 Process Engineering*

Process engineering focuses on interaction between components within a process or system to produce the desired product or result. The role is really to be the connection between design engineering and operations. With the dual, intertwined scopes for this particular project, process engineering was the conduit between Linde/ISBL and SCS/OSBL as well. After basic engineering was complete, SCS and Linde worked together to integrate the new, retrofit design of the carbon capture system into the existing power plant operations.

As the first major endeavor of the FEED task, the project team was able to complete a hazards and operability review (HAZOP). At project kickoff, the plan had been to bring Linde engineers from the Dresden team to the United States for a joint, in-person HAZOP meeting. However, governmental and corporate travel restrictions due to the COVID-19 pandemic made an in-person meeting impossible. While joint virtual options were discussed, time zone differences and the difficulty of analysis and conversation in large virtual meetings led the team to a different solution. Linde engineers in Dresden conducted the HAZOP for the scope inside the battery limits (ISBL). This information was then provided to SCS for review and identification of any impacts to the interconnections with the plant outside the battery limits (OSBL) of the carbon capture system. SCS conducted a review with Plant Daniel operations and engineering personnel to ensure as many perspectives as possible were included. The final product was a HAZOP report that was included in the FEED package.

Linde process engineers developed process descriptions for the major equipment areas within the post-combustion carbon capture (PCC) system. These descriptions outline the interactions between subsystems, process equipment, and the various process streams, serving as a critical reference point for other engineering disciplines.  Next, process data sheets were refined into equipment specifications sufficient to obtain estimated pricing for major process equipment units.

SCS engineers' first task was to identify utility needs of the PCC system that could be met by existing power plant sources versus new sources.  This included a detailed evaluation of regeneration steam sources and economics, a determination that new cooling water and instrument air systems would be required, and confirmation that existing facilities would be sufficient for potable water, demineralized water, cooling tower makeup, and wastewater treatment.  SCS engineers worked with subject matter experts to specify new equipment and obtain pricing for those systems.

Process engineering continued to be the connecting mechanism for ISBL and OSBL design scopes across disciplines throughout the course of the FEED.

### *2.4.2 Mechanical and Piping*

Mechanical engineers were responsible for designing the layout of and interconnections between the major process equipment established during the basic design phase of the project.  Engineers from Linde collaborated with SCS engineers to determine a reasonable layout for the carbon capture equipment and the footprint in relation to the existing NGCC facility.  Once the carbon capture equipment layout was finalized, these groups continued to collaborate on the best locations for utility tie-ins and the location of new BOP equipment, such as the cooling tower and instrument air systems.  It was decided that a single battery-limit location between the existing steam turbine and the PCC unit made sense for most of the utilities supplied from existing plant sources, as shown in Figure 1.

With the exception of large flue gas ducts, pipe routing and design was also a function filled by mechanical engineers.  SCS provided initial piping design specifications early in the project.  Linde engineers then designed and routed all piping for the ISBL scope, including lines for solvent, steam, condensate, process water, cooling water, and instrument air.  SCS engineers were responsible for OSBL piping to and from the battery limits, including steam, condensate, instrument air, potable water, , demineralized water, and wastewater collection.  The interfaces for cooling water supply, return, makeup and blowdown were established at the south end of the PCC unit near the location of the new cooling tower.

Once the pipe routing designs were complete, engineers from both Linde and SCS were able to compile material quantities to inform the overall project estimate.  Information provided for the estimate included the material, size, thickness, and linear length of piping. Estimates of the required fittings and welds were also provided.

Mechanical engineers also specified the pumps and fans required for this retrofit.  These specifications made it possible to obtain quotes for the equipment items and informed the development of a load list and electrical design.

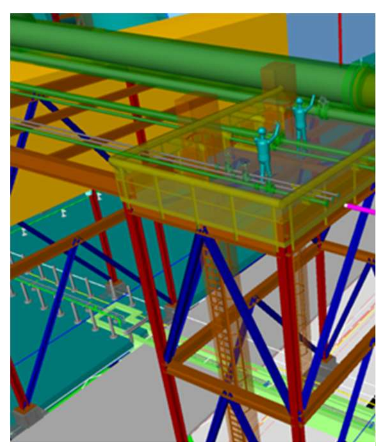


*Figure 1: 3D Model Screenshot of Tie-Ins at Battery Limit*

### *2.4.3 Instrumentation, Control and Electrical Engineering*

Instrumentation, controls, and electrical engineering was another area of collaboration between SCS and Linde personnel. These scopes for ISBL and OSBL were coordinated and updated according to the work of other disciplines as well.

SCS provided general instrumentation specification requirements to Linde early in the project. Linde instrumentation personnel then created an instrument list for the ISBL scope. Data sheets for each type of instrument required were created and used for pricing of instruments in the estimate. SCS instrumentation engineers did the same for all new instruments in the OSBL scope. The total input/output (IO) count was then turned over to controls engineers to inform that work.

Controls engineers were responsible for taking the IO information and process operating descriptions and creating a control system architecture to accomplish the goals of the carbon capture system. SCS and its operating companies use a specific type of control system hardware and software for all generating facilities and it was determined during the project that the best course of action for a retrofit would be to expand the current system to include the carbon capture plant controls rather than having different systems. SCS provided typical specifications to Linde before work began on the new scope. Linde engineers developed a control system architecture and control philosophy which was then reviewed and augmented by SCS to include the OSBL additions. These specifications were provided to the control system vendor to obtain a budgetary estimate for such a retrofit.

Electrical engineers were responsible for ensuring adequate power supply for equipment and instrumentation within the carbon capture island. This started with Linde engineers creating an ISBL load list from the equipment list and control architecture. They then designed a stand-alone, motor control and electrical supply building that would be located within the capture area. Due to the limited number and scale of new OSBL equipment electrical loads, SCS determined that local, outdoor power supply equipment would be the best choice for those items. SCS engineers determined that a new high-voltage power supply would be required and consulted with transmission design engineers to develop a conceptual power supply system from the existing 230kV lines to feed the carbon capture system.

### *2.4.4 Civil and Structural Engineering*

Civil and structural engineers were responsible for scope such as site preparation design, foundation design, process containment, large duct design, and structural steel. While the ISBL/OSBL scope separation was finite and clear for other engineering disciplines, SCS was responsible for the entire foundation design scope. Again, these efforts required significant collaboration between SCS and Linde personnel.

The first step in civil design was to evaluate the existing site conditions to inform the subsequent retrofit design efforts. Surface topography and preliminary underground obstruction surveys were conducted before a drilling contractor was brought in to perform cone penetration testing of the soils in the proposed area. Since the equipment layout could be adjusted during FEED or detailed designs, a grid pattern (see Figure 2) was used to provide an overview of the area. Those evaluations were analyzed and documented in a geotechnical report that was distributed to design engineers for reference.  Hydro-excavation to confirm underground obstructions was not conducted and will be needed in subsequent project steps.


*Figure 2: Cone Penetration Test Plan for Plant Daniel*

With the soil and underground information established, SCS civil engineers were able to create an analytical model for foundation and structural steel loads and reactions.  Linde engineers provided equipment and structural loads and locations for the ISBL scope.  This information was aggregated in the model and used to develop the deep foundation and concrete mat designs.  Linde engineers also coordinated with the process engineering group to develop an initial stormwater management and chemical containment plan, including reservoir volumes and appropriate drain depths and slopes.  This was also provided to SCS civil design to be incorporated into the overall foundation design plan.  This plan quantified the number of deep foundations, the amount of concrete required, and an installation plan.

Structural steel design was again split along the lines of ISBL and OSBL.  Linde design engineers developed the structural steel design for all equipment support, pipe supports, and personnel access within the carbon capture system.  SCS design engineers produced drawings for the pipe support steel and ductwork from the existing plant to the carbon capture system.  Both groups produced material takeoff quantities as an input to the overall project estimate.

### *2.4.5 Facilities Engineering*

SCS personnel were responsible for evaluating the existing facilities and determining required modifications or expansions to support a carbon capture retrofit.  Linde provided recommendations on operations and maintenance personnel required to support the carbon capture system as well as the appropriate operator interface setup within the control room.  SCS process engineers worked with Mississippi Power personnel at Plant Daniel to confirm that the existing facilities that support Unit 4, including the administration building, control room, and maintenance shop, have adequate space to incorporate the needs of the carbon capture process with minor modifications. The new electrical building to support the carbon capture process was specified as part of the electrical design and included appropriate HVAC design.

Site security and logistics were also evaluated by the project team. The available footprint within the existing Plant Daniel site simplified these consideration as existing site security features would also be able to serve the carbon capture facility. The plant also has an existing warehouse system and site access procedures. The carbon capture design team made sure to design pipe bridges and ductwork that crossed existing plant roads to avoid impeding delivery traffic. Outages for the carbon capture system would be aligned with the existing combined cycle scheduled outage plan as well. SCS and Linde engineers coordinated to ensure these timelines were in sync.

### 2.5 Cost and Schedule Estimation

The project team compiled the design inputs from both SCS and Linde to develop an overall schedule and estimate for the carbon capture retrofit design. SCS Technical and Project Solutions (T&PS) has a project controls group that is responsible for developing estimates and schedules for most projects executed by Southern Company and its operating companies. The project controls team collects inputs from internal SCS design discipline teams, construction planning resources, and any external vendors and contractors. Those inputs are then applied to a resource loaded schedule and estimate through an internal tool for project estimating. For this project, SCS project controls took the lead and collected inputs from SCS design teams, Linde design teams, and construction planning to produce the requested schedule and estimate for the carbon capture design.

#### *2.5.1 Procurement and Fabrication Planning*

SCS cooling tower subject matter experts obtained a budgetary estimate from a commonly used vendor for the new cooling tower. Other OSBL equipment was minor and could be estimated based on recent projects. Linde estimated the procurement costs for the ISBL equipment and materials. Approximately 95% of the mechanical equipment costs were determined based on vendor quotes. The remaining 5% used Linde's inhouse data from similar, previous projects. Electrical and instrumentation equipment and materials were based on unit rates from currently executed projects. Piping and steel quantities were based on unit rates derived from inhouse data supported by vendor quotes. These were based on a global sourcing basis but with all currencies converted to US dollars (2021). Fabrication timeline information was sourced from vendors as well.

#### *2.5.2 Construction Estimate and Planning*

SCS T&PS has standard procedures for constructability reviews and work planning. These procedures detail items like modularization, project safety planning, site logistics, construction equipment access, heavy haul/lift plans, installation risk assessment, work package development, construction permitting, contracting methodology, quality assurance and control, site security, outage integration, construction management, craft labor availability forecasting, and post construction site restoration. These reviews and processes inform the productivities and sequencing of the overall engineering, procurement, and construction schedule. SCS personnel applied these steps to both the OSBL and ISBL designs. While much of the work was completed by internal SCS resources, regional contractors were consulted to review the FEED for modularization opportunities and to establish the heavy haul/lifts plan. The results were handed over to project controls to inform the project cost estimate and schedule.

#### *2.5.3 Cost and Schedule Estimation*

SCS project controls personnel developed the project cost estimate and schedule in concert. The cost estimate is considered an overall +/- 15% estimate based on the level of engineering detail and material quantities provided by the Linde and SCS design teams. These quantities and the craft labor productivity estimations provided by construction planning allowed for the development of a schedule and labor costs for installation. Costs are organized into division of work (DOW) packages and cash flows are applied using typical cost curves from SCS' internal tool. 2021 nominal US dollars were the cost basis, and these were escalated through the project period using a T&PS internal tool. After consulting with Mississippi Power, SCS decided not to include financing costs in the estimate. As a regulated utility, many variables are considered when determining the method of cost recovery for construction financing. The authority to approve cost recovery mechanisms lies with the Mississippi Public Service Commission (MPSC). Rather than speculate on what the MPSC would approve, the project team decided to omit financing costs from the FEED estimate.

SCS T&PS also has existing procedures for the review and approval of project cost estimates. Schedule and estimate challenge meetings were held with design discipline leads, T&PS subject matter experts, and management personnel to review the FEED results. Upon completion of the review, SCS then compiled the FEED design information, cost estimate, and schedule into a report that was submitted to NETL for review.

## 3.0 SUMMARY OF FEED RESULTS

The following sections summarize the FEED work products of the project team. The information herein excludes trade secret and/or proprietary information.

### 3.1 Project Scope

Plant Daniel Unit 4 has two GE 7FA combustion turbines that exhaust into Vogt triple pressure heat recovery steam generators (HRSG) to produce steam for one GE TC2F D11 steam turbine. The HRSGs are equipped with supplemental duct firing to increase steam production if electrical load requires. The unit produces a nominal 525 MWe (net). It began operation in May 2001.

*Figure 3: Mississippi Power Plant Daniel Unit 4*

To be consistent with previous benchmark studies such as the NETL baseline, the project team determined that the design basis for the FEED should account for the capture of 90% of the $CO_2$ from the flue gas of both combustion turbines at full load conditions. The FEED scope starts with the design of the ductwork to move the flue gas from the existing HRSG stack to the $CO_2$ capture process, includes the entirety of the PCC equipment up to the $CO_2$ product compressor discharge, and any interconnections with existing plant utilities or process streams. Southern Company has produced the design and estimate associated with everything outside the battery limits (OSBL) of the $CO_2$ capture unit while Linde has produced the design and estimate inside the battery limits (ISBL). This is represented graphically in Figure 4.

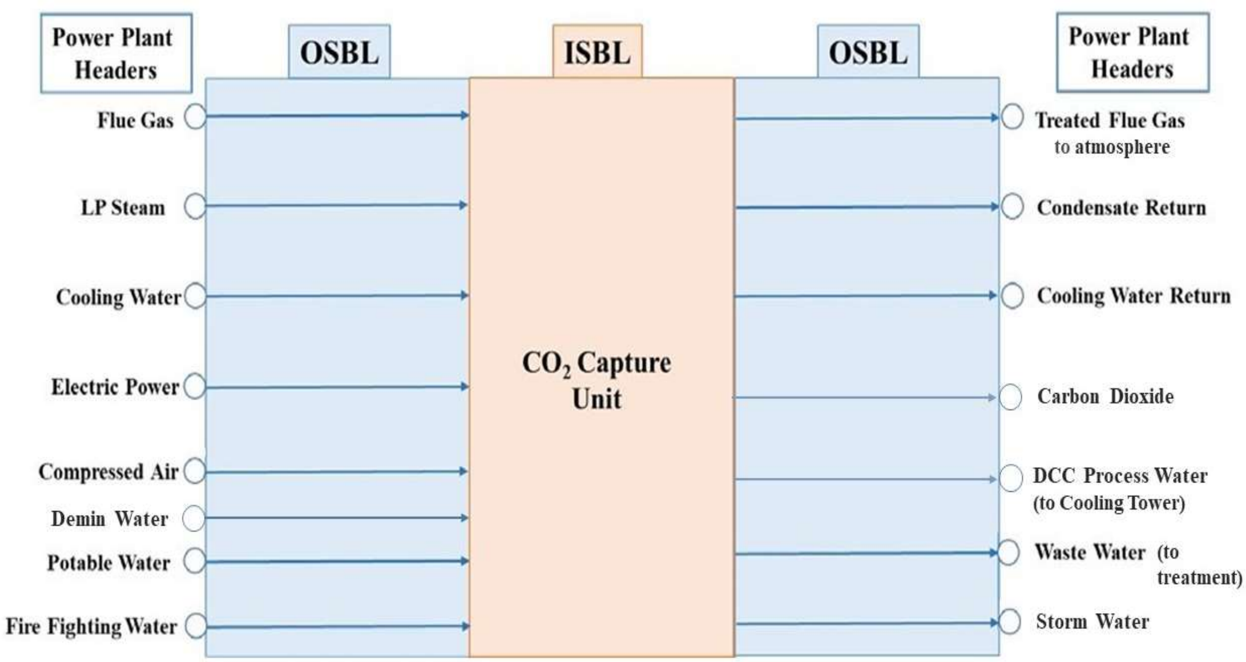



*Figure 4: FEED Battery Limit Illustration*

## 3.2 Project Design Basis

### *3.2.1 Site Characteristics*

Plant Daniel Unit 4 is in the unincorporated community of Escatawpa, MS just west of Mississippi Highway 63. The nearest municipality is Moss Point, MS which is listed as the physical address of the facility as shown in Table 1.

*Table 1: Plant Daniel Location Details*

| | |
|---|---|
| Address | 13201 MS-63<br><br>Moss Point, MS 39562 |
| Elevation above sea level (ft) | Approx. 29 ft |
| Distance to coastline | Approx. 15 miles |
| Latitude | 30°31’48”N |
| Longitude | 88°33’22”W |

Several areas within the plant were evaluated for the PCC unit plot space as shown in Figure 5 below. Area 1 was chosen as the plot for design purposes. Plant Daniel has used Area 1 extensively, without issue, for lay down and transportation during past projects.


*Figure 5: Potential PCC Plant Locations*

Cars, trucks, and construction vehicles can access the site from Mississippi state highway – MS 63 and Berkley Road which are suitable for non-permitted vehicles with dimensions listed in Table 2:

*Table 2: Non -Permitted Transportation Limits*

| Vehicle Dimension | Unit | Maximum Limit Without Permit |
|---|---|---|
| width | ft | 8.5 |
| height | ft | 13.5 |
| total length | ft | 99 |
| total weight | lbs (tons) | 80,000 (40) Gross Vehicle Weight, 20,000 (10) Single Axle; 34,000 (17) Tandem Axle; 42,000 (21)Tridem Axle |

For larger and heavier transports, a state-issued permit would be required. As part of the FEED, a detailed transport study was performed for the largest process equipment.

Although there is no barge access to the site, equipment can be barged into Pascagoula and/or Moss Point and transported via Hwy 63 (~14 miles). The site is also equipped with a rail spur which is owned by Mississippi Power Company (MPC) and maintained by Mississippi Export Railroad which could be used for equipment and materials deliveries. Figure 6 shows access to the plant site from potential transportation routes.

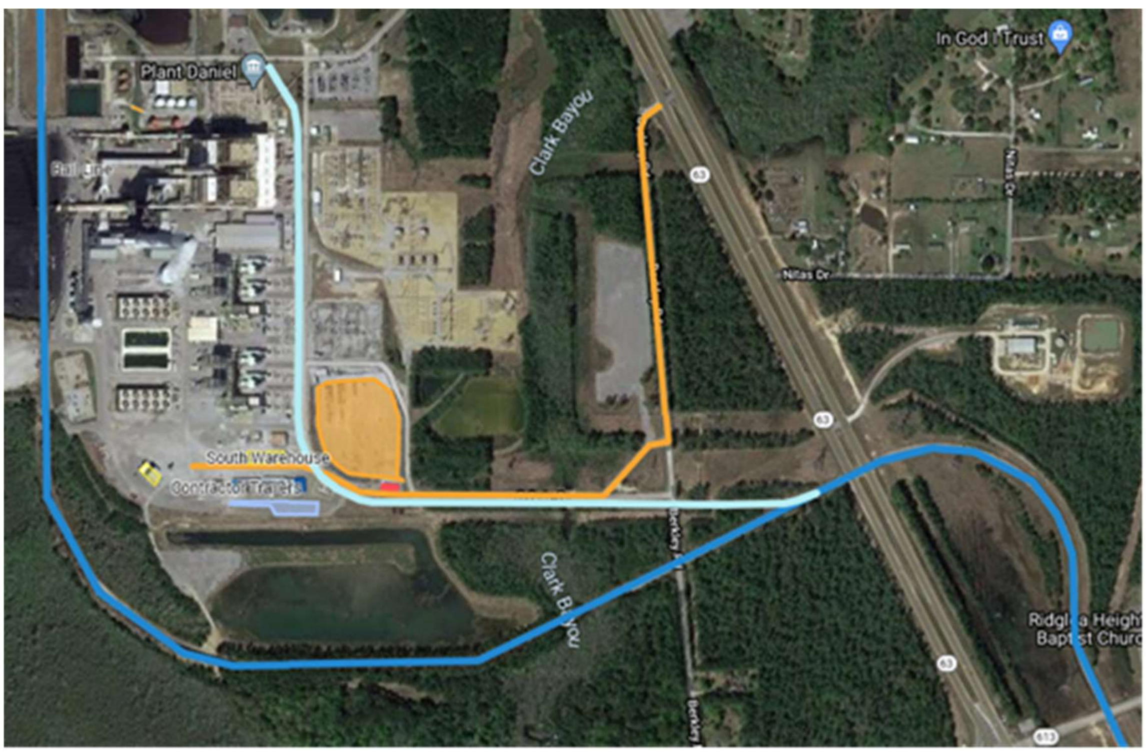



*Figure 6: Plant Access Routes*

**Dark Blue** = Railroad line
**Light Blue** = On site Railroad line to switchyard
**Orange** = Previous haul route for large equipment

Available utilities identified during design basis development include electrical power, steam, cooling water makeup and blowdown, demineralized water, potable water, service water, fire water, instrument air and plant air. In the FEED design, most utilities were routed to the battery limit of the PCC unit with two exceptions. Cooling tower makeup and blowdown were routed directly to/from the cooling tower and electric power was fed directly to a new electrical building in the PCC unit.

The existing AC and DC station service infrastructure was determined to be insufficient for the power required for $CO_2$ capture and compression. A new 230kVAC substation was estimated by Mississippi Power to provide three phase power to the PCC facility at 34.5kVAC and 60 Hz. Linde utilized this feed to design electrical components which supply the voltage levels needed for PCC equipment in a new ISBL electrical building.

An evaluation of various steam supply options determined extraction from the crossover between the Intermediate Pressure (IP) turbine and the Low Pressure (LP) turbine, in combination with steam produced in the Heat Recovery Steam Generator (HRSG) LP section, provided the optimal steam supply configuration. The steam supply study and ultimate design parameters are summarized in Table 3 below with detailed analysis provided in section 3.4.8.

*Table 3: Design Regenerator Reboiler Steam Conditions*

| **Parameter** | | **Design Case** |
|---|---|---|
| Temperature | °F | 20°F superheat minimum |
| Pressure | psia | 54.6 |

Evaluation of the existing cooling water system determined a new cooling tower will be required to supply the $CO_2$ capture process as detailed in section 3.4.8. Demineralized water, service water, potable water to be used for safety showers and eye wash stations, instrument air, and plant/service air are available from existing plant sources and would be supplied to the battery limit at the following operating conditions:

*Table 4: Design Utility Supply Conditions*

| | | | min. | norm. | max. |
|---|---|---|---|---|---|
| Demineralized Water | Pressure | psig | | 60 | |
| | Temperature | °F | 50 | 60-80 | 90 |
| Service Water | Pressure | psig | 60 | 80 | 95 |
| | Temperature | °F | 75 | 90 | 100 |
| Potable Water | Pressure | psig | | 106 | |
| | Temperature | °F | 50 | 60-80 | 90 |
| | Pressure | psig | 80 | 90 | 100 |

| | | | | | |
|---|---|---|---|---|---|
| Instrument Air & Plant/Service Air | Temperature | °F | | 80 | |

Nitrogen is not available from the plant and not planned to be supplied for instrument purposes.

### 3.2.2 Site Ambient Conditions

*Table 5: Design Ambient Conditions*

| | |
|---|---|
| Maximum Design Ambient Temperature (deg F) | 100 |
| Minimum Design Ambient Temperature (deg F) | 14 |
| Maximum Design Relative Humidity (%) | 85 |
| Ambient Air Pressure (psia) | 14.7 |

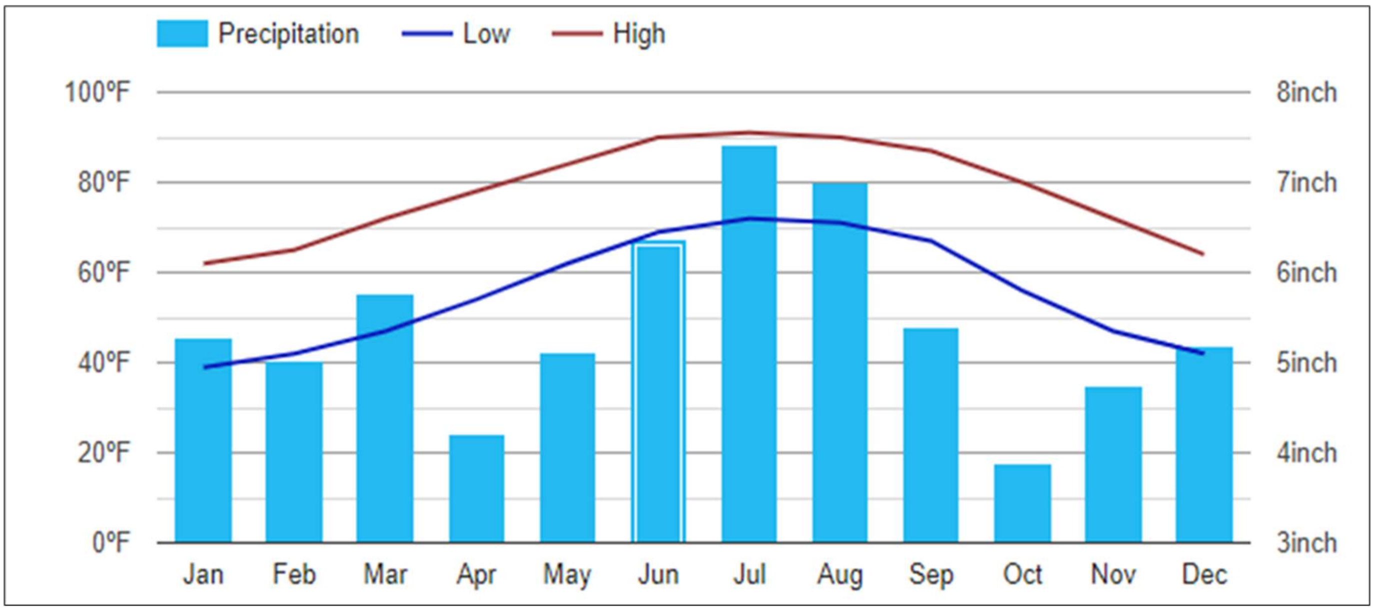



*Figure 7: Average Ambient Conditions for Moss Point, MS (chart from https://www.usclimatedata.com/climate/moss-point/mississippi/united-states/usms0690)*

*Table 6: Earthquake Codes*

| |
|---|
| ASCE 7-10/IBC 2012 |
| Risk Category III |
| Site Class D |
| Ss = 0.095 g |
| S1 = 0.059 g |
| SDC: B SEISMIC DESIGN CATEGORY |

### 3.2.3 Site Specific Design Considerations

The site is in an industrial area and the team did not identify any applicable regulatory/zoning restrictions that would prevent siting of the project. A ground snow design loading (according to ASCE 7-16/IBC 2018) of 0 PSF was used for the FEED. Design parameters for rain and wind are shown in the tables below.

*Table 7: Design Rainfall Intensity*

| Maximal | Average | Comments |
|---|---|---|
| 14.6 in per 24 hours | 10.9 in per 24 hours | Rainfall information from NOAA for Mississippi, USA |

*Table 8: Wind Design Codes and General Information*

| | Code | Comments |
|---|---|---|
| Building / structural steel | American Standard<br>IBC, ACI, ASCE, AWS, ASTM, PIP, AISC<br>Linde Standard ASCE 7-16/IBC 2018 | Load actions on building structures |
| Tanks, silos | ASCE 7-16/IBC 2018 API 600, API 620, API 650 | Loads of vertical vessels due to wind and seismic effects |
| Vessels, apparatus, pipes | ASCE 7-16/IBC 2018, API 620<br>ASME BPVC SECTION VIII, ASME B31.1, ASME B31.3 | Loads of vertical vessels due to wind and seismic effects |

*Table 9: Maximum Wind Design Value*

| maximal (miles/h) | Comments |
|---|---|
| 172 mph | Exposure C (Wind-borne debris region) |

### *3.2.4 Fuel Feedstock and Flue Gas Characteristics*

Plant Daniel currently has two approved suppliers for the natural gas feed to the CC units, the Southeast Supply Header (SESH) and Gulf South pipelines. SESH is the primary supplier. Representative natural gas compositions for 2021 are shown in Table 10.

*Table 10: Plant Daniel representative natural gas compositions*

| | | Avg | Max | Min |
|---|---|---|---|---|
| Heating Value | (BTU/CF) | 1,017 | 1,041 | 1,008 |
| Spec Grav | | 0.58 | 0.59 | 0.58 |
| Wobbe Idx | | 1,332 | 1,356 | 1,323 |
| $CO_2$ | mol% | 1.54 | 1.80 | 1.00 |
| $N_2$ | mol% | 0.12 | 0.20 | 0.04 |
| $C_1$ | mol% | 96.19 | 96.83 | 94.30 |
| $C_2$ | mol% | 1.92 | 4.15 | 1.14 |
| $C_3$ | mol% | 0.16 | 0.29 | 0.11 |
| $IC_4$ | mol% | 0.04 | 0.05 | 0.02 |
| $NC_4$ | mol% | 0.02 | 0.03 | 0.01 |
| $IC_5$ | mol% | 0.01 | 0.01 | 0.00 |
| $NC_5$ | mol% | 0.00 | 0.01 | 0.00 |
| $C_6$ | mol% | 0.00 | 0.01 | 0.00 |
| $C_6$+ | mol% | 0.01 | 0.01 | 0.00 |

The natural gas composition used in modeling combustion turbine performance to provide design flue gas compositions to the PCC unit is shown in Table 11. It should be noted the sulfur content of the natural gas was considered to be insignificant to the $CO_2$ capture process. Recent samples from the SESH pipeline indicated total sulfur levels of less than 3 ppmw.

*Table 11: Design Natural Gas Conditions*

| | | |
|---|---|---|
| Methane ($CH_4$) | % mol | 95.69 |
| Ethane ($C_2H_6$) | % mol | 2.14 |
| Propane ($C_3H_8$) | % mol | 0.62 |
| N-Butane ($C_4H_{10}$) | % mol | 0.29 |
| N-Pentane ($C_5H_{12}$) | % mol | 0.07 |
| Hexanes, Avg. ($C_6H_{14}$) | % mol | 0.11 |
| Nitrogen ($N_2$) | % mol | 0.28 |
| Carbon Dioxide ($CO_2$) | % mol | 0.80 |

A summary of the flue gas design parameters for the PCC Plant, excluding EGR, are shown in Table 12. The values listed in the "Design" case were used for the primary dimensioning of the new PCC plant equipment while the equipment design margins were based on the "Max" cases. For example, the maximum flue gas flow of the 'Max/25F' case established the design margin needed in the Direct

Contact Cooler (DCC), blower, and absorber equipment while the additional water content from duct firing in the 'Max/95F' case set the basis for flue gas cooling equipment in the DCC circulation loop.

*Table 12: Flue Gas Design Parameters*

| | | Max | | Design | Min |
|---|---|---|---|---|---|
| Ambient | °F | 25 | 95 | 65 | 95 |
| Combustion Turbines Operating | 1 / 2 | 2 | 2 | 2 | 1 |
| Duct Burner Status | On / Off | Off | On | Off | Off |
| Combustion Turbine Load | % | Near 100% | 100% | 100% | 50% |
| Combustion Turbine Steam Inj | On / Off | Off | On | Off | Off |
| Relative Total Mass Flow | | 1.06 | 0.98 | 1 | 0.32 |
| Estimated HRSG Exit Temp (after PCC integration) | °F | 240 | 240 | 240 | 240 |
| Current Stack Exit Pressure | psia | 14.65 | 14.65 | 14.65 | 14.65 |
| Anticipated DCC Inlet Pressure | psia | 14.39 | 14.43 | 14.42 | 14.56 |
| Approximate Stack Constituents | | | | | |
| Molecular Weight | lb/lbmole | 27.5 - 28.5 | | | |
| $N_2$ | Mol % | 69.0 – 75.0 | | | |
| $O_2$ | Mol % | 10.2 – 12.8 | | | |
| $CO_2$ | Mol % | 3.9 – 4.2 | | | |
| H2O | Mol % | 7.9 – 16.0 | | | |
| Ar | Mol % | 0.82 – 0.90 | | | |

### *3.2.5 Environmental Requirements*

#### *Air Permitting*

The construction of a new source of air emissions, or the modification of an existing source of air emissions, requires an air permit issued by the Mississippi Department of Environmental Quality (MDEQ). New or modified sources of emissions will trigger one of three types of air permitting, depending on the ambient air quality at the location of the facility and on the amount of new or increased emissions. "Minor" increases will require a state construction or minor permit, while "major" increases will trigger PSD review for areas in attainment with air quality standards or Non-attainment New Source Review (NNSR) assessments for proposed construction in areas that do not meet air quality standards[1]. A project can result in a combination of permits on a pollutant-by-pollutant basis. Importantly, PSD and NNSR permits, if required, must be obtained prior to beginning any construction activities. A PSD applicability review assesses the emissions profile of a proposed project for the purpose of determining which permits are required.

---

[1] An area is classified as unclassifiable/attainment if the ambient air quality concentration for a specific pollutant, as measured by an ambient monitor or indicated by air dispersion modeling, meets or is cleaner than the standard concentration level for a set of averaging periods. Jackson County, Mississippi, the area in which the proposed Project is located, is currently designated as unclassifiable/attainment for all NAAQS. Criteria pollutants are those for which EPA has established NAAQS and consist of $PM_{10}$, $PM_{2.5}$, CO, NOx, $SO_2$, lead, and ozone, which is formed through the photochemical reaction of VOC and NOx in the atmosphere.

If a PSD permit is required, it must be obtained prior to beginning construction. Once all engineering data, such as layouts, emissions data, stack parameters, etc., required to develop an air permit application is available to the permitting team, the timeline to develop an application and obtain a major PSD permit-to-construct is approximately 24 months as shown in the summary project schedule. Timelines can vary due to complexity of the project, permitting authority resources, and public participation.

Importantly, changes in the project design, including what may be considered minor adjustments, can affect the PSD applicability analysis. Accordingly, it is important to finalize as much of the design work as possible prior to submitting an air permit application and any changes should be discussed with the permitting team.

Preliminary estimates of the air emission impacts of adding PCC to a NGCC unit indicate potential increases in some PSD pollutants that would require PSD review including a BACT evaluation, air quality assessment, and other steps. After completing this process, state regulatory authorities would make a final determination on whether additional control technologies are required to manage PSD pollutants. For this FEED study and estimate, no additional control technologies were included other than standard features of the absorber wash section.

### *Water Permitting*

Plant Daniel has a National Pollutant Discharge Elimination System (NPDES) permit with Mississippi Department of Environmental Quality (MDEQ) that was issued in 2015 and expired in 2020. As of late 2020, Plant Daniel is under administrative continuance awaiting a newly issued permit from MDEQ.

Retrofit of the PCC process per the FEED design would add an internal wastewater stream discharged to the Industrial Waste Water Pond (IWWP) at Plant Daniel, and an additional blowdown stream from the cooling towers would add to the existing cooling tower discharge, prior to final discharge to the Black Creek Cooling Facility (BCCF). These additional wastewater streams would require an NPDES permit modification. However, since this is an internal stream and the BCCF is non-waters of the US, based on conversations with MDEQ, a potential project would expect to be required to submit a safety data sheet (SDS) of any newly added chemical processes, a memo explaining the treatment plan, calculated concentrations at the discharge point, and an updated water balance drawing. Therefore, no additional wastewater control technologies were identified or included in the FEED design or estimate.

#### Stormwater Permitting

Stormwater collected both outside and within the process containment curb would be discharged through the existing South Stormwater Basin. Stormwater collected within the process containment boundary would be verified to be free of chemicals (amine solvent, anti-foam agent, etc.) and oil & grease prior to being discharged. Contaminated stormwater would be manually extracted from the sump via vac truck or pump and routed to the IWWP or another external destination for treatment.

Plant Daniel is currently permitted under the MDEQ Industrial Stormwater General Permit. Application for recoverage would not be required with retrofit of PCC to the unit, however, MPC Environmental Affairs staff would need to update the site Stormwater Pollution Prevention Plan (SWPPP) to include any new potential pollutants to stormwater. The updated SWPPP would be submitted to MDEQ.

$CO_2$ capture Cooling Tower Blowdown (CTBD)

CTBD would be discharged along with the existing Unit 3 and 4 Cooling Tower Blowdown to the BCCF canal. Flue gas condensate from the DCC cooler would be routed to the cooling tower system as makeup. The cooling tower would be design for three cycles of concentration and the blowdown would not require further treatment.

Process Wastewater

Process Wastewater would consist of process condensate from the $CO_2$ compressor package and wastewater from the solvent reclaim unit. Based on current water quality estimates, Process Wastewater would be transferred to the site's existing IWWP through the Unit 4 steam turbine area sump and discharged to BCCF as described previously.

Maintenance Wash Wastewater

Maintenance wash water from both pre-commissioning and outage activities would be expected to have significantly variable water quality. This waste stream would be drained and collected at the slop vessel and then transferred to a maintenance water tank included in the FEED cost estimate for intermediate storage. Options for handling this waste stream include the existing IWWP, temporary treatment, or off-site disposal depending on the characteristics of the stream.

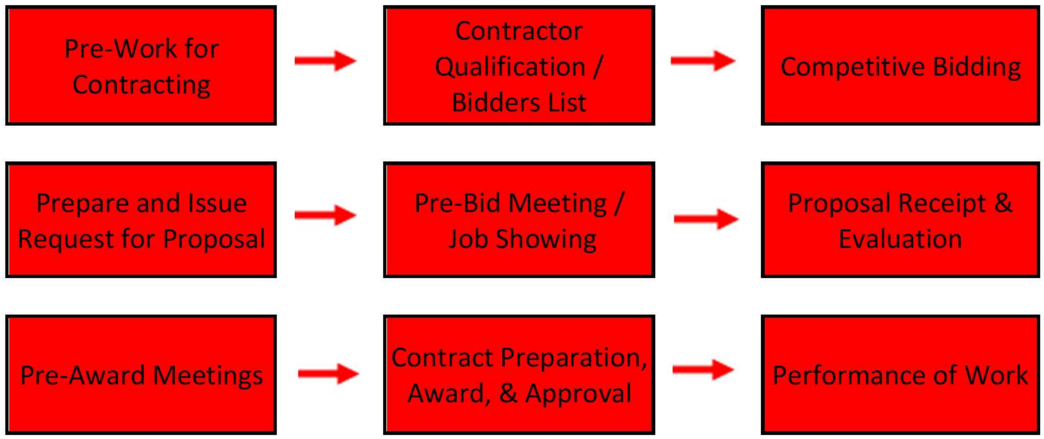
*Solid Waste Disposal*

Circulating solvent in a $CO_2$ capture process typically becomes impacted by salts and other impurities over time. These constituents must be removed to maintain long-term solvent performance. For the FEED, the solvent loop includes both mechanical filters and a carbon vessel containing consumable materials which would be replaced periodically. Based on applicable plant experience, the constituents are not expected to be hazardous, so the filters and activated carbon could be tested and declared nonhazardous before disposal in an off-site landfill. No additional control technologies are expected or included in the FEED design or estimate.

### 3.3 Basic Contracting and Purchasing Strategy

The pricing methodology used in a contract may be turnkey, lump sum, unit price, time and material, cost plus, or a combination of the above. Each pricing methodology has its advantages and disadvantages. The User (company personnel who initiates the contract) and the Lead Support Organizations (LSOs) will jointly determine the best pricing methodology to use, based upon the services to be performed, goods or commodities to be procured, and other factors.

The following "Contract Development Process" sets forth basic contracting activities listed in sequence to their occurrence. Some of these steps or activities do not apply to all contracts but are provided for consideration when the need for a contract has been identified. Most of these steps will be performed by the LSO for major or high-risk contracts. For contract procurement activities delegated to the User, the User should consider these steps or activities in procuring the contract service and should document when and why any steps were omitted.




Pre-Work for Contracting

Contract preparation activities that may be performed by the User include:

- Identify business, technical, and other risks and issues associated with services to be performed or the goods or commodities to be procured.
- Prepare specifications and/or comprehensive scope of work to be performed (adequately detailed to allow for competitive bidding).
- Identify Company or other third-party documents or other records which may be provided or made available to determine if confidentiality protection is needed.
- Identify the work schedule (start and end dates at a minimum) for the work.
- Identify prospective bidders technically capable to provide the services.
- Consider the pricing type desired.

Contractor Qualification and Bidders List

To do business with the Company, all potential contractors must:

- Commercially qualify (the extent of due diligence is determined by overall contract risks – due diligence can include, but is not limited to, creditworthiness, legally qualified to conduct business in the applicable state(s), evaluation of outstanding litigation, etc.)
- Conduct business transactions according to the highest ethical standards
- Comply with all applicable local, state and federal laws
- Demonstrate on-time deliveries, low pricing, and high-quality work or service
- Foster a relationship of mutual trust
- Be technically qualified as determined by the User.

Southern Company has a Supplier Diversity Program to actively seek small and diverse businesses that offer quality, reliable, and competitively priced goods and services. Additionally, by virtue of our business with the federal government, each of our operating companies are contractually committed to exercise commercially reasonable and good faith efforts to provide subcontracting opportunities to small business, veteran-owned small business, service-disabled veteran-owned small business, HUBZone small business, small disadvantaged business, and women-owned small business concerns. The program identifies disqualification factors including the following:

1. Felony conviction of Contractor or current officers within the last five years;
2. Disbarment from doing business with Federal Governmental within the last five years;
3. Pending criminal review or proceeding of Contractor or current officers;
4. Previous unsatisfactory work performance or contractor breach of contract;
5. Unsatisfactory Safety performance (reference *Chapter IV* for specific requirements); or
6. Other substantial compliance or legal issues.

If applicable, a bid list will be developed generally for the sources below:

- Contractors that have previously satisfactorily performed similar work or provided similar leased equipment/commodities for the User or the Company.
- Contractors that have previously satisfactorily performed similar work for Affiliates
- Prospective contractors who have been pre-qualified to bid on Company contracts
- Prospective contractors identified by the Company supplier diversity function

Bid lists will only include potential contractors that are considered capable of performing work or providing the goods or commodities in conformance with all contract requirements and to whom the Company is prepared to award the contract if they submit the lowest evaluated bid.

Competitive Bidding

In developing contracts, the Company seeks to obtain the highest value for the lowest evaluated price, which is not necessarily the lowest price. The primary method that the Company uses to obtain the highest value is to seek competitive bids. Competitive bids are solicited from a sufficient number of bidders as a method of seeking effective competition.

The reasons for not obtaining competitive bid prices are discussed below:

- Insufficient time to obtain competitive bids due to emergency or other unavoidable circumstances.
- Lack of other qualified contractors.
- Sufficient information is available from similar, recent bids to justify commitment
- Agreements relating to research and developmental, and environmental contracts.
- Strategic partnerships or other teaming agreements.
- Small dollar contracting activities, as defined in applicable Company procedures.
- Prohibited by law or professional code of conduct.
- Other authorized applicable Company exemptions.

A formal Request for Proposal (RFP) consisting of transmittal letter, instructions to bidders, written detailed specifications, drawings, general, special and/or supplemental terms and conditions, and/or proposal forms is the preferred basis for obtaining competitive bids.

Proposal Receipt & Evaluation

The purpose of the evaluation of the proposal is to determine the highest value (combining commercial and technical evaluations) for the lowest evaluated cost. The lowest price does not necessarily mean the highest value. After award of the work, the bidders may be told who was awarded the work and in what order their bids were ranked, but shall never be informed of the dollar amounts, differences, or percentage differences.

Contract Preparation, Award, and Approval

Before any contract is approved, it shall be in writing and in proper form. Except for emergency or other approved circumstances, all contracts shall be in writing and fully executed (signed by both parties). The contract should be first signed by the Contractor and then signed by the responsible Company representative.

A Limited Notice to Proceed (LNTP) is used in special circumstances to allow the contractor to proceed with certain elements of the work (such as drawings, design, etc.) while negotiations on the final contract are still underway. Once the contract is signed by both parties, a notice to proceed will be issued to the contractor.

## 3.4 Engineering Design Packages

The following subsections provide examples of the engineering packages produced as part of the FEED. Please note that some information that is not included in this report was produced to inform the estimate but embodies trade secrets and/or proprietary information and has been protected accordingly.

### *3.4.1 Process Engineering*

Process engineers produced the following deliverables in support of the overall FEED effort.

#### *Process Area Descriptions*

Flue Gas Pre-Treating

Flue gas is routed to the PCC plant from the HRSG outlet of each combustion turbine at low pressure and a temperature range of about 240°F. The flue gas is routed from the stack of one HRSG to one PCC train resulting in the following configuration:

- Flue Gas from stack HRSG 1 → PCC train 1
- Flue Gas from stack HRSG 2 → PCC train 2

The current FEED package design basis is an “open” HRSG stack concept. Neither the design nor the cost estimate includes diverter dampers at the HRSG stacks. This decision was made early in conceptual development to minimize perceived risk and design/construction costs associated with pulling a vacuum on the flue gas transfer duct and DCC if the damper inadvertently closed during PCC blower operation. However, computational fluid dynamics (CFD) modeling conducted after the equipment was designed indicated this configuration would present challenges in controlling the amount of air ingress through the stacks. Additional analysis is needed, when detailed fan curves and control logic are available during detailed design, to determine if this configuration is consistently achievable and if the risks and costs associated with vacuum warrant the additional complexity and risks of an "open" HRSG stack.

The incoming flue gas of each HRSG is split into two flue gas streams per PCC train. The control of the flue gas flow is identical for both PCC trains. Whereas one flue gas stream per train is flow controlled, the other flue gas stream is regulated by differential pressure. Flow control is based on the calculated flue gas flow of the corresponding gas turbine train. The generated flow signal is divided by two and transferred as a set point to the flow controller actuating the IGV of the Flue Gas Blower. The remaining flue gas flow is differential pressure controlled based on atmospheric pressure via the IGV of the Flue Gas Blower.

Flue gas enters the respective DCC column where it is cooled to the required inlet temperature of the downstream Absorber column. Circulating water is pumped by the DCC Circulation Pump to the top of the respective Direct Contact Cooler while flue gas enters at the bottom of the cooling column. Thus, water passes in a counter current direction to the flue gas and removes heat from the gas stream. Circulating process water is cooled in the DCC Cooler by means of cooling water. Condensed water from the Flue Gas is used as makeup to the PCC process cooling tower.

After passing through the DCC, the cooled flue gas is pressurized by the Flue Gas Blower to overcome the pressure drop of all upstream and downstream PCC equipment until the gas leaves the Absorber Column as Treated Flue Gas to atmosphere.

### $CO_2$ Absorption

Like the Flue Gas Pre-Treating section, the $CO_2$ Absorption section of the PCC plant is divided into two sub-systems per PCC train resulting in four Absorber Columns in total. The pressurized flue gas is fed from the Flue Gas Blower to the bottom of the respective Absorber Column. Upstream of the first of the two Absorber Columns, Flash Gas coming from the Rich Solution Flash Vessel is mixed into the flue gas flow. In the Absorber Column, the flue gas passes in a counter-current flow to the liquid washing agents.

Each Absorber Column consists of four different sections (A to D). The lower two sections (C & D) represent the $CO_2$ absorption section which is operated with the amine-based washing agent. In the $CO_2$ absorption section, 90% of the CO2 is captured from the flue gas. The upper two segments (A & B) are divided into a "dry" bed section and a backwash section. Both upper sections are designed to reduce impurities (e.g., trace amine) out of the gas stream.

In the Absorber Column, flue gas passes upwards through two packed absorption beds which promote the mass transfer of $CO_2$ from the gas into the circulating amine wash liquid. The temperature in this section increases due to the exothermic absorption process. Amine Solution entering the Absorber Column above the $CO_2$ Absorption section is collected below the first of the two packed beds before being redistributed over the second absorption bed. A high-performance packing with low pressure drop and high mass transfer capacity leads to an optimized column diameter.

The two beds in the emission control section of the Absorber Column target the precipitation of liquid carried over from the Absorber beds. In the upper column beds process water passes counter-current to the upstreaming gas flow. With the implementation of both bed sections emissions in the gas flow leaving the Absorber Column are effectively controlled and reduced. The emission control section consists of a “Dry” bed and a backwash section. In the backwash section wash water is circulated by the respective Absorber Wash Water Pump from the first chimney tray through the water-cooled Absorber Wash Water Cooler. Demineralized water from battery limit is supplied to the wash water cycle to avoid the accumulation of amines in the water cycle and to adjust the water balance of the plant. $CO_2$-lean flue gas leaves the top of the Absorber Column and is sent to atmosphere as Treated Flue Gas.

The $CO_2$-rich absorbent solution withdrawn at the bottom of each Absorber is fed by the Rich Solution Pump via the Rich/Lean Solution Heat Exchanger to the Rich Solution Flash Vessel. From the flash vessel, the Rich Solution flow is controlled via valve, using the incoming $CO_2$ flow with the flue gas as control variable. In the Rich/Lean Solution Heat Exchanger, Rich Solution is heated by Lean Solution leaving the Stripper Interstage Heater.

### Regeneration

In the Flash Vessel, the rich amine solution streams from the two Absorber sub-systems are combined. A small vapor fraction is separated from the Rich Solution flow and recycled back to one of the Absorber Columns of each train. The flash vessel pressure is regulated via pressure control valve located at the gas outlet of each flash vessel.

The Rich Solution Booster Pump transfers the preheated Rich Solution from the Flash Vessel to the respective Stripper Column. The solution flow rate is regulated via liquid level control in the Flash Vessel.

Regeneration of the amine solution is fulfilled in the Stripper Column. Each Stripper Column consists of three packed bed sections. While the two lower sections are designed as stripping segments, the top section is the wash section run with process condensate from the respective Stripper Reflux Drum.

The hot Rich Solution enters the upper part of the stripping section and passes counter-current to the ascending vapor generated in the Reboiler. The amine solution is collected on the chimney tray between both stripping sections. It is further heated in the Stripper Interstage Heater with hot Lean Solution leaving the Stripper at the bottom. The heated Rich Solution is fed back to the Stripper column above the lower stripping section and passes downwards counter-current to the vapor.

The installation of the Stripper Interstage Heater Pump and the Stripper Interstage Heater are an integral part of the low energy, efficient process configuration that allows to significantly reduce the specific thermal energy consumption of the process.

Superheated LP Steam from battery limit is used to provide the regeneration heat in the Stripper Reboiler. The required thermal duty of the reboiler is adjusted by regulating the effective heat transfer area. The Reboiler duty is derived by the $CO_2$ flow entering each Absorber sub-system with the flue gas. In the Reboiler the LP Steam is condensed and Steam Condensate is collected in the Steam Condensate Drum. Steam Condensate is sent back level-controlled to battery limit via Steam Condensate Pump.

After leaving the Stripper Column, the wet $CO_2$ gas is cooled in the Stripper Condenser against cooling water. Condensate and $CO_2$ rich gas are separated in the Stripper Reflux Drum. Whereas the condensate is returned to the top of the Stripper Column by the Stripper Reflux Pump, the $CO_2$ Raw Gas is sent to the $CO_2$ Compression Unit. The pressure in each Stripper column is regulated via suction pressure control by the respective $CO_2$ compressor.

Regenerated Amine Solution leaves the bottom of the Stripper Column and is cooled in the Stripper Interstage Heater. Downstream of the Stripper Interstage Heater, the flow of $CO_2$ lean amine solution is re-divided to supply the two Absorber sub-systems with the required amine flow. The total Lean Solution flowrate is controlled via liquid level in the Stripper Column. The precooled Lean Amine Solution to each Absorber sub-system is further cooled in the Rich/Lean Solution Heat Exchanger with Rich Solution coming from the Absorber Column. Final cooling is achieved in the Lean Solution Cooler, operated with cooling water. Cooled Lean Solution is routed back to the Absorber Column by the Lean

Solution Pump. Downstream of each Lean Solution Pump, a small portion of the lean solution is routed to the Reclaiming Unit. The plant design includes one reclaiming unit for the whole plant (two trains).

In one of the two Absorbers of train 1 and train 2 a portion of Lean Solution is routed over a Mechanical Filter and an Activated Carbon Filter which are used to eliminate solid matters. Solid elements might be generated by solution degradation or can be introduced with the feed gas stream.

### $CO_2$ Compression and Drying

The $CO_2$ Raw Gas from each Stripper is compressed in a centrifugal, multi-stage $CO_2$ Compressor Unit. The oil system and all Gas Coolers are considered as part of the compressor unit.

The $CO_2$ compressor is divided in a low-pressure section and a high-pressure section. After compression in the low-pressure section the $CO_2$ gas is cooled in the Raw $CO_2$ Chiller Unit against a refrigerant to reduce the water concentration in the gas flow. The generated condensate is separated in the Water Separator. All condensate flows generated in the interstage gas coolers of the $CO_2$ Compressor and the condensate produced in the Water Separator are collected in the Condensate Flash Vessel. The Condensate Flash Vessel is operated near atmospheric pressure. Whereas the separated flash gases are vented via the Vent Gas Silencer to Atmosphere the condensate is pumped by the Condensate Flash Vessel Pump to battery limit.

The compressed $CO_2$ leaves the $CO_2$ compressor at around 2200 psig and is routed to battery limit.

### *Block Flow Diagram*

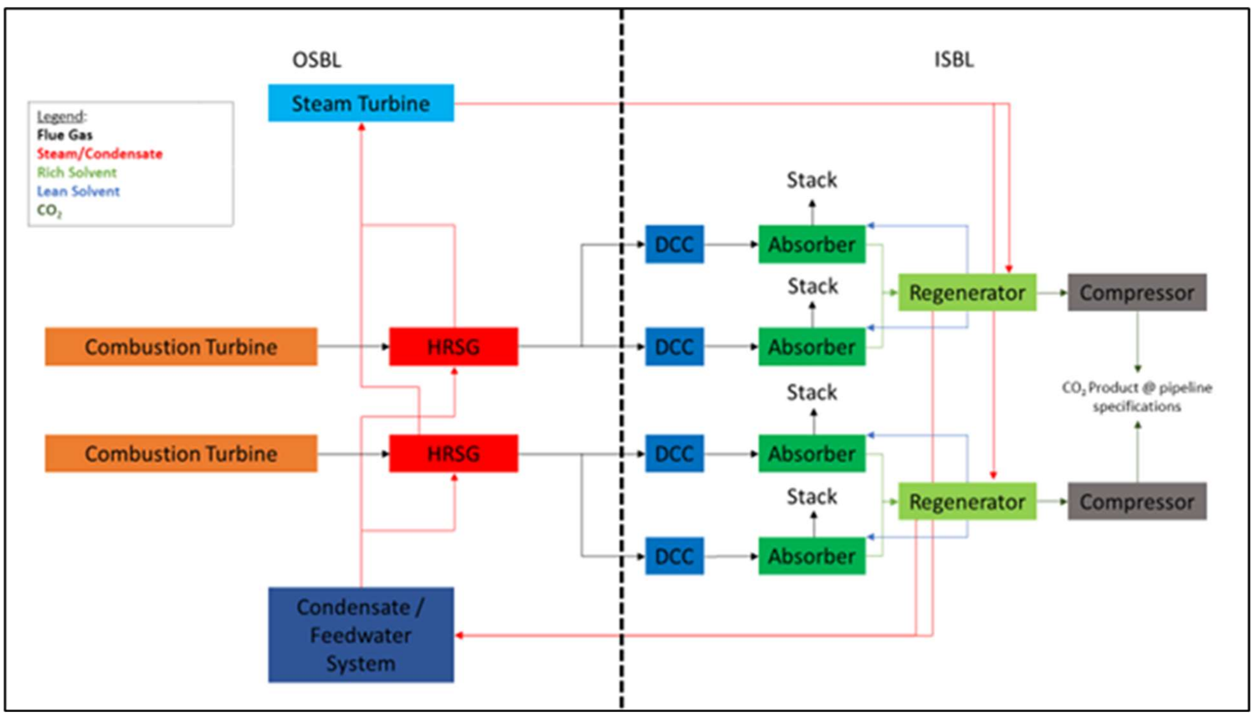



*Figure 8: Block Flow Diagram*

### *Process Flow Diagram and Heat and Material Balances*

A summary Process Flow Diagram (PFD) is shown in Figure 9. A full heat and material balance (HMB) would embody trade secrets for the PCC system, but a summary of 1 $CO_2$ capture train is provided in Table 13.

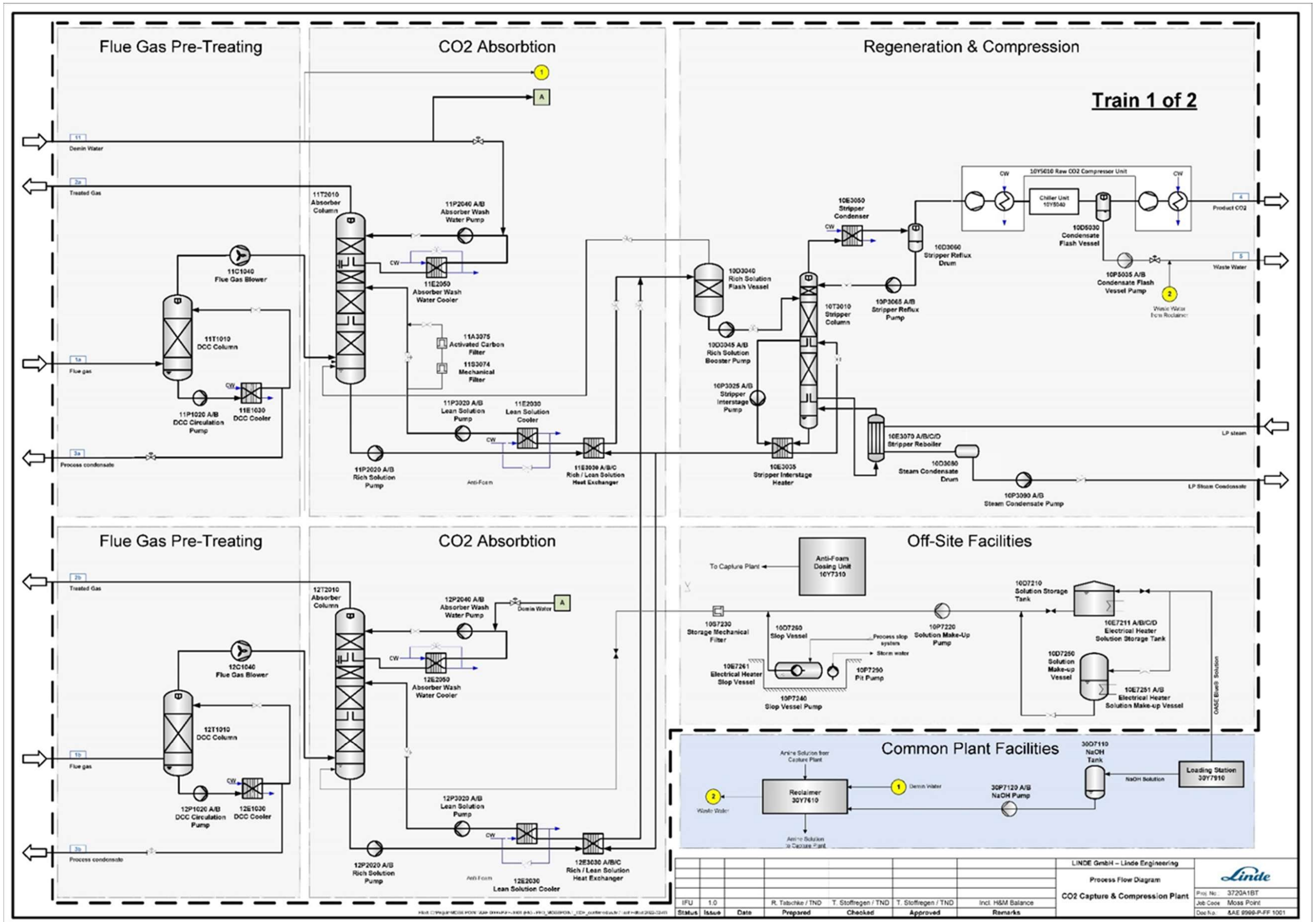



*Figure 9: Process Flow Diagram*

*Table 13: PCC Heat and Material Balance*

Linde GmbH, Linde Engineering Dresden

## NCC20002 Carbon Capture Study

**FEED Study for Carbon Capture Systems on Natural Gas Power Plants**

Linde

| | | | |
|---|---|---|---|
| Project | MOSS POINT | Project No. | 3720A1BT |
| Client | Southern Company | Date | 2022-06-28 |
| Capacity | 2443 ShortTPD | Issue | Issue 2.0 |
| | Design Case | Prepared | Tatschke |

**Stream List** Feed, Product and By-Products

| Stream | | Flue Gas Sub-Train 1/4 | Flue gas Sub-Train 2/4 | Treated Gas Sub-Train 1/4 | Treated Gas Sub-Train 2/4 | Condensate Sub-Train 1/4 | Condensate Sub-Train 2/4 | Product CO2 Train 1 | Waste Water Train 1 | Demin Water Train 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream-Number | | < 1 a > | < 1 b > | < 2 a > | < 2 b > | < 3 a > | < 3 b > | < 4 > | < 5 > | < 11 > |
| Molar Flow | MMSCFD(60F) | 591 | 591 | 566 | 566 | 8 | 8 | 42 | 3 | 10 |
| Mass Flow | lb/hr | 1'839'500 | 1'839'500 | 1'728'710 | 1'728'710 | 15'055 | 15'055 | 203'670 | 6'557 | 20'613 |
| Actual Volume Flow | ft3/hr | 33'283'385 | 33'283'385 | 25'824'534 | 25'824'534 | 243 | 243 | 5'705 | 105 | 332 |
| Temperature | F | 240 | 240 | 110 | 110 | 95 | 95 | 115 | 84 | 77 |
| Pressure | psia | 15 | 15 | 15 | 15 | 60 | 60 | 2'215 | 48 | 95 |
| | | | | | | | | | | |
| Mass Flow CO2 | lb/hr | 113'149 | 113'149 | 11'314 | 11'314 | 1 | 1 | 203'621 | - | - |
| Mass Flow CO2 | ShortTPD | 1'358 | 1'358 | 136 | 136 | 0 | 0 | 2'443 | - | - |
| **Component** | | | | | | | | | | |
| CO2 | Mol-Frac | 0.039595 | 0.039595 | 0.004139 | 0.004139 | 0.000015 | 0.000015 | 0.999434 | 0.000413 | 0.000000 |
| H2O | Mol-Frac | 0.090599 | 0.090599 | 0.086228 | 0.086228 | 0.999975 | 0.999975 | 0.000554 | 0.999160 | 1.000000 |
| Nitrogen | Mol-Frac | 0.739689 | 0.739689 | 0.773542 | 0.773542 | 0.000006 | 0.000006 | 0.000005 | 0.000000 | 0.000000 |
| Argon | Mol-Frac | 0.008800 | 0.008800 | 0.009204 | 0.009204 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Oxygen | Mol-Frac | 0.121298 | 0.121298 | 0.126869 | 0.126869 | 0.000002 | 0.000002 | 0.000002 | 0.000000 | 0.000000 |
| CO | Mol-Frac | 0.000008 | 0.000008 | 0.000009 | 0.000009 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| NO | Mol-Frac | 0.000001 | 0.000001 | 0.000001 | 0.000001 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| NO2 | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| SO2 | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| HCl | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Ammonia | Mol-Frac | 0.000002 | 0.000002 | 0.000000 | 0.000000 | 0.000002 | 0.000002 | 0.000000 | 0.000068 | 0.000000 |
| Methane | Mol-Frac | 0.000008 | 0.000008 | 0.000008 | 0.000008 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| NaOH | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Amine | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000338 | 0.000000 |
| AcetAldehyde | Mol-Frac | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000004 | 0.000022 | 0.000000 |

### *Piping and Instrument Diagram*

Piping and instrumentation diagrams (P&IDs) were created for the project but include information that embodies trade secrets and are considered protected data.

### *HAZOP/PHA*

Linde conducted a Hazard and Operability (HAZOP) study as part of the project. A report was produced but also embodies trade secrets and is considered protected data.

### *Major Process Equipment Specifications and Data Sheets*

Major process equipment specifications were produced and used to obtain vendor quotes to support the FEED estimate. However, these equipment specifications do embody trade secrets and are considered confidential information.

### *Equipment List*

SCS and Linde developed the following equipment lists for the OSBL and ISBL scopes, respectively.

*Table 14: OSBL Equipment List*

| Description |
|---|
| Cooling Water System Cooling Tower, 10 cell, Mechanical Draft, Fiberglass Construction |
| Cooling Water System Circulating Pumps (2 ea.), 61,500 gpm, 124' TDH, Vertical Pumps with Drivers |
| Instrument/Plant Air System Air Compressors (2 ea.), 200 HP, 125 PSIG, Air Cooled compressors with Drivers, Filters, and Dryers |
| Demineralized Water Pumps (2 ea.), 100 gpm, 170' TDH, Horizontal End Suction Pumps with Drivers |

*Table 15: ISBL Equipment List (Per $CO_2$ Capture Train)*

| Description |
|---|
| Rich Solution Flash Vessel, Column, Packing Column, Qty: 1 |
| Stripper Reflux Drum, Vessel, Vessel Vertical, Qty: 1 |
| Steam Condensate Drum, Vessel, Vessel Horizontal, Qty: 1 |
| Stripper Interstage Heater, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Stripper Condenser, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Stripper Reboiler, Straight Tube Heat Exchanger, Multi Pipe, Qty: 4 |
| Stripper Interstage Pump, Pump, Centrifugal, Qty: 2 |
| Rich Solution Booster Pump, Pump, Centrifugal, Qty: 2 |
| Stripper Reflux Pump, Pump, Centrifugal, Qty: 2 |
| Steam Condensate Pump, Pump, Centrifugal, Qty: 2 |
| Stripper Column, Column, Packing Column, Qty: 1 |
| Raw $CO_2$ Compressor, Compressor, Centrifugal, Qty: 1 |
| Refrigerant Compressor, Compressor, Centrifugal, Qty: 1 |
| Condensate Flash Vessel, Vessel, Vessel Vertical, Qty: 1 |

| **Description** |
| --- |
| Water Separator, Vessel, Vessel Vertical, Qty: 1 |
| Interstage Cooler I, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Interstage Cooler II, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Interstage Cooler III, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Interstage Cooler IV, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Interstage Cooler V, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Raw $CO_2$ Cooler, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Refrigerant Condenser, Straight Tube Heat Exchanger, Stand-Alone, Qty: 1 |
| Raw Gas Chiller, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Vent Gas Silencer, Silencer, Blow-Off, Qty: 1 |
| Condensate Flash Vessel Pump, Pump, Centrifugal, Qty: 2 |
| Raw $CO_2$ Compressor Unit, Package Unit, Compressor Unit, Qty: 1 |
| Raw $CO_2$ Chiller Unit, Package Unit, Refrigeration Unit, Qty: 1 |
| Solution Storage Tank, Tank, Single Wall Flat Bottom Tank, Qty: 1 |
| Solution Make-up Vessel, Vessel, Vessel Vertical, Qty: 1 |
| Slop Vessel, Vessel, Vessel Horizontal with Boot, Qty: 1 |
| Electrical Heater Solution Storage Tank, Electrical Heater, Integrated, Qty: 4 |
| Electrical Heater Solution Make-up Vessel, Electrical Heater, Integrated, Qty: 2 |
| Solution Make-up Pump, Pump, Centrifugal, Qty: 1 |
| Slop Vessel Pump, Pump, Centrifugal, Qty: 1 |
| Pit Pump, Pump, Centrifugal, Qty: 1 |
| Storage Mechanical Filter, Filter, Filter (Cartridge), Qty: 1 |
| Antifoam Dosing Unit, Package Unit, Inhibitor Dosing Uni, Qty: 1 |
| Flue Gas Blower, Compressor, Blower/Fan, Qty: 1 |
| DCC Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| DCC Circulation Pump, Pump, Centrifugal, Qty: 2 |
| DCC Column, Column, Packing Column, Qty: 1 |
| Flue Gas Blower, Compressor, Blower/Fan, Qty: 1 |
| DCC Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| DCC Circulation Pump, Pump, Centrifugal, Qty: 2 |
| DCC Column, Column, Packing Column, Qty: 1 |
| Activated Carbon Bed, Adsorber, Adsorber Vertical, Qty: 1 |
| Lean Solution Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Absorber Wash Water Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Rich/Lean Solution Heat Exchanger, Multi Stream Heat Exchanger, Plate & Frame, Qty: 3 |
| Rich Solution Pump, Pump, Centrifugal, Qty: 2 |
| Absorber Wash Water Pump, Pump, Centrifugal, Qty: 2 |
| Lean Solution Pump, Pump, Centrifugal, Qty: 2 |
| Mechanical Filter, Filter, Filter (Cartridge), Qty: 1 |

| Description |
| --- |
| Absorber Column, Column, Packing Column, Qty: 1 |
| Lean Solution Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Absorber Wash Water Cooler, Multi Stream Heat Exchanger, Plate & Frame, Qty: 1 |
| Rich/Lean Solution Heat Exchanger, Multi Stream Heat Exchanger, Plate & Frame, Qty: 3 |
| Rich Solution Pump, Pump, Centrifugal, Qty: 2 |
| Absorber Wash Water Pump, Pump, Centrifugal, Qty: 2 |
| Lean Solution Pump, Pump, Centrifugal, Qty: 2 |
| Absorber Column, Column, Packing Column, Qty: 1 |
| NaOH Tank, Vessel, Vessel Vertical, Qty: 1 |
| Electrical Heater NaOH Tank, Electrical Heater, Integrated, Qty: 2 |
| Reclaiming Unit, Package Unit, Inhibitor Dosing Unit, Qty: 1 |
| Truck Unloading Station, Package Unit, Loading Station, Qty: 1 |

### *Overpressure Relief, Flare Study, and Dispersion*

Linde performed analysis to show that any releases of $CO_2$ product from the PCC island vent locations do not create harmful $CO_2$ concentrations near the ground.  Detailed design will need to ensure that no personnel access platforms are located immediately adjacent to safety relief valves.

### *Summary of Effluents, Emissions, Consumable Materials, and Utility Load*

Utility and consumable information embodies trade secrets, but the following tables provide information on the effluents and emissions associated with the FEED based on the design case.

*Table 16: Treated Flue Gas from Absorber Column*

| Parameter | Unit | Treated Flue Gas 1 Absorber Column | Treated Flue Gas 4 Absorber Column |
|---|---|---|---|
| Molar Flow | MMSCFD | 565.6 | 2'262.6 |
| Mass Flow | lb/hr | 1'728'714 | 6'914'855 |
| Actual Volume Flow | ft3/hr | 25'824'596 | 103'298'383 |
| Temperature | °F | 110 | 110 |
| Pressure | psia | 14.7 | 14.7 |
| Mass Flow CO2 | lb/hr | 11'315 | 45'259 |
| Mass Flow CO2 | ShortTPD | 136 | 543 |
| | | | |
| Molar Flow | $Nm^3/hr$ | 631'461 | 2'525'845 |
| Mass Flow | tonne/h | 784 | 3137 |
| Actual Volume Flow | m3/h | 731'271 | 2'925'084 |
| Temperature | °C | 43 | 43 |
| Pressure | bara | 1.014 | 1.014 |
| Mass Flow CO2 | tonne/h | 5.1 | 20.5 |
| Mass Flow CO2 | MTD | 123.2 | 492.7 |
| | | | |
| **Composition** | | | |
| CO2 | Vol% | 0.41 | 0.41 |
| H2O | Vol% | 8.62 | 8.62 |
| Nitrogen | Vol% | 77.35 | 77.35 |
| Argon | Vol% | 0.92 | 0.92 |
| Oxygen | Vol% | 12.69 | 12.69 |
| NOx | ppmv | 1 | 1 |
| CO | ppmv | 9 | 9 |
| Ammonia | ppmv | < 5 | < 5 |
| SO2 | ppmv | 0 | 0 |
| VOC | ppmv | < 11 | < 11 |

*Table 17: Vent Gas from Condensate Flash Vessel*

| Parameter | Unit | Vent Stream from Condensate Flash Vessel 10D5030 | Vent Stream from Condensate Flash Vessel 20D5030 |
|---|---|---|---|
| Molar Flow | MMSCFD | 0.01 | 0.01 |
| Mass Flow | lb/hr | 45 | 45 |
| Actual Volume Flow | ft3/hr | 443 | 443 |
| Temperature | °F | 104.8 | 104.8 |
| Pressure | psia | 14.70 | 14.70 |
| Mass Flow CO2 | lb/hr | 44 | 44 |
| Mass Flow CO2 | ShortTPD | 0.53 | 0.53 |
| | | | |
| Molar Flow | Nm3/hr | 11 | 11 |
| Mass Flow | kg/h | 21 | 0.02 |
| Actual Volume Flow | m3/h | 13 | 13 |
| Temperature | °C | 40.5 | 40.5 |
| Pressure | bara | 1.01 | 1.01 |
| Mass Flow CO2 | kg/h | 20 | 20 |
| Mass Flow CO2 | MTD | 0.48 | 0.48 |
| | | | |
| **Composition** | | | |
| CO2 | Vol% | 92.55 | 92.55 |
| H2O | Vol% | 7.44 | 7.44 |
| VOC | ppmv | 79 | 79 |
| Ammonia | ppmv | 14 | 14 |

*Table 18: Vent Gas from Solution Storage Tank*

| Parameter | Unit | 10D7210 | 20D7210 |
|---|---|---|---|
| Flow (peak discontinuous) | SCFM / Nm³/h | 60 / 102 | 60 / 102 |
| Pressure | psia / bara | atmospheric | atmospheric |
| Temperature | °F / °C | 86 / 30 | 86 / 30 |
| **Composition** | | | |
| $CO_2$ | mol% | 0.03 | 0.03 |
| $H_2O$ | mol% | 1.7 | 1.7 |
| $N_2$ | mol% | 77.01 | 77.01 |
| $O_2$ | mol% | 20.36 | 20.36 |
| Ar | mol% | 0.90 | 0.90 |
| Amine | ppmv | 15 - 25 | 15 - 25 |

*Table 19: Vent Gas from Solution Make-up Vessel*

| Parameter | Unit | 10D7250 | 20D7250 |
|---|---|---|---|
| Flow (peak discontinuous) | SCFM / Nm³/h | 60 / 102 | 60 / 102 |
| Pressure | psia / bara | atmospheric | atmospheric |
| Temperature | °F / °C | 86 / 30 | 86 / 30 |
| **Composition** | | | |
| $CO_2$ | mol% | 0.03 | 0.03 |
| $H_2O$ | mol% | 1.7 | 1.7 |
| $N_2$ | mol% | 77.01 | 77.01 |
| $O_2$ | mol% | 20.36 | 20.36 |
| Ar | mol% | 0.90 | 0.90 |
| Amine | ppmv | 15 - 25 | 15 - 25 |

*Table 20: Vent Gas from Slop Vessel*

| Parameter | Unit | 10D7260 | 20D7260 |
|---|---|---|---|
| Flow (peak discontinuous) | SCFM / Nm³/h | 60 / 102 | 60 / 102 |
| Pressure | psia / bara | atmospheric | atmospheric |
| Temperature | °F / °C | 86 / 30 | 86 / 30 |
| **Composition** | | | |
| $CO_2$ | mol% | 0.03 | 0.03 |
| $H_2O$ | mol% | 1.7 | 1.7 |
| $N_2$ | mol% | 77.01 | 77.01 |
| $O_2$ | mol% | 20.36 | 20.36 |
| Ar | mol% | 0.90 | 0.90 |
| Amine | ppmv | 15 - 25 | 15 - 25 |

*Table 21: Vent Gas from NaOH Tank*

| **Parameter** | **Unit** | **30D7110** |
|---|---|---|
| Flow (peak discontinuous) | SCFM / $Nm^3/h$ | 60 / 27 |
| Pressure | psia / bara | atmospheric |
| Temperature | °F / °C | 86 / 30 |
| **Composition** | | |
| $H_2O$ | mol% | 3.30 |
| $N_2$ | mol% | 75.51 |
| $O_2$ | mol% | 19.96 |
| Ar | mol% | 0.88 |
| NaOH | mol% | 0.35 |

*Table 22: Flue Gas Condensate from Flue Gas Pre-Treating*

| **Parameter** | **Unit** | **Flue Gas Condensate from 1 DCC** | **Flue Gas Condensate Total from 4 DCC** |
|---|---|---|---|
| Mass Flow | lb/hr | 15'055 | 60'222 |
| Actual Volume Flow | USGPM | 30 | 121 |
| Temperature | °F | 94.7 | 94.7 |
| Pressure | psia | 60.5 | 60 |
| | | | |
| Mass Flow | tonne/h | 6.8 | 27.3 |
| Actual Volume Flow | m3/h | 6.9 | 27.5 |
| Temperature | °C | 34.8 | 34.8 |
| Pressure | bara | 4.2 | 4.2 |
| | | | |
| **Composition** 1) | | | |
| H2O | wt% | 100 | 100 |
| CO2 | ppmwt | 15 | 15 |
| Nitrogen | ppmwt | 6 | 6 |
| Argon | ppmwt | 0 | 0 |
| Oxygen | ppmwt | 2 | 2 |
| Ammonia | ppmwt | 2 | 2 |

Note 1): The table contains the most common components of the FG condensate. Components like ammonia, HCl and solids might be present in the flue gas entering the PCC Plant and will be disposed with the FG condensate.

Table 23: Process Condensate from $CO_2$ Compression & Drying Unit and Reclaiming Unit

| Parameter | Unit | Process Condensate Contaminated – 10/20D5030 & Reclaimer combined |
|---|---|---|
| Mass Flow | lb/hr | 13'114 |
| Actual Volume Flow | USGPM | 26 |
| Temperature | °F | 89 |
| Pressure | psia | 38.00 |
| | | |
| Mass Flow | tonne/h | 5.9 |
| Actual Volume Flow | m3/h | 5.9 |
| Temperature | °C | 31 |
| Pressure | bara | 2.62 |

Table 24: Activated Carbon

| Parameter | Unit | Per Train (1 of 2 Trains) |
|---|---|---|
| Type | 1) | Spent Activated Carbon |
| Quantity | ft³ / m³ | 2'328 / 66 |
| | lb / kg | 65'360 / 29'700 |
| Expected Lifetime | months | 12 |

### 3.4.2 Civil Engineering

The following subsections describe the civil engineering deliverables produced during the project.

#### Soil Load Analysis

Soil load analysis was performed for areas around the Plant Daniel Unit 4 combined cycle power plant and process island. A subsurface investigation report, which included foundation recommendations, was developed and provided to civil/structural design to inform the FEED efforts. This report provided the following recommendations:

- Augered cast-in-place piles (ACIP), or simply augercast piles, have been used successfully on many projects in the coastal region, including Plant Daniel. Preliminary discussions regarding this project indicated that augercast piles would be sufficient to support the anticipated loading.
- Foundation tip depths are expected to be between 55 and 75 feet.
- The subgrade for any shallow footings should be undercut by 24 inches and backfilled with structural fill.
- Slabs should be supported on at least 24 inches of structural fill or compacted crushed stone.

- Based on the results of seismic testing, the site is considered Class D in accordance with IBC 2021.

### *Storm Water Runoff Plan*

Plant Daniel has an existing stormwater runoff pond and all stormwater collected in the vicinity of the carbon capture island will be routed there. The stormwater network drawing on the following page, Figure 10, shows the plan developed by SCS civil engineers.

### *Spill Containment Assessment*

The project team evaluated spill containment requirements for the carbon capture system and developed a plan for each equipment train. Figure 11 displays the spill containment plan for each train that was incorporated into the foundation design. A containment curb surrounds all equipment containing solvent or derivatives along with U-drains and a sump for equipment draining for maintenance and for surface water collection. Material collected in the sump can be tested and routed as appropriate, either for treatment or disposal.

The standard approach for determining spill containment volume is to contain the largest full vessel plus an additional 10% for storm events. The project team confirmed that the curbed area plus the included sump exceeds that volume and no additional containment designs were required.

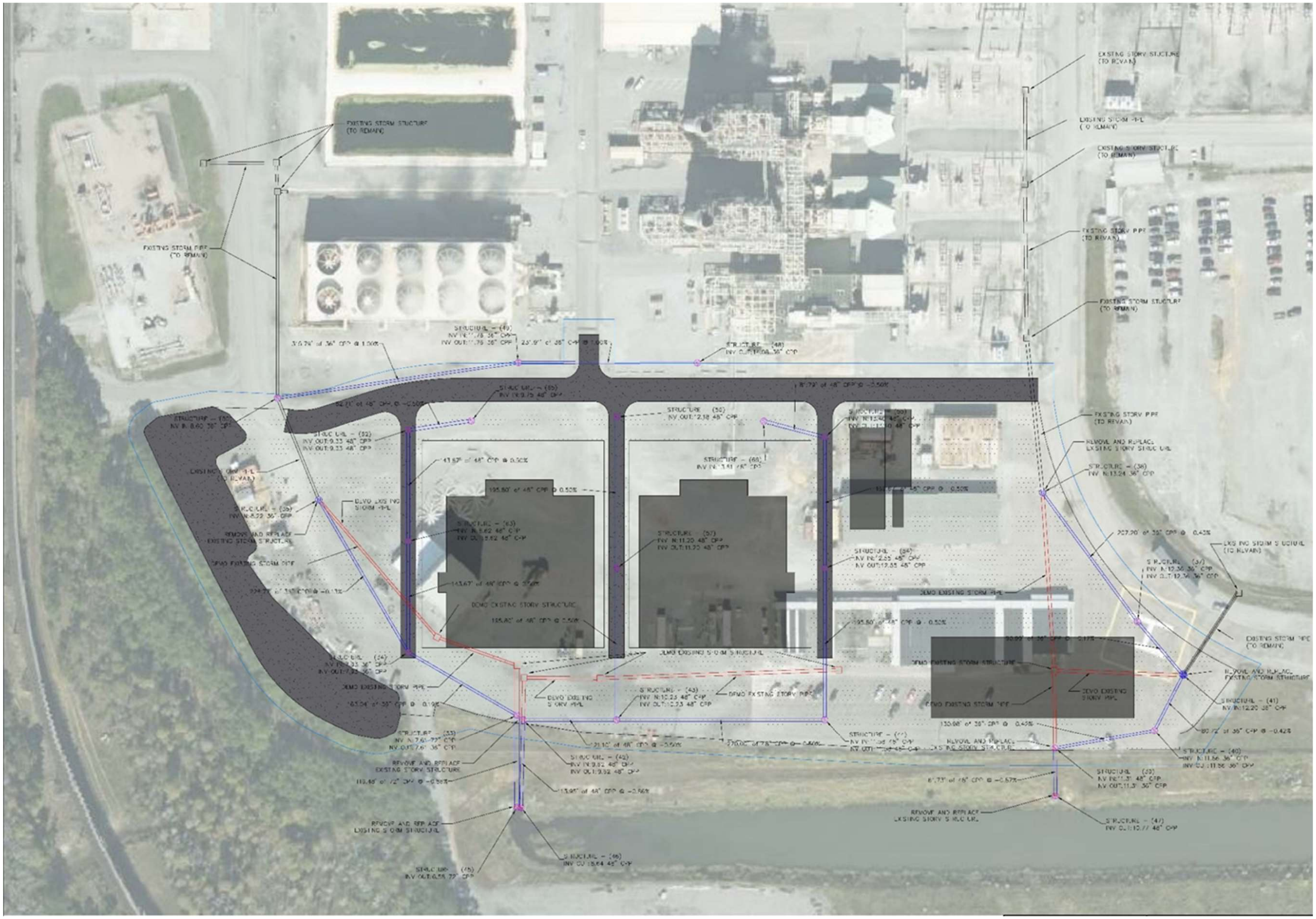


*Figure 10: Stormwater Network Drawing*

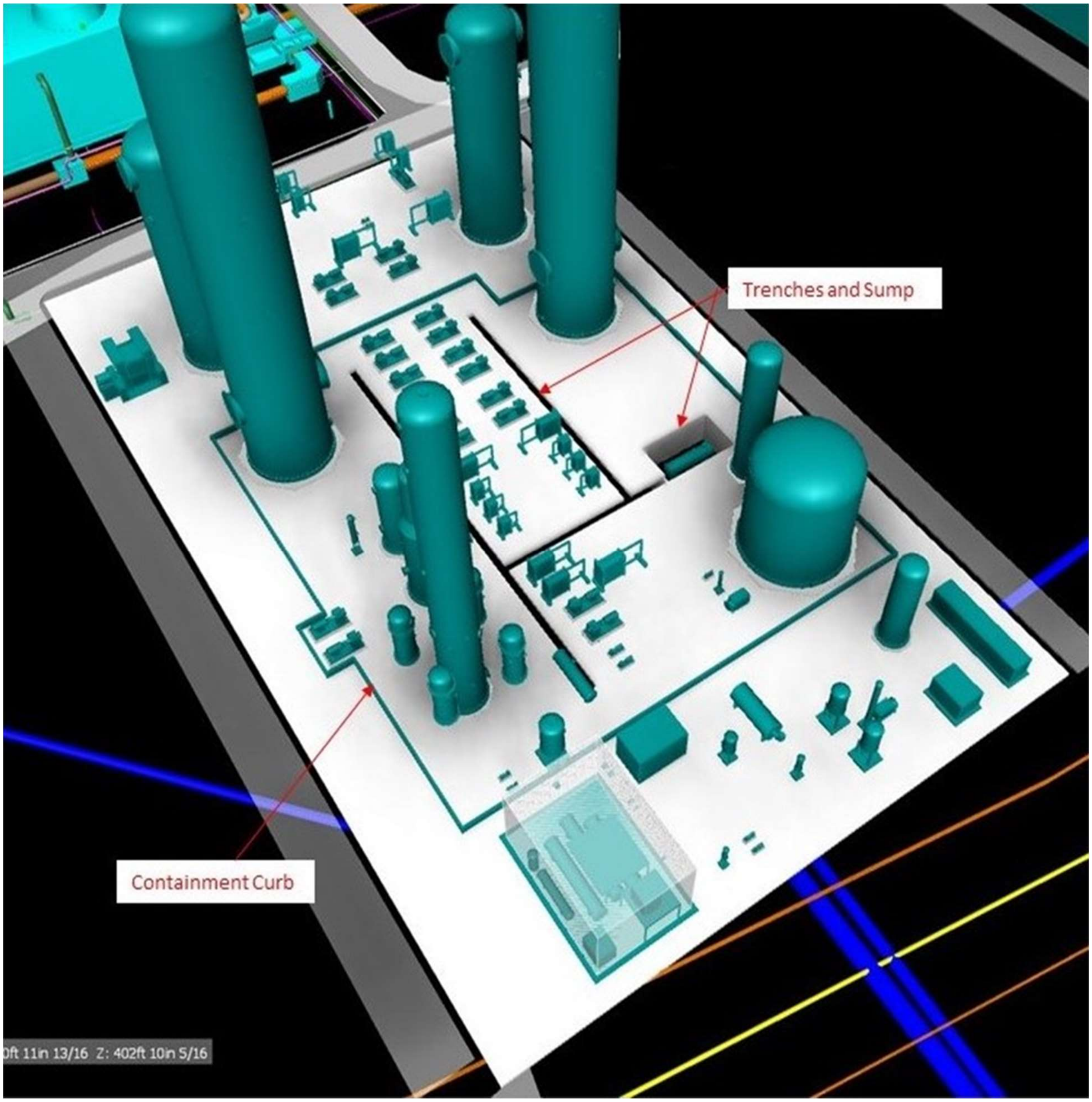



*Figure 11: Spill Containment Plan from 3D Model*

### *3.4.3 Structural Engineering*

SCS engineers were responsible for the overall foundation design and all OSBL structural steel. Linde engineers provided the structural steel design within the ISBL boundaries. The following sections outline the deliverables provided by structural engineers from both organizations that informed the cost and schedule estimates.

#### *Foundation Design Drawings*

SCS engineers produced foundation design drawings that detail the locations of underground deep foundations, mats, surface pads, drains, containment, and equipment pads. SCS engineers have standard detail drawings for the different components of foundation design and executed this specific design to reference and make use of those existing details. An example, summary drawing of the overall foundation design can be found in Figure 12 on the following page.

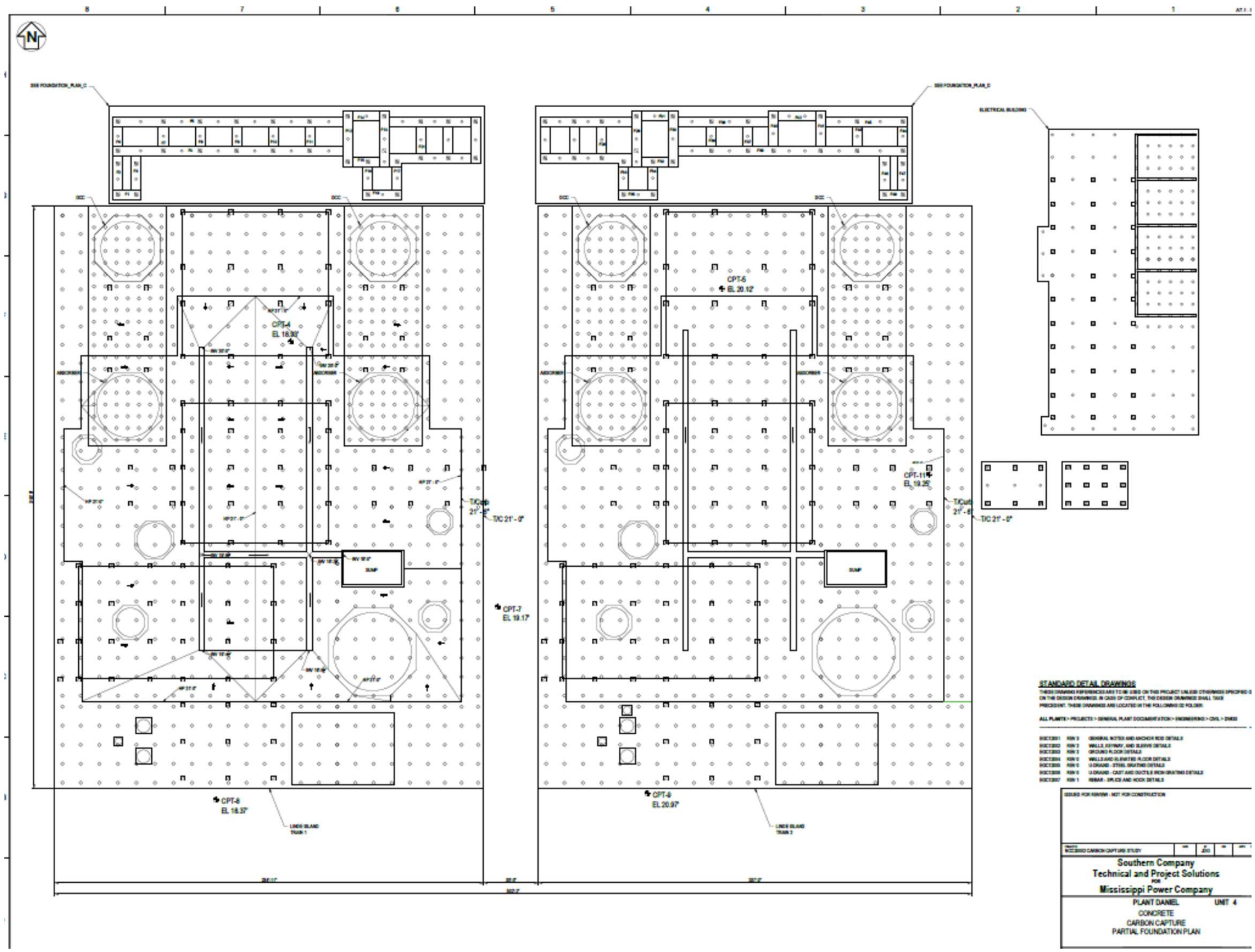



*Figure 12: Foundation Plan Drawing for ISBL*

### *Structural and Architectural Drawings*

SCS and Linde structural engineers produced drawings for all the structural and supporting steel for the OSBL and ISBL scopes, respectively.

*Table 25: OSBL Structural Drawings*

| Drawing Title / Description |
|---|
| Breaching & Duct Addition to Outlet Stack, Field Assembly & Details |
| Breaching & Duct Addition to Outlet Stack Details |
| Breaching & Duct Addition to Outlet Stack Base Ring Assembly & Details |
| Ductwork - Carbon Capture Duct 4A-03 Plan and Elevations |
| Ductwork - Carbon Capture Duct 4A-03 Plan and Elevations |
| Ductwork - Carbon Capture Duct 4A-09 Plan and Elevations |
| Ductwork - Carbon Capture Duct 4A-09 Plan and Elevations |
| Ductwork - Carbon Capture General Arrangement Sections |
| Ductwork - Carbon Capture General Arrangement Sections |
| Ductwork - Carbon Capture General Arrangement Plan |
| Ductwork - Carbon Capture General Arrangement Southwest Isometric View |
| Ductwork - Carbon Capture Support Arrangement Plan |
| Ductwork - Carbon Capture Support Arrangement Plan |
| Ductwork - Carbon Capture Expansion Joint Schedule and Details |
| Structural Steel - Carbon Capture Duct Support Steel Plan T/STL EL. 57'-6" |
| Structural Steel - Carbon Capture Duct Support Steel Plan T/STL EL. 57'-6" |
| Structural Steel - Carbon Capture Duct Support Steel Plan T/STL EL. 45'-4 1/4" |
| Structural Steel - Carbon Capture Duct Support Steel Plan T/STL EL. 45'-4 1/4" |
| Structural Steel - Carbon Capture Pipe Bridge Steel Plan T/STL EL. 66'-6" & Bents |
| Structural Steel - Carbon Capture Pipe Bridge Steel EL @ Bents |
| Structural Steel - Carbon Capture Pipe Bridge Steel EL @ Bents |
| Structural Steel - Carbon Capture Pipe Bridge Steel EL @ Bents |
| Structural Steel - Carbon Capture Ductwork Support Steel General Arrangement Plan |

*Table 26: ISBL Structural Drawings*

| Drawing Title / Description |
| --- |
| Design Basis and Criteria CSA Steel Structural |
| GROUNDLEVEL |
| Piperack / cablerack Isometric Views |
| Piperack / cablerack Plan views |
| Piperack / cablerack Axis A, B |
| Piperack / cablerack Rows |
| Cablerack Isometric Views |
| Cablerack Plan views |
| Cablerack Axis A, B |
| Cablerack Rows |
| Cablerack Isometric Views, Plan Views |
| Cablerack Rows, Axis |
| Flue Gas Pre-Treating Equipment Structure Isometric Views |
| Flue Gas Pre-Treating Equipment Structure Plan views |
| Flue Gas Pre-Treating Equipment Structure Axis A - D |
| Flue Gas Pre-Treating Equipment Structure Rows 1 - 4 |
| Flue Gas Pre-Treating Stairtower, Pipe Support Structure Isometric Views |
| Flue Gas Pre-Treating Stairtower, Pipe Support Structure Plan views |
| Flue Gas Pre-Treating Stairtower, Pipe Support Structure Plan views |
| Flue Gas Pre-Treating Stairtower, Pipe Support Structure Axis A - D, A-A |
| Flue Gas Pre-Treating Stairtower, Pipe Support Structure Rows 1 - 2 |
| $CO_2$ Absorption Equipment Structure Isometric Views |
| $CO_2$ Absorption Equipment Structure Plan views |
| $CO_2$ Absorption Equipment Structure Plan views |
| $CO_2$ Absorption Equipment Structure Axis A - D |
| $CO_2$ Absorption Equipment Structure Axis E |
| $CO_2$ Absorption Equipment Structure Rows 1 - 4 |

| Drawing Title / Description |
|---|
| Regeneration Equipment Structure Isometric Views |
| Regeneration Equipment Structure Plan views |
| Regeneration Equipment Structure Plan views |
| Regeneration Equipment Structure Axis A - D |
| Regeneration Equipment Structure Rows 1 - 4 |
| Regeneration Equipment Structure Rows 5 - 6, 0, Section A-A |
| $CO_2$ Compression & Drying Equipment Structure Isometric Views |
| $CO_2$ Compression & Drying Equipment Structure Plan views |
| $CO_2$ Compression & Drying Equipment Structure Axis A - D |
| $CO_2$ Compression & Drying Equipment Structure Rows 1 - 4 |

The following figures are screenshots from the 3D model to provide examples of the type of structural steel design performed.

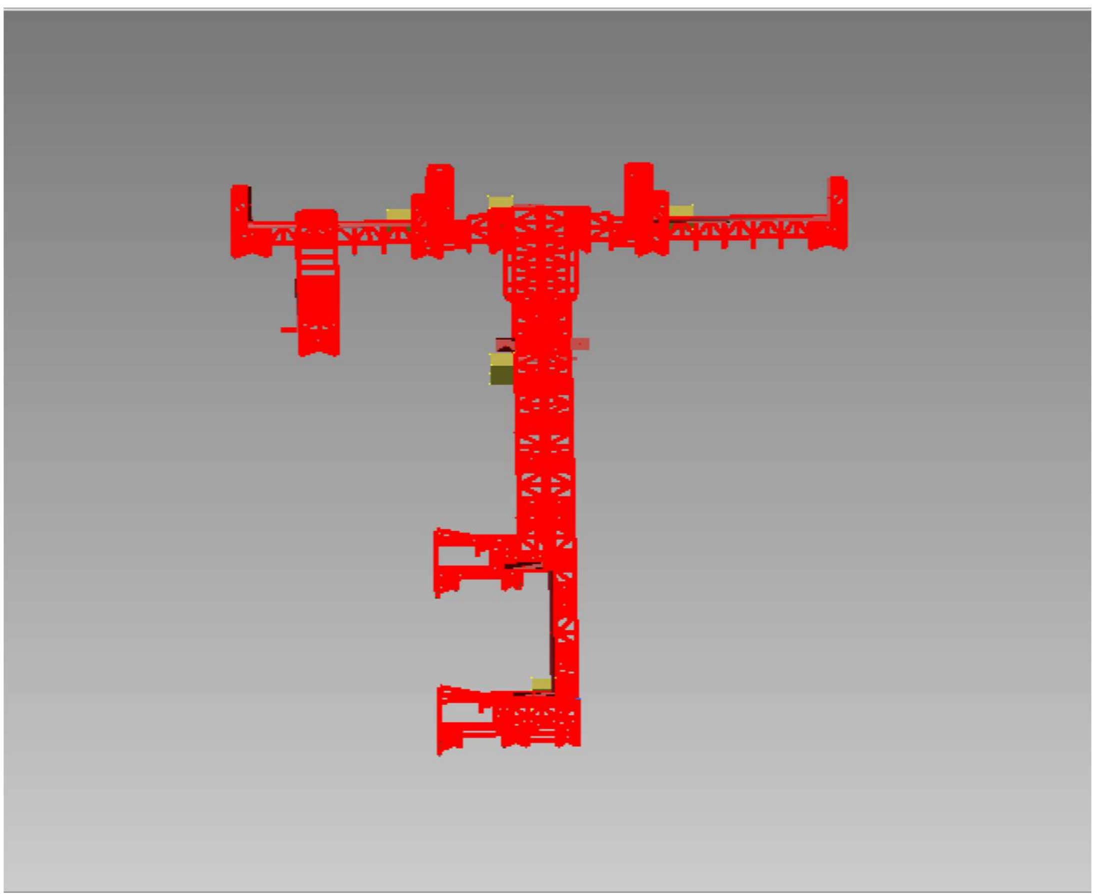


*Figure 13: Flue Gas Ductwork Structural Support Steel*

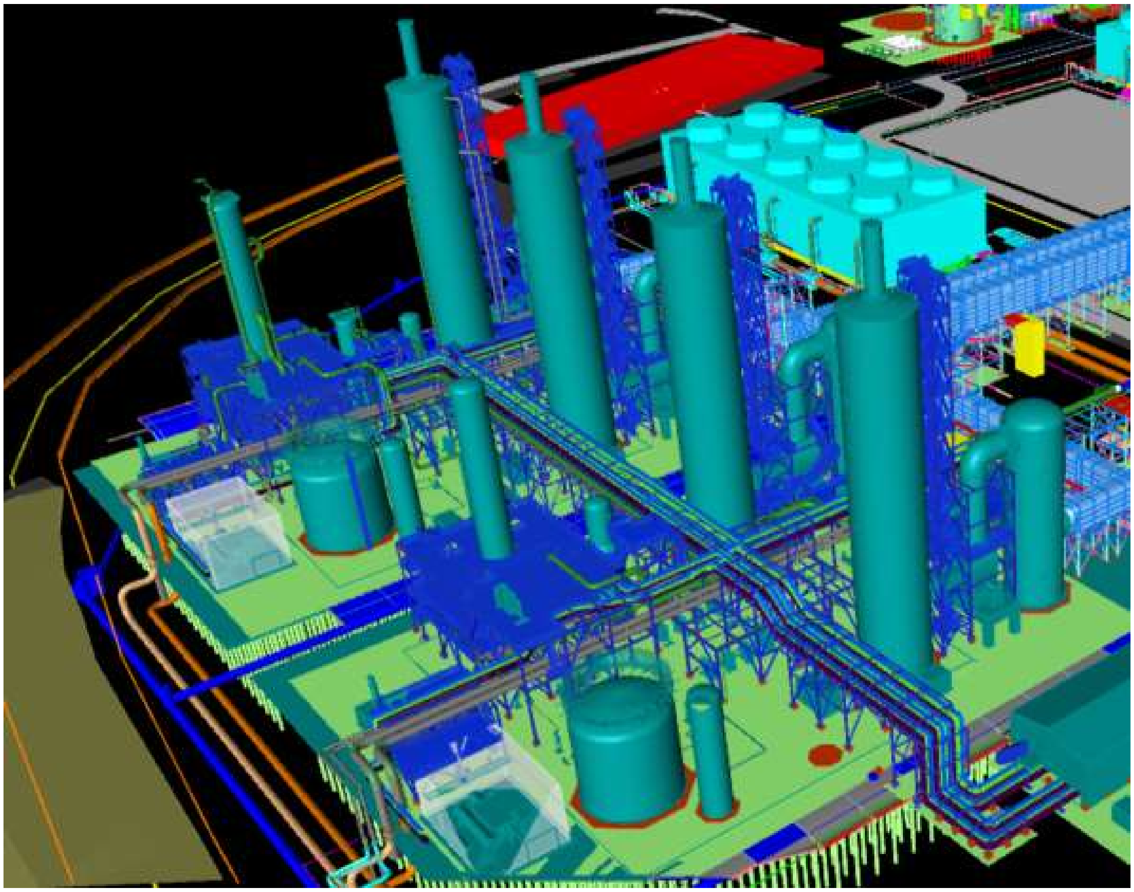


*Figure 14: ISBL Structural Steel (Highlighted in Blue)*

### *Material Take-Offs*

Structural engineers determined material take-off quantities from the design drawings. These were sorted into appropriate categories to inform construction and cost estimation. Table 27 below summarizes the materials required in major general categories. This list is not all inclusive.

*Table 27: Structural Material Take-Offs*

| Commodity Type | Quantity | Unit |
|---|---|---|
| Augercast Piling | ~129,000 | Linear feet |
| Concrete Foundations | ~29,000 | Cubic yards |
| Elevated Concrete Slabs | 718 | Cubic yards |
| Equipment Grout | ~2,700 | Cubic feet |
| Structural Steel – Various | ~3,700 | Tons |
| Ductwork | ~1,100 | Tons |

### *3.4.4 Mechanical Engineering*

Mechanical engineers were responsible for establishing the overall retrofit layout and designing piping between the existing plant, the carbon capture island, and within the carbon capture system. SCS engineers designed piping from the combined cycle facility to the battery limit and Linde engineers took over at the battery limit and designed piping between the different pieces of equipment.

### *General Site Plan View*

Plan view and iso view drawings were created for the process. The engineering drawings do include some trade secret equipment sizing information and thus are not included in this report. However, the following figures are screenshots from the integrated 3D model and provide an example of what was created.

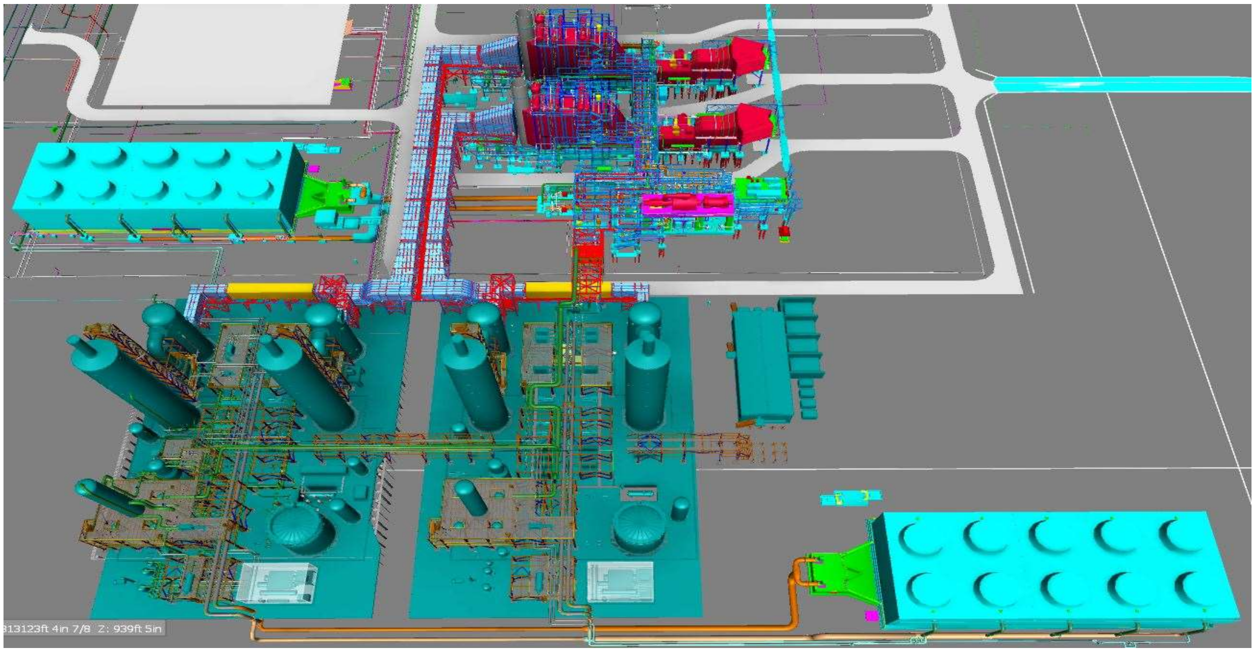


*Figure 15: Plan View of Integrated Facility*

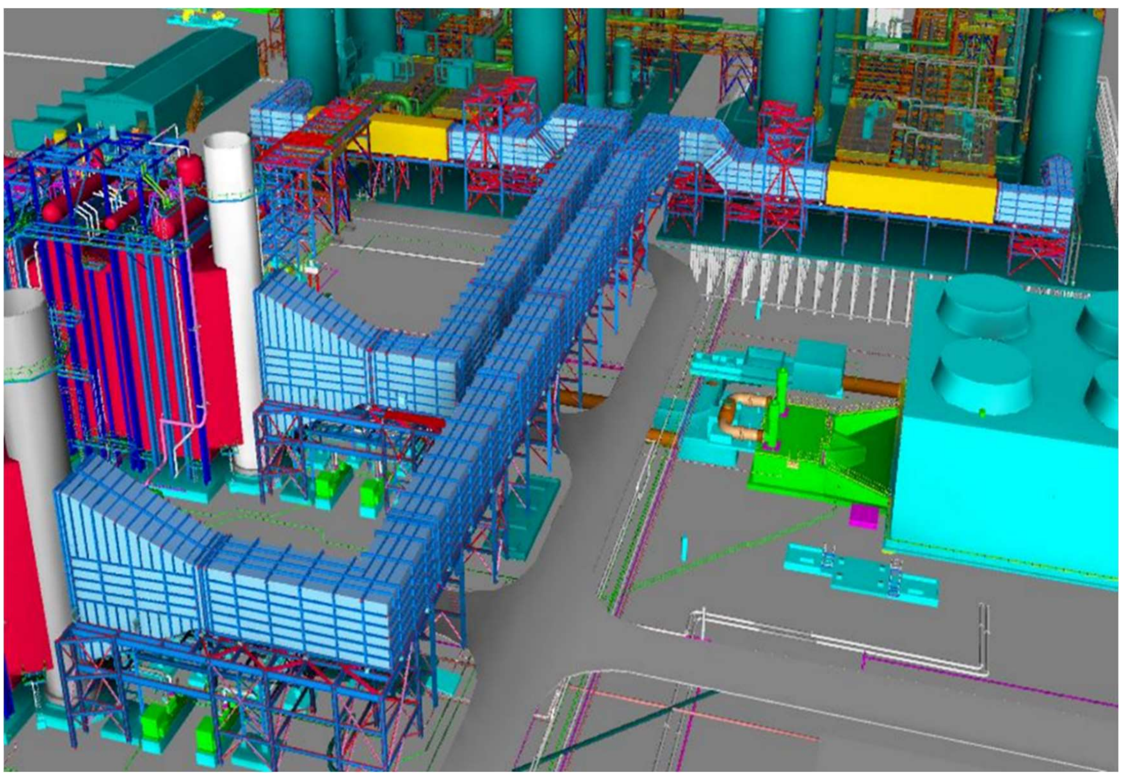


*Figure 16: Iso View from north - stack breech and flue gas transfer duct*

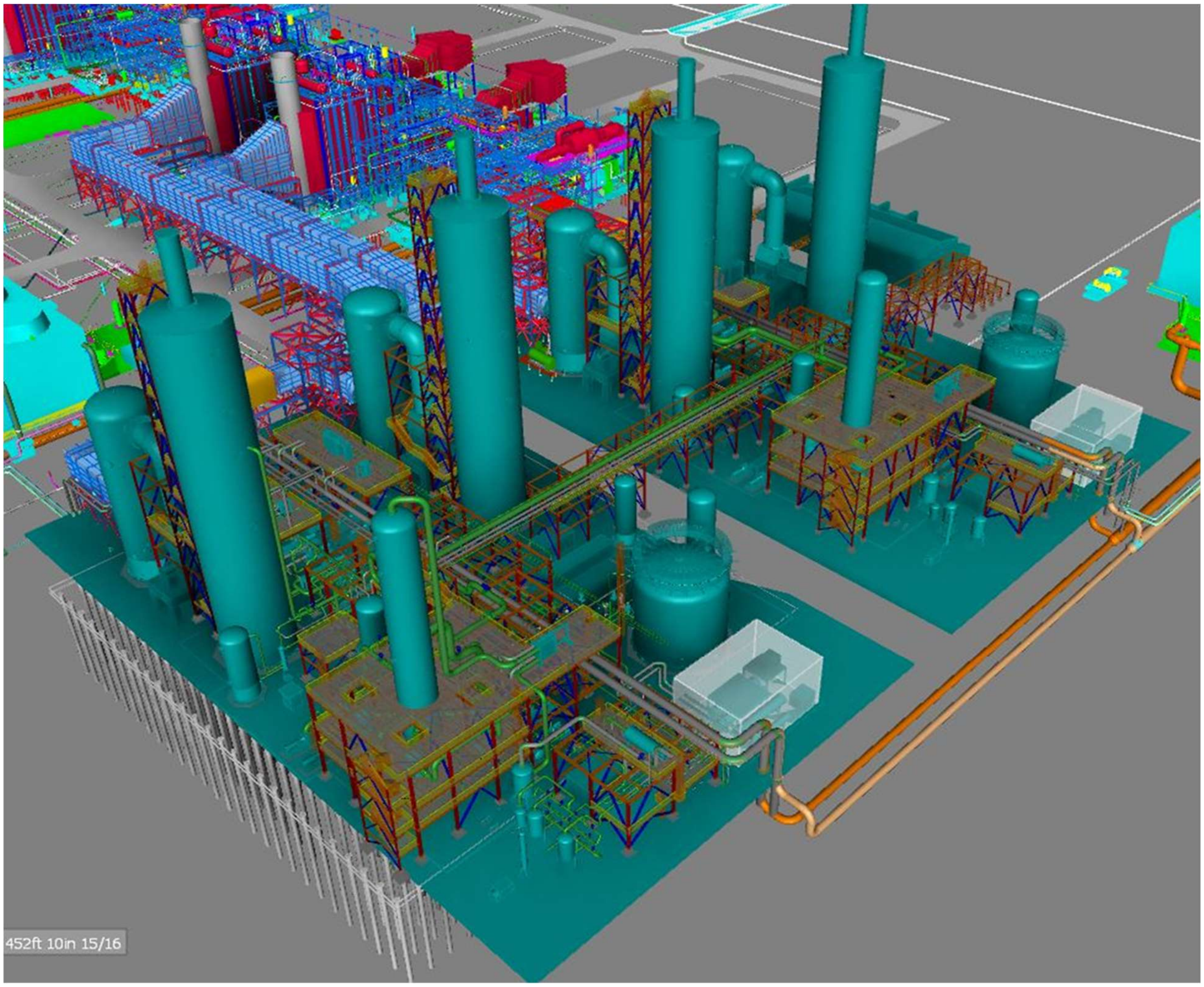



*Figure 17: Iso View from southwest - PCC process*

## *3D Model and/or equipment elevation sections & plan drawings*

The following figures are screenshots from the project's 3D model to provide an example of the elevation views of the overall facility.

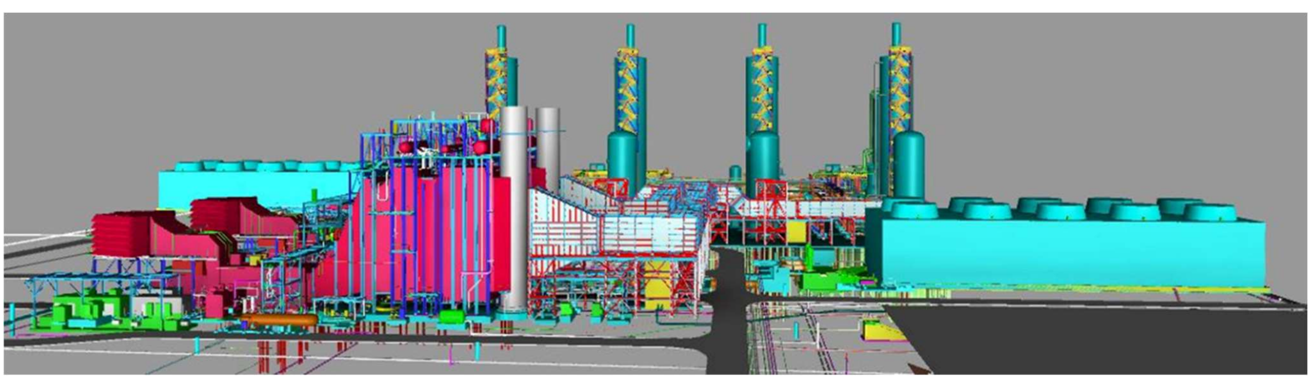


*Figure 18: Elevation view from north*

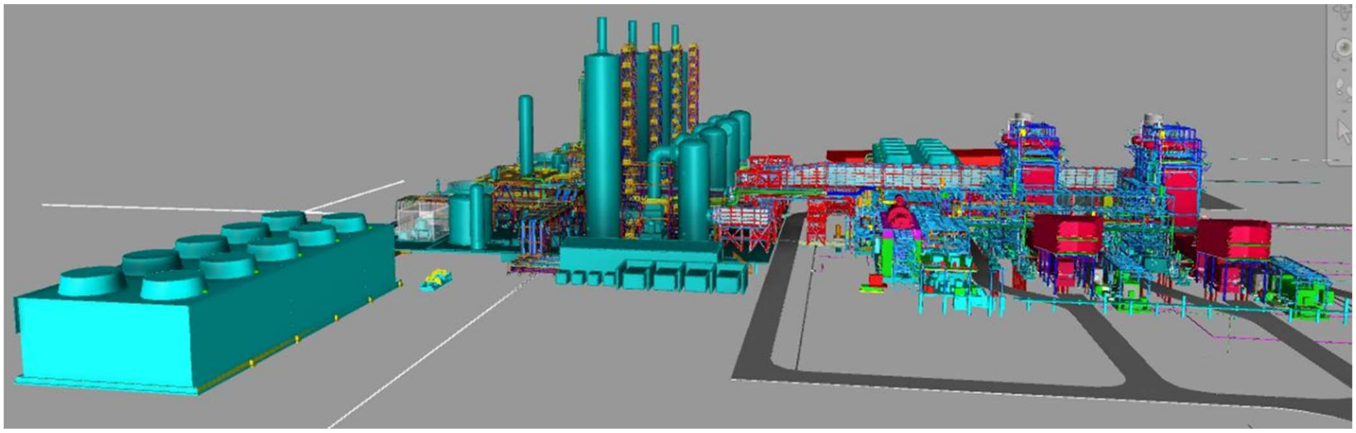


*Figure 19: Elevation view from east*

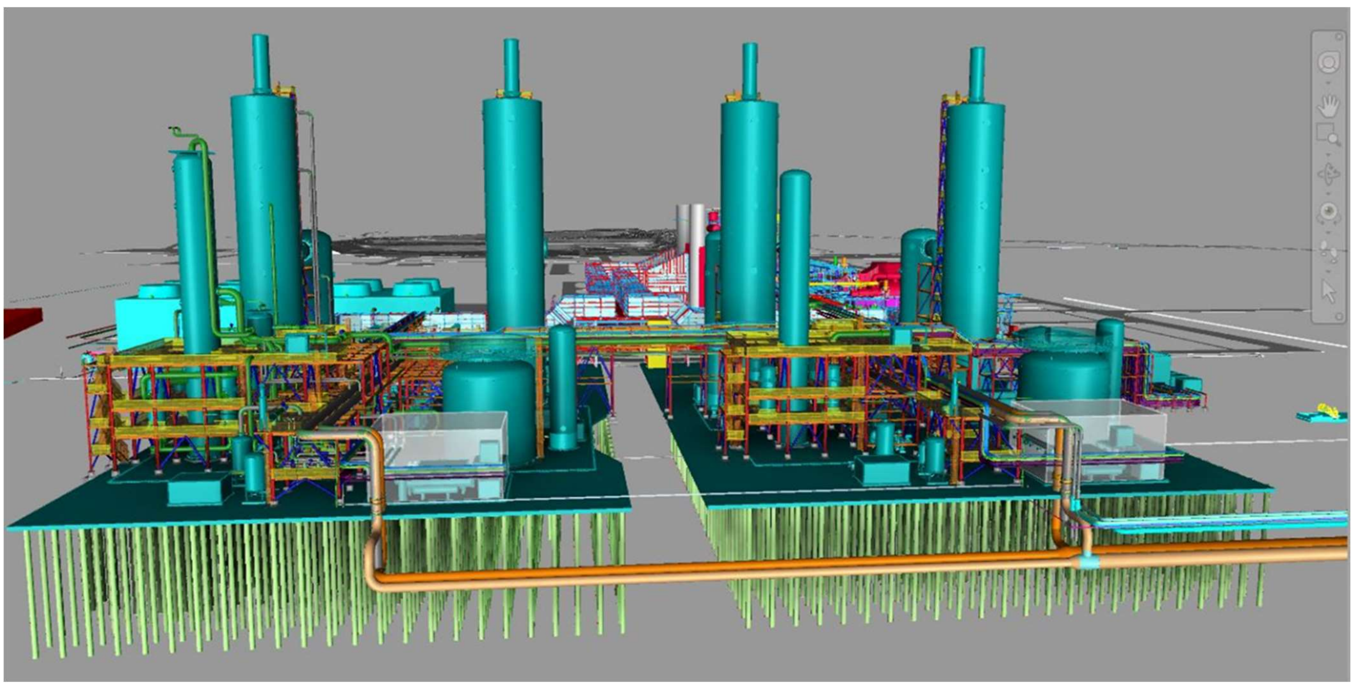


*Figure 20: Elevation view from south*

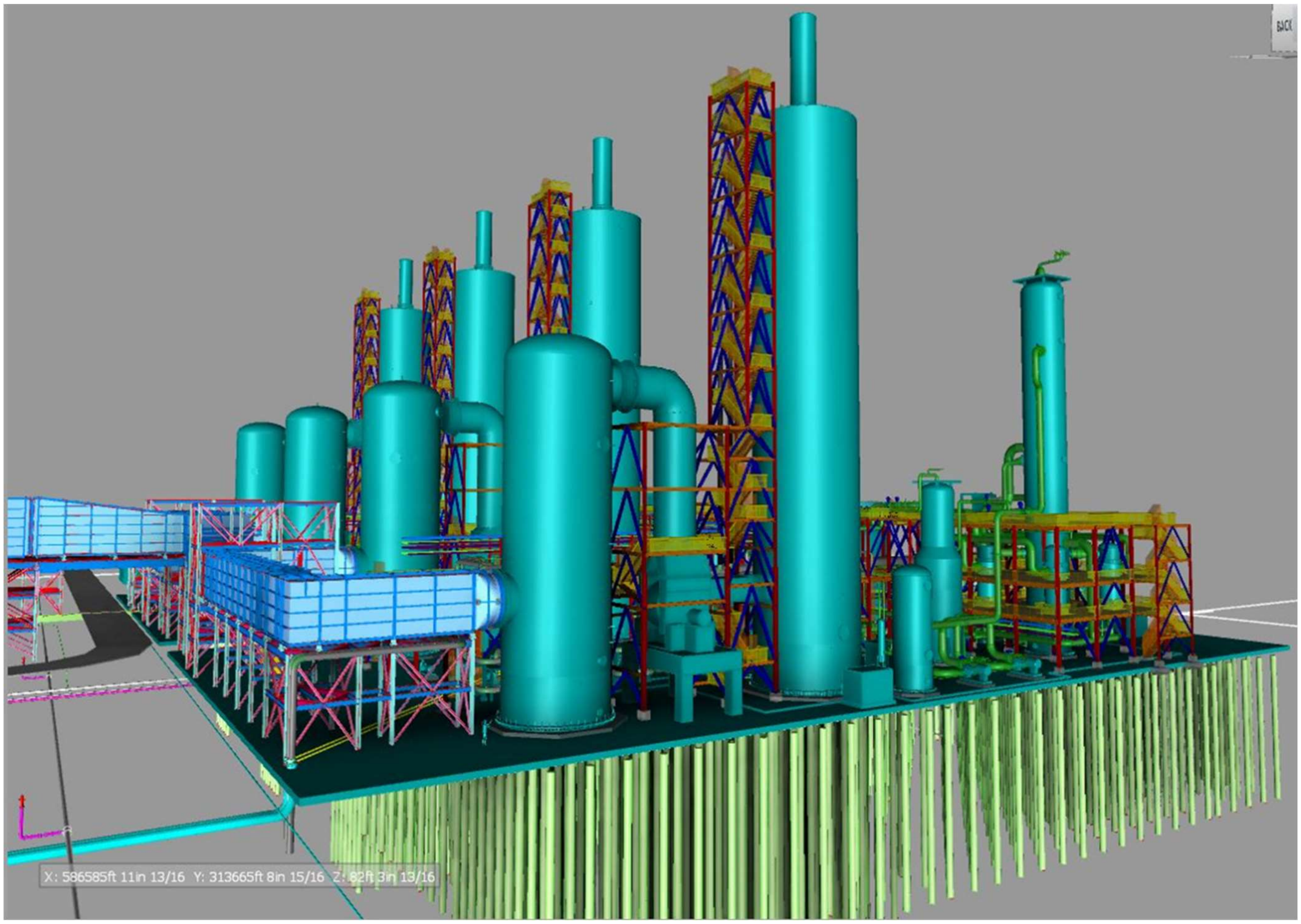



*Figure 21: Elevation view from west*

### *Piping/tracing/insulation line list and material specification*

SCS provided general piping specifications used in generating facilities and Linde engineers confirmed that all piping specifications meet or exceed those standards. Linde produced a line list that indicates the material of construction, sizing, and insulation purpose for every type of pipe used in the carbon capture system. Some of this information would embody trade secrets and so it is not included in this report.

### *Piping Isometrics and Layout/Routing Drawings for the largest, most critical lines*

Isometrics and layout drawings are provided to construction for field fabrication or installation of piping. Formal construction drawings were not isolated and produced as part of the FEED but the routing and isometric information is embodied in the project's 3D model. The following figures illustrate the piping design for the largest, most critical lines in the carbon capture process.

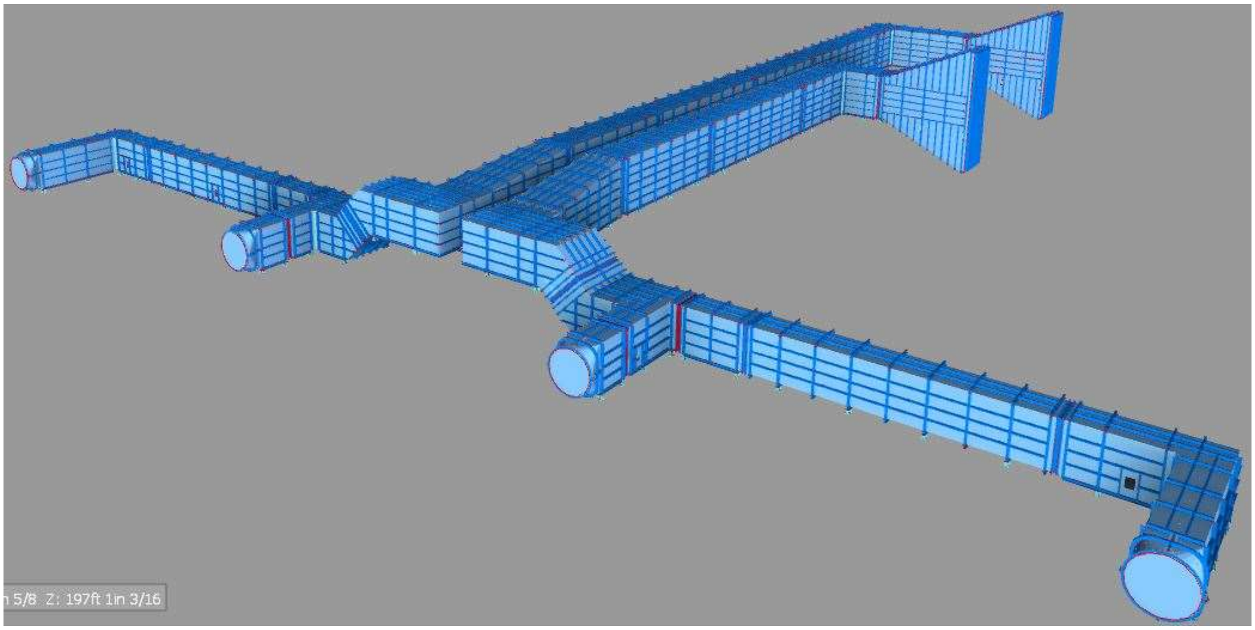



*Figure 22: Flue gas transfer duct from southeast*

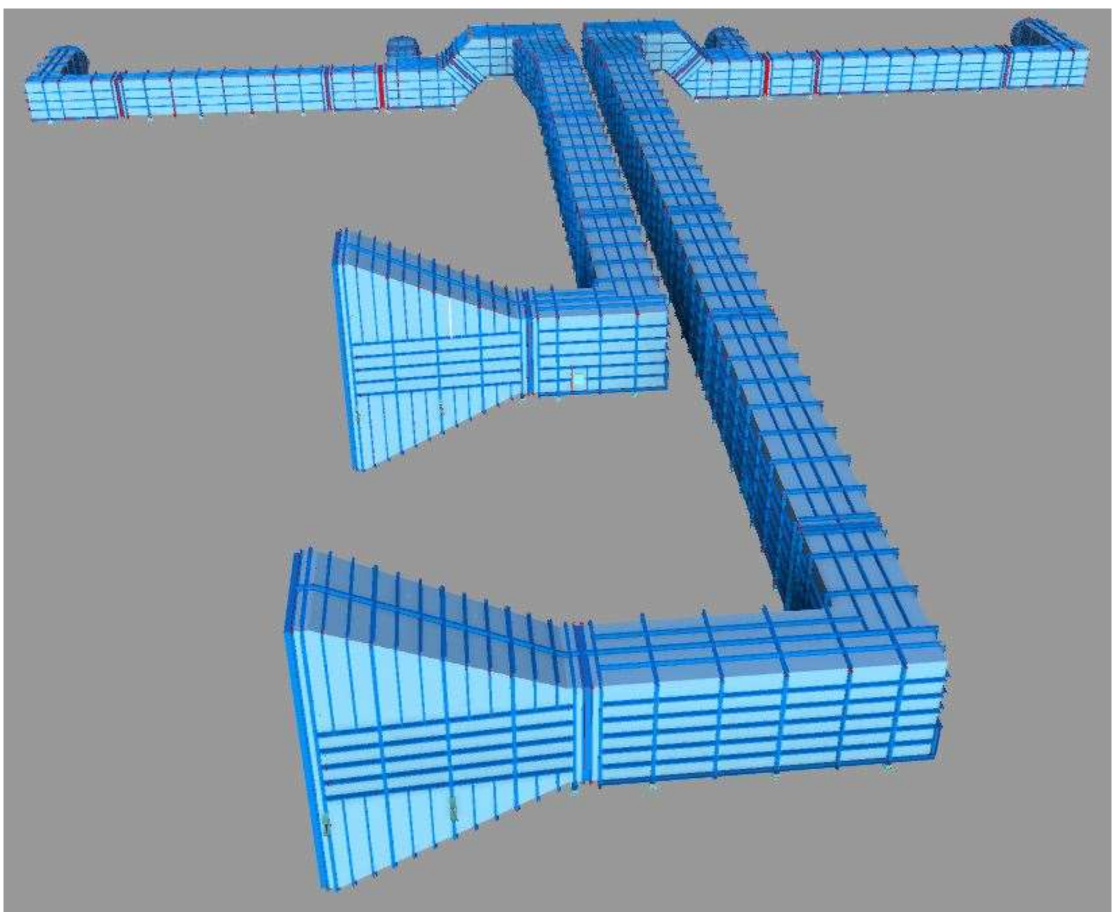


*Figure 23: Flue gas transfer duct from north*

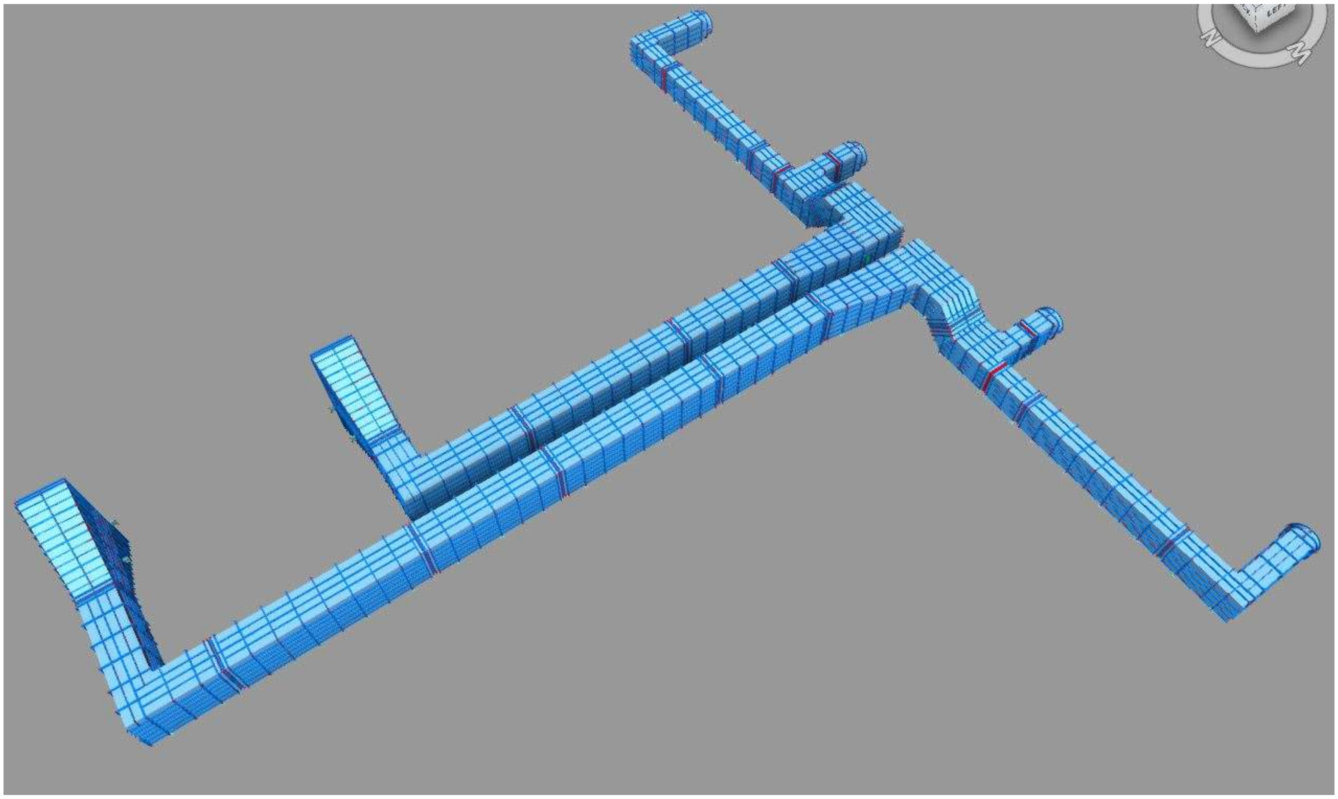


*Figure 24: Flue gas transfer duct ISO view*

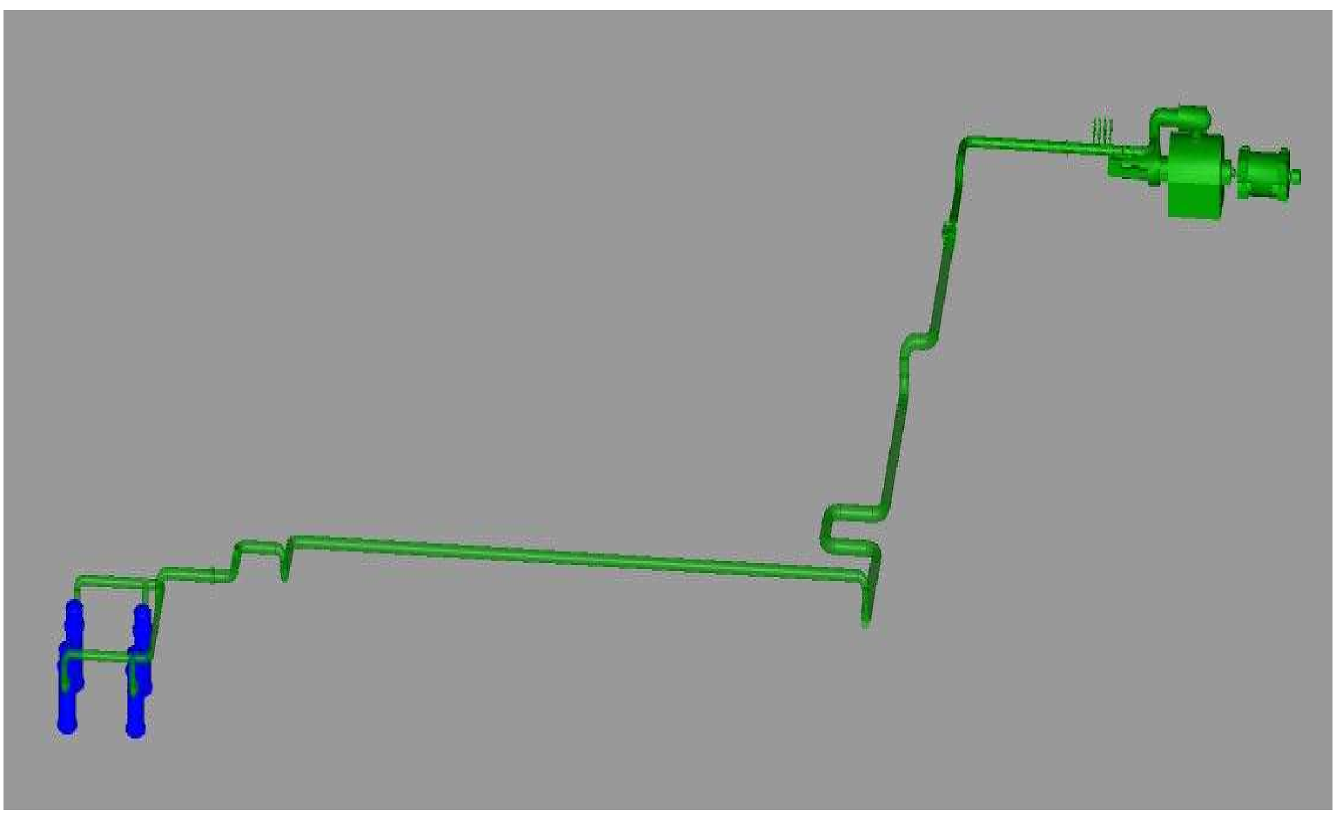


*Figure 25: Train 1 steam piping from south*

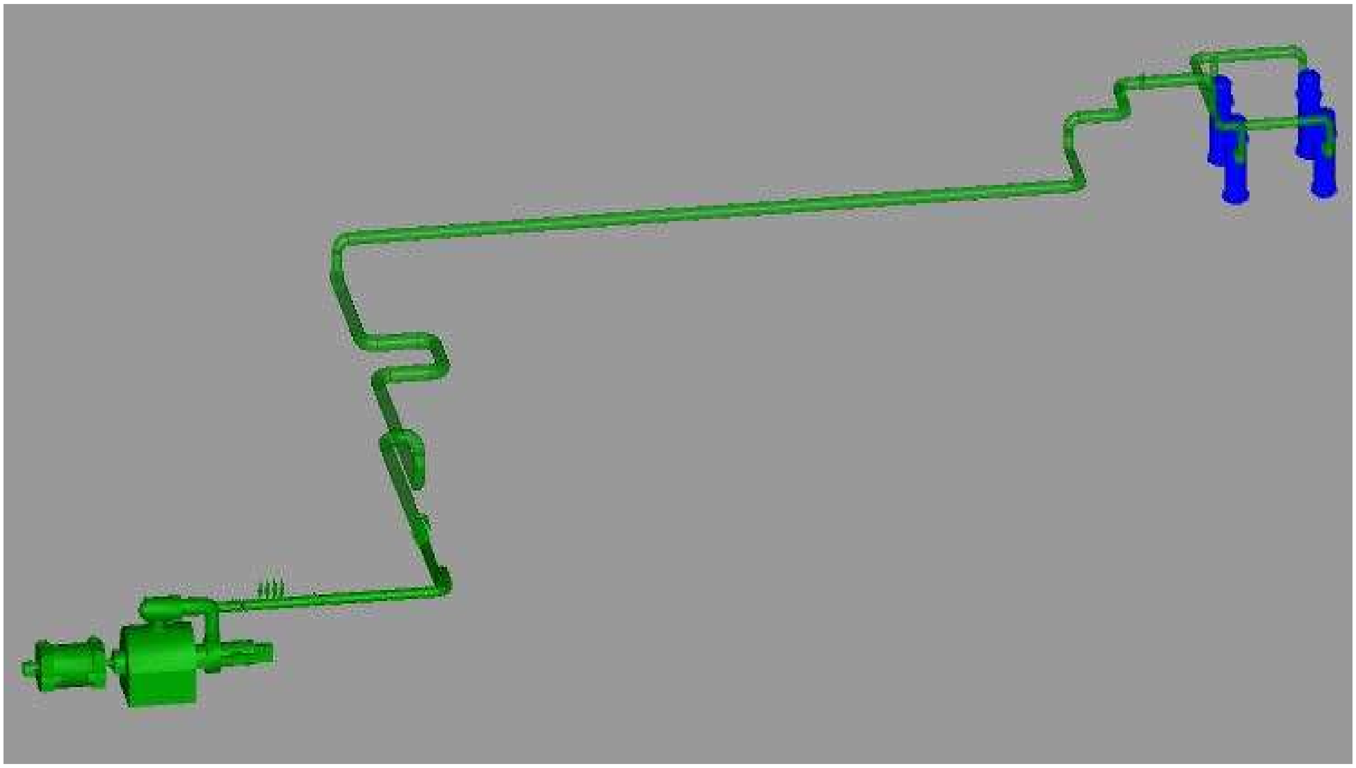


*Figure 26: Train 1 steam piping from north*

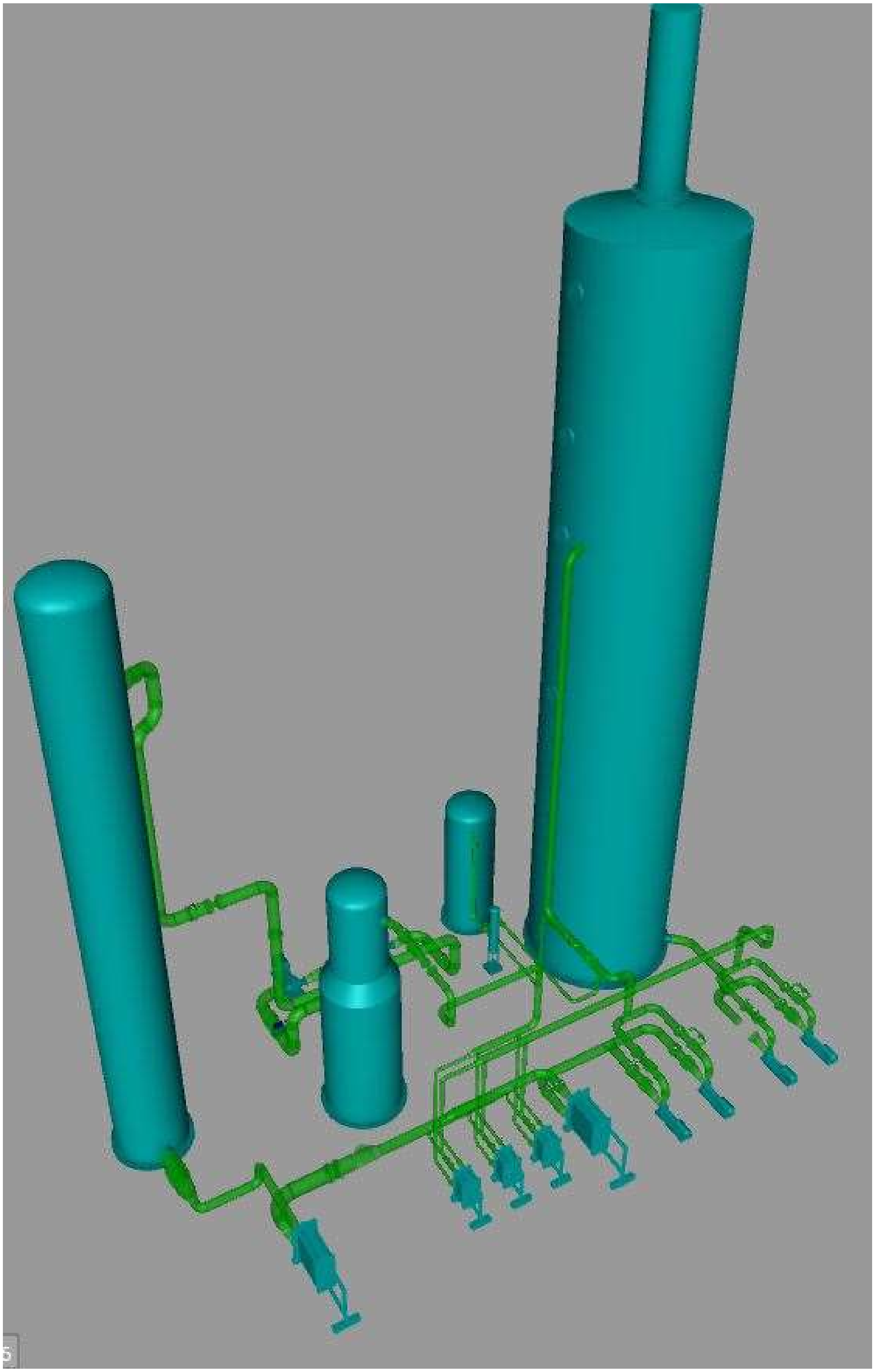


*Figure 27: Train 1 Rich/Lean solvent loop (1 absorber) from east*

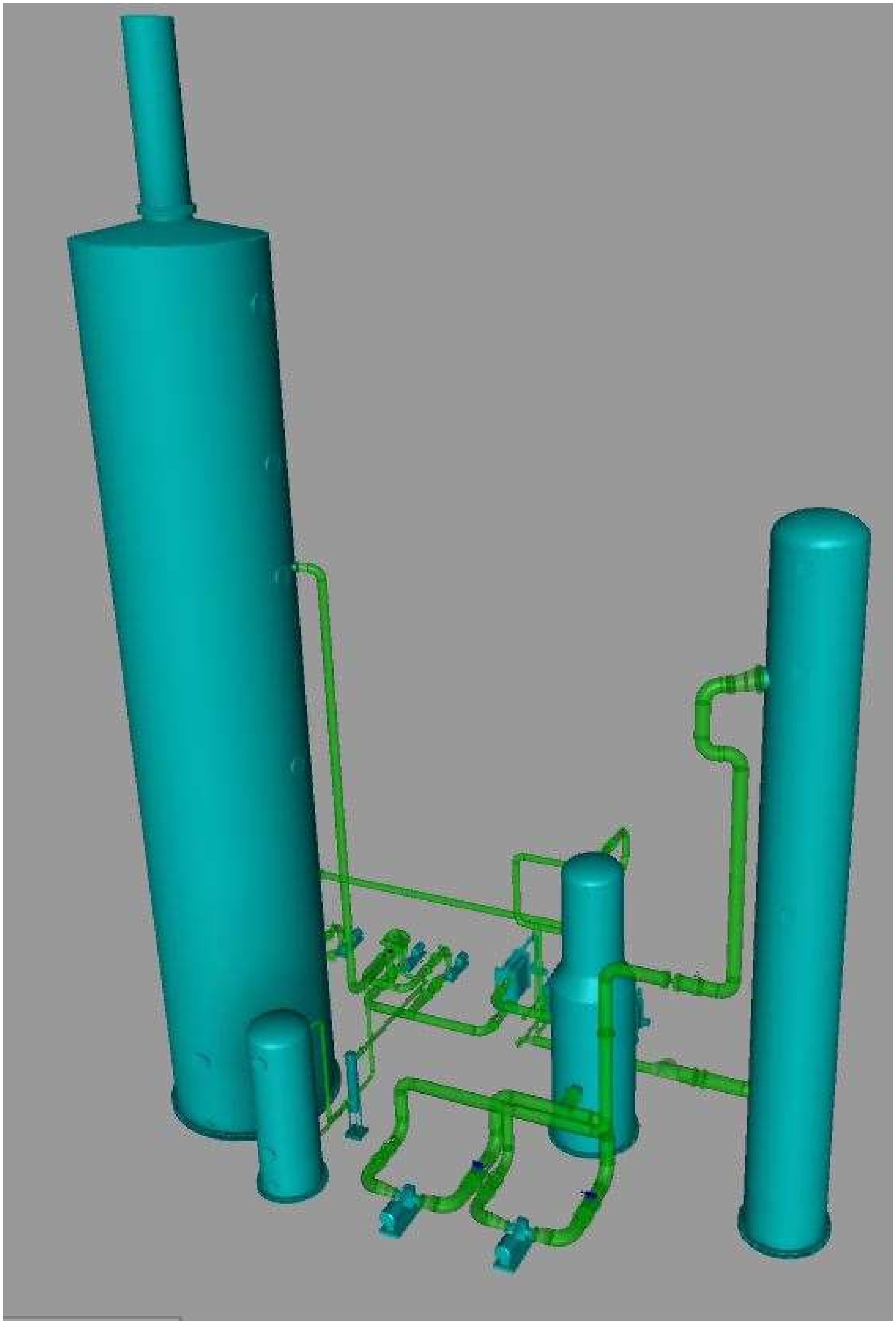


*Figure 28: Train 1 Rich/Lean solvent loop (1 absorber) from west*

### *3.4.5 Electrical Engineering*

Electrical engineering design was a coordinated effort between Linde engineers in the ISBL and SCS engineers in the OSBL scope. The following sections summarize the findings and required additions to support a $CO_2$ capture retrofit.

#### *Electrical Load Lists*

The following tables outline the electrical loads associated with the carbon capture retrofit. Please note than any "A/B" equipment should only have one load being served at a time.

*Table 28: OSBL Electrical Load List*

| Load | Size | Voltage |
|---|---|---|
| Circulating Water Pump A/B | 2,350 HP | 4160 |
| Cooling Tower Fans MCC Transformer A | 1500 KVA | 4160/480 |
| Cooling Tower Fans MCC Transformer B | 1500 KVA | 4160/480 |
| Cooling Tower Fan A | 200 HP | 480 |
| Cooling Tower Fan B | 200 HP | 480 |
| Cooling Tower Fan C | 200 HP | 480 |
| Cooling Tower Fan D | 200 HP | 480 |
| Cooling Tower Fan E | 200 HP | 480 |
| Cooling Tower Fan F | 200 HP | 480 |
| Cooling Tower Fan G | 200 HP | 480 |
| Cooling Tower Fan H | 200 HP | 480 |
| Cooling Tower Fan I | 200 HP | 480 |
| Cooling Tower Fan J | 200 HP | 480 |
| Miscellaneous Loads (Cooling Tower) | 45 KVA | 480 |
| Air Compressor A/B | 200 HP | 480 |
| Air Dryer A/B | 79 KW | 480 |
| Miscellaneous Loads (Air Compressor A) | 45 KVA | 480 |
| Miscellaneous Loads (Air Compressor B) | 45 KVA | 480 |
| Demineralized Water Pump A/B | 25 HP | 480 |

*Table 29: ISBL Electrical Load List*

| Load | Size | Voltage |
|---|---|---|
| Stripper Interstage Pump A/B | 544 HP | 4160 |
| Rich Solution Booster Pump A/B | 680 HP | 4160 |
| Stripper Reflux Pump A/B | 20 HP | 480 |
| Steam Condensate Pump A/B | 40 HP | 4160 |
| Raw $CO_2$ Chiller | 483 HP | 4160 |
| $CO_2$ Compressor | 12,916 HP | 13800 |
| $CO_2$ Compressor - Motor Heater | 1 kW | 120 |
| $CO_2$ Compressor - 480 V | 30 HP | 480 |
| Refrigerant Compressor | 483 HP | 4160 |
| Regeneration Gas Blower | 100 HP | 480 |

| Load | Size | Voltage |
|---|---|---|
| Regeneration Gas Heater | 300 kW | 480 |
| Solution Storage Tank Heater A/B/C/D | 10 kW | 480 |
| Solution Make-Up Pump | 50 HP | 480 |
| Slop Vessel Pump | 15 HP | 480 |
| Solution Make-Up Vessel Heater A/B | 10 kW | 480 |
| Slop Vessel Pit Pump | 15 HP | 480 |
| DCC Circulation Pump A/B | 612 HP | 4160 |
| Flue Gas Blower | 4,487 HP | 4160 |
| Flue Gas Blower - Motor Heater | 1 kW | 120 |
| Flue Gas Blower - Lube Oil System | 18 kW | 480 |
| Rich Solution Pump A/B | 483 HP | 4160 |
| Absorber Wash Water Pump A/B | 272 HP | 4160 |
| Lean Solution Pump A/B | 483 HP | 4160 |
| Condensate Flash Vessel Pump A/B | 4 HP | 480 |
| NaOH Tank Heater A/B | 10 kW | 480 |
| Reclaiming Unit | 40 HP | 480 |
| Truck Unloading Station | 30 HP | 480 |
| Cooling Water Booster Pump | 1251 HP | 4160 |
| Make-Up Water Pump A/B | 20 HP | 480 |

### *One Line Diagrams*

Linde engineers created a single-line diagram to show the basic power supply within the carbon capture system and to inform the electrical equipment building design. This included some equipment information that is considered trade secret and thus is not included in this report.

### *Electrical Equipment Specifications*

General electrical engineering specifications were developed for the PCC process to provide to vendors for all electrical equipment within the project scope. These included a general electrical specification and specific requirements for battery and charger systems, cable buses, inverters, motor control centers, medium voltage switchgear, low voltage switchgear, and transformers. All electrical equipment was estimated in compliance with these requirements.

Linde also developed a specification and obtained a quote for a packaged electrical equipment center (PEEC) building. That specification and layout was incorporated into the project's 3D model design, as can be seen in Figure 30 below.

### *Cable Tray Routing Concepts*

Typical cable tray design and routings were developed for the FEED study. These concepts are shown for the PCC process in Figure 29 and 30 below. SCS has typical cable tray concepts that would be utilized.

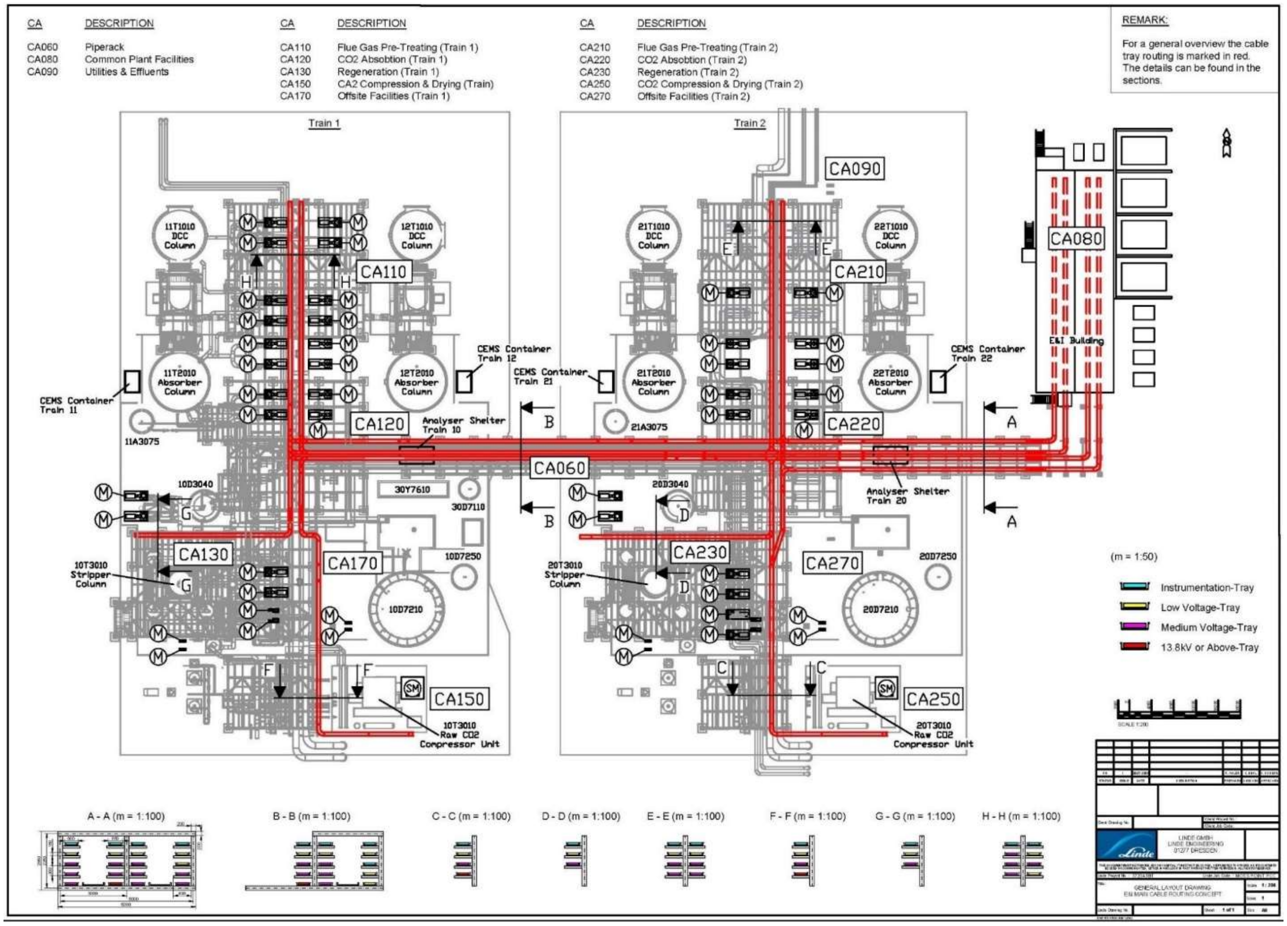



*Figure 29: PCC process cable tray routing plan view*

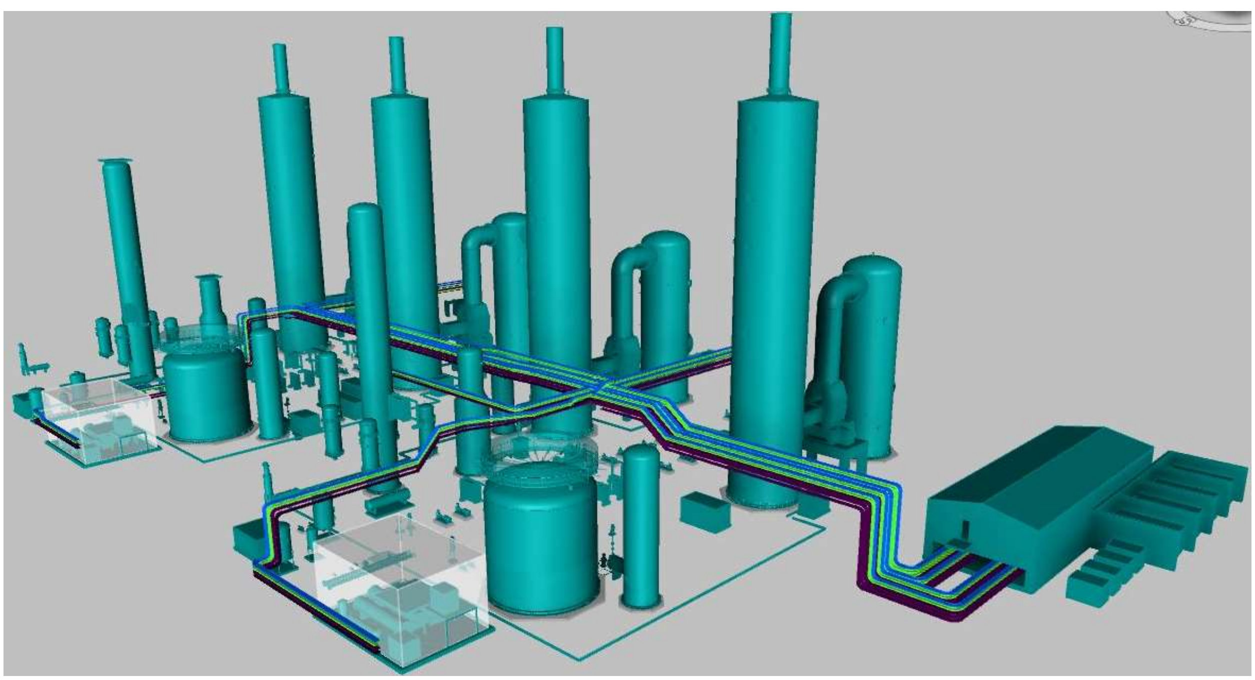


*Figure 30: Cable tray routing ISO view*

*Lighting*

Lighting will be designed to meet applicable local safety standards. It will be placed on the modules where applicable and field installed where not applicable.  SCS has lighting design standards for use.

*Conceptual Power Supply*

SCS engineers conducted a conceptual power supply study to determine the impact of loads required to support the new equipment.  This study developed an electrical system model with configurations for load flow, voltage, and short circuit cases for modes of operation such as outage, startup, normal operation, and worst-case contingency.  Short circuit and motor starting scenarios were also considered.

*Balance of Plant Load Study*

SCS engineers evaluated the existing site electrical infrastructure to determine if it was sufficient to support the new loads associated with carbon capture.  The team concluded that existing switchgear and buses on the site are not capable of providing adequate motor starting for all the new OSBL needs, much less the new Linde ISBL loads.  It was determined that the new demineralized water pumps could be supported by existing equipment, but the remaining loads would need to be served by a new electrical feed.

*Transmission Substation Coordination and Estimate*

A new 230 kV substation was designed to provide the carbon capture system with 34.5 kV power.  SCS coordinated this effort with Mississippi Power Transmission and the cost was included in the estimate.  This would be an outdoor substation and so the design included site grading, foundations, fencing, grounding, wiring, and equipment installation.

*Conceptual Relay Protection Plan*

The project team developed a relay protection plan for the electrical equipment within the carbon capture system.  This plan identified approved relay devices, appropriate transformer applications, motor relays, fuse applications, bus relay applications, and grounding.

*Large Power Transformer Specification*

SCS provided general specifications for large power transformers to Linde.  These specifications informed the design of the new transformers required to power the carbon capture system.

### *3.4.6 Instrumentation & Controls Engineering*

Instrumentation and controls (I&C) engineering was a coordinated effort between SCS and Linde.  The following sections detail the process by which this scope was designed and estimated.

*Control System Architecture Specification*

A general specification for the distributed control system (DCS) architecture was developed by the project team. This specification covers both the needs of the new system as well as integration with the current plant infrastructure. Also, the project team developed a control system philosophy to govern how the system would be configured and how the plant would be controlled. Both of these were provided to an outside vendor and a detailed proposal was developed for the DCS communication network.  This information is not included in this report since it embodies trade secret information for both Linde and the controls system vendor.

### *Instrument Lists and Specifications*

Specific Instrument specifications were developed for all the instrumentation to be added within the ISBL and OSBL scopes of the FEED project. Instrument lists were also developed. The following tables list the instruments that were identified for the ISBL and OSBL scopes.

*Table 30: ISBL Instruments*

| Device Type | Count |
|---|---|
| Continuous extractive gas analyzer | 9 |
| Analyzer sample box | 31 |
| Water leakage sensor | 1 |
| Differential pressure transmitter | 35 |
| Electromagnetic flowmeter | 11 |
| Solenoid valve | 32 |
| Butterfly control valve | 14 |
| Approximation measuring | 16 |
| Vortex flowmeter | 6 |
| Globe valve | 30 |
| Coriolis mass flowmeter | 2 |
| Generic flowmeter | 2 |
| Rotameter | 3 |
| Motor control center, E-technology | 44 |
| Emergency hand switch, local | 25 |
| Valve | 3 |
| End position switch | 9 |
| Butterfly valve | 10 |
| Differential pressure transmitter with remote seal | 17 |
| Radar | 11 |
| Level limit switch | 20 |
| Magnetic level gauge with limit switch | 4 |
| Magnetic level gauge | 12 |
| Level transmitter | 1 |
| Pressure transmitter | 57 |
| Pressure gauge | 31 |
| Pressure Switch | 3 |
| Self-actuating valve | 4 |
| Temperature transmitter with thermometer | 119 |
| Thermometer PT100 4-wire | 14 |
| Temperature switch universal NC | 10 |
| Vibration transmitter | 2 |
| Damper | 4 |
| Ball valve | 5 |

*Table 31: OSBL Instruments*

| | |
|---|---|
| Level Transmitter | 4 |
| Pressure Transmitter | 3 |
| Vibration Switch | 20 |
| Oil Level Switch | 10 |
| Flow Orifice | 2 |
| Flow Transmitter | 2 |
| Temperature Element | 3 |
| Flow Valve | 1 |
| Block Valve | 3 |
| Temperature Control Valve | 1 |
| Drain Valve | 2 |
| Pressure Regulator | 1 |

#### *Communications Infrastructure*

The PCC process will be integrated within the current Plant Daniel communication infrastructure. All phone, internet, remote SCADA, and similar needs will be provided within the current systems.

### *3.4.7 Fire Protection Engineering*

The only combustible material in the PCC process is lube oil associated with rotating equipment. Based on the process description, exterior fire hydrants should be sufficient for this exposure. No sprinkler system would be required. An underground piping system can be extended from the existing fire main utilizing Class 350 ductile iron piping and restrained joint fittings or a 200 psig rated HDPE piping system with a minimum diameter of 8" required to supply fire hydrants per NFPA 24 – Standard for the Installation of Private Service Fire Mains.

It is also recommended to install a smoke detection system in the electrical room using NFPA 72 as the primary code document. The detection system will need to send a signal back to the control room.

For the new $CO_2$ capture cooling tower, the existing Unit 4 cooling tower header will be tapped to create a supply header near the $CO_2$ capture facility. Two hydrants will be installed along the north edge of the facility. Additionally, the new supply header will feed new hydrants next to the new $CO_2$ capture cooling tower. The new hydrants will be configured like the existing Unit 4 cooling tower hydrants.

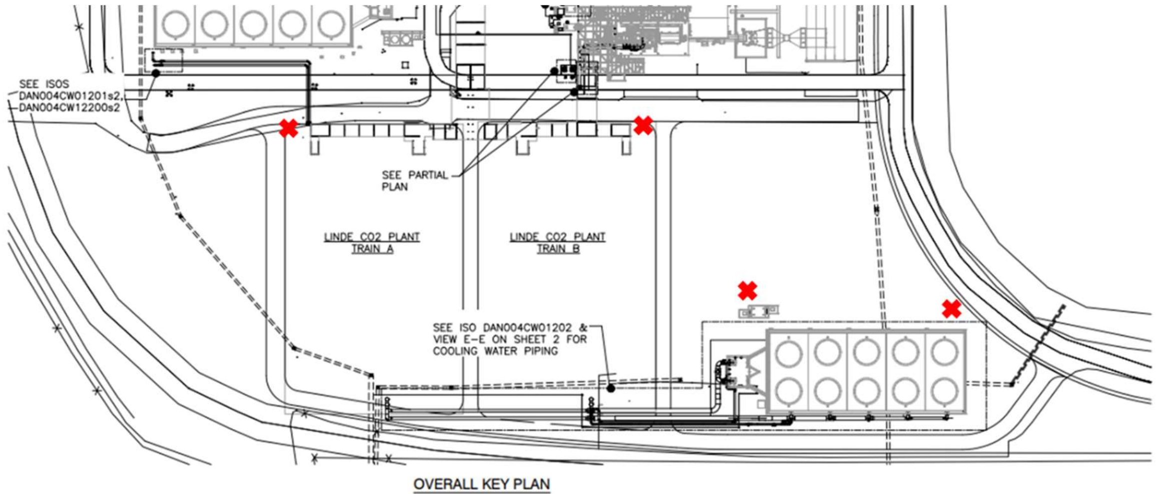



*Figure 31: Potential locations for exterior fire hydrants/cannons*

### *3.4.8 Facilities Engineering*

A carbon capture retrofit requires supporting facilities. The following sections describe modifications and upgrades required to support the project.

#### *Buildings and HVAC*

Existing Unit 4 facilities, including the administrative building, control room, and maintenance shop, have adequate space to incorporate the needs of the PCC process with modifications. Since there are no new OSBL process buildings, no new HVAC systems are needed. The new ISBL electrical building will include new HVAC systems.

#### *Cooling Tower Design and Cost Estimate*

The capacity of the existing Unit 4 mechanical draft cooling tower was evaluated during the FEED study to determine if it could accommodate the additional heat load of the PCC process. It was anticipated that the significant steam extraction from the steam cycle for solvent regeneration may reduce the steam turbine condenser duty enough to allow the existing tower to supply part of the cooling capacity for the PCC process and reduce the size and cost of a new PCC tower. However, evaluation of critical operating scenarios revealed the full capacity of the existing tower was needed for emergency events such as a full steam turbine bypass. The project team did not want to vent main steam and did not feel a design to quickly reroute large volumes of cooling water flow from the PCC process to the steam turbine condenser was feasible with acceptable risk to equipment, so a separate full sized cooling tower was included in the PCC design.

The “Max /95F” case was used for the cooling tower design as it represented the highest heat load and cooling water need from the PCC system. The cooling water need per train in this case was 62,000 gpm, so with two trains in service, this equated to a total 125,000 gpm, generally equivalent to the design flow for the cooling towers on most of Southern Company’s combined cycle units. The cooling tower was sized for 135,000 gpm, which includes 10,000 gpm of additional operating margin. Similarly, the 21°F cooling range required by this case was equivalent to the design range of many of Southern Company’s CC towers. Thus, the final design of the cooling tower for the PCC system effectively duplicated a common cooling tower design found throughout the Southern Company fleet.

Makeup water for the PCC system cooling tower will be taken from the Black Creek Cooling Facility utilizing existing plant makeup pumps and discharged back into the same canal. Materials of construction and fill type were based on the operating experience of Units 3 and 4. The location of the new tower is south of the PCC system, away from the existing Unit 4 cooling tower to minimize any adverse effects on its performance due to plume recirculation. The design and operating conditions in the following table were used to obtain a vendor estimate.

*Table 32: Cooling Tower Design and Operating Conditions*

| Cooling Tower Design and Operating Conditions | |
|---|---|
| Circulating Water Flow | 135,000 gpm (30,662 $m^3$/h) |
| Hot (Inlet) Water Temp. | 107.5°F (41.9°C) |
| Cold (Outlet) Water Temp. | 86.5°F (30.3°C) |
| Wet Bulb Temp., Inlet | 80.0°F (26.7°C) |
| Tower Pump Head | 37.2 ft (11.3 m) |
| Total Fan Power, Driver Output | 1,966.3 HP (1,466.2 kW) |
| Drift Loss, % of Circulating Flow | 0.0005 % |
| Evaporation Loss (at Design) | 2,613 gpm (594 $m^3$/h) |
| Design Wind Load | In accordance with ASCE 7-16 (Exposure C) |
| Design Seismic Load | In accordance with local Uniform Building Codes (Seismic Zone 0) |
| Tower Site (Ground Level, Roof, etc.) | Ground |
| Elevation Above Sea Level | 0.0 ft (0.0 m) |
| Tower Exposure | 2 Sides Open with air inlet guides |

The underground circulating water piping material for the PCC cooling tower is designed with Prestressed Concrete Cylinder Pipe (PCCP) while the aboveground piping in the PCC process will be stainless steel. Equipment in the PCC system (primarily the 304 SS heat exchangers) dictated no more than three cycles of concentration (COC). At three COC, the cooling water is corrosive and would need a mild steel corrosion inhibitor. The use of PCCP effectively mitigates the internal and external corrosion risk for underground pipe.

### *Steam Source Study*

A steam source study was conducted to evaluate options for supplying the steam required by the $CO_2$ capture process, considering the plant-specific requirements. The selection of a steam source was influenced by multiple factors such as capital cost, operating costs, efficiency, plant operating requirements, flexibility, and operational complexity. Once selected, the $CO_2$ capture steam source and configuration were refined for the FEED effort.

#### Power Cycle Description

Each "F" class combustion turbine generator at Daniel Unit 4 exhausts into a dedicated, triple pressure heat recovery steam generator (HRSG), providing steam for a common steam turbine. Duct burning and steam injection capabilities are included to mitigate gas turbine thermal lapse at higher ambient conditions. Refer to Figure 32 for a block flow diagram of the Daniel Unit 4 power cycle.

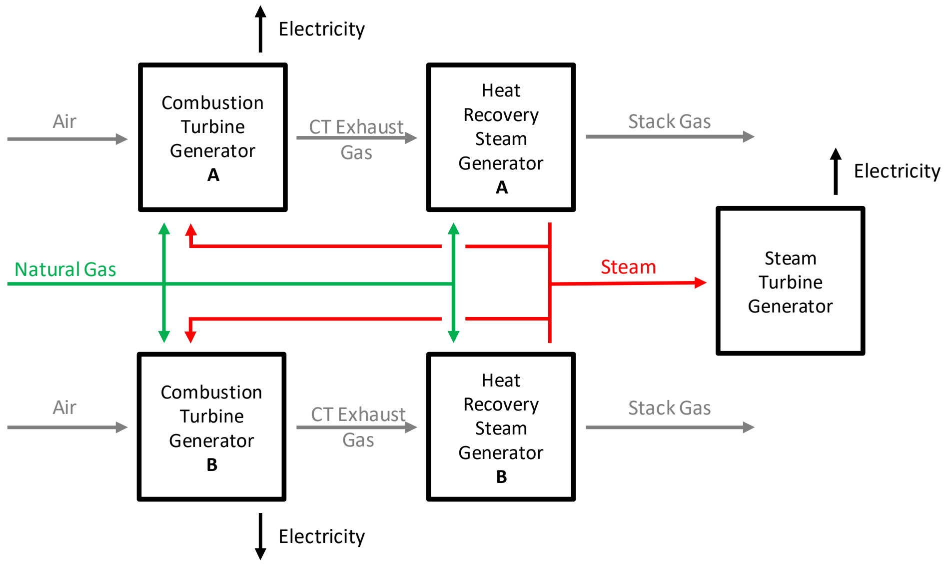



*Figure 32: Plant Daniel Unit 4 Power Cycle*

Several of the steam source options evaluated extraction steam from the Daniel Unit 4 steam cycle for use by the $CO_2$ capture process. The steam cycle consists of a steam turbine generator, two identical HRSGs, a surface condenser, and the associated auxiliaries and interconnecting piping. The steam turbine is a tandem compound reheat arrangement. The high pressure (HP) and intermediate pressure (IP) steam turbines share a common casing, while the two-flow low pressure (LP) steam turbine is in a separate casing.

As shown in Figure 33, main steam generated in the high pressure section of each HRSG is admitted into the HP section of the steam turbine and partially expands, generating electricity. The cold reheat steam exhausted from the HP steam turbine is returned to the HRSGs, combined with Intermediate Pressure (IP) steam, and reheated. The resulting hot reheat steam is admitted to the IP section of the steam turbine and expands, generating electricity. Low pressure steam generated in each HRSG is combined with the IP exhaust before entering the crossover for admission into the LP section of the steam turbine. The steam expands in the LP steam turbine, generating electricity, before exhausting to a surface condenser.

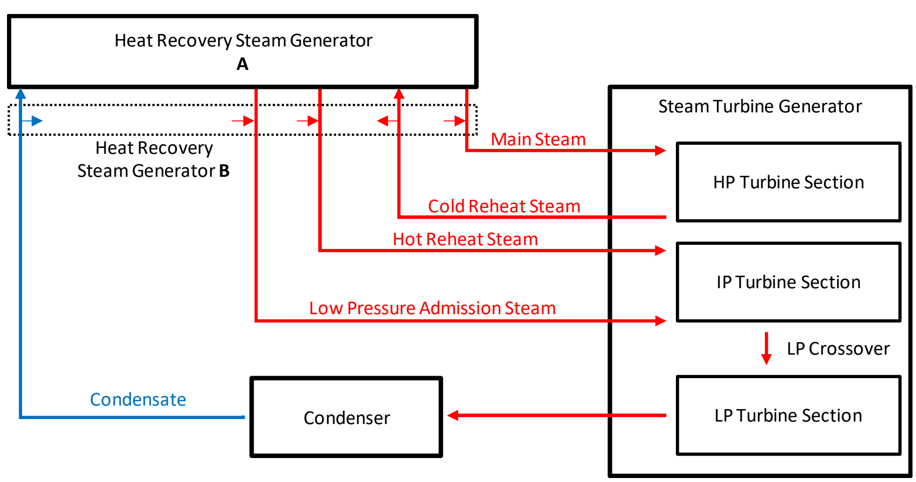



*Figure 33: Plant Daniel Unit 4 Steam Cycle*

Each of the existing streams below was evaluated as potential sources to supply steam to the PCC process:

- Main Steam
- Cold Reheat Steam
- Hot Reheat Steam
- Low Pressure Admission Steam
- LP Crossover Steam

## Operating Characteristics

As a dispatchable power plant, Daniel Unit 4 adjusts combustion turbine load to meet electricity demand. Combustion turbine load directly affects steam flow, so as combustion turbine load changes, steam flow also changes. Figure 34 shows the variability of steam flow through the steam turbine across the load range. Also shown is the general range of operation with a single combustion turbine and both combustion turbines. The maximum operating pressure for each of the sources is shown in Table 32.

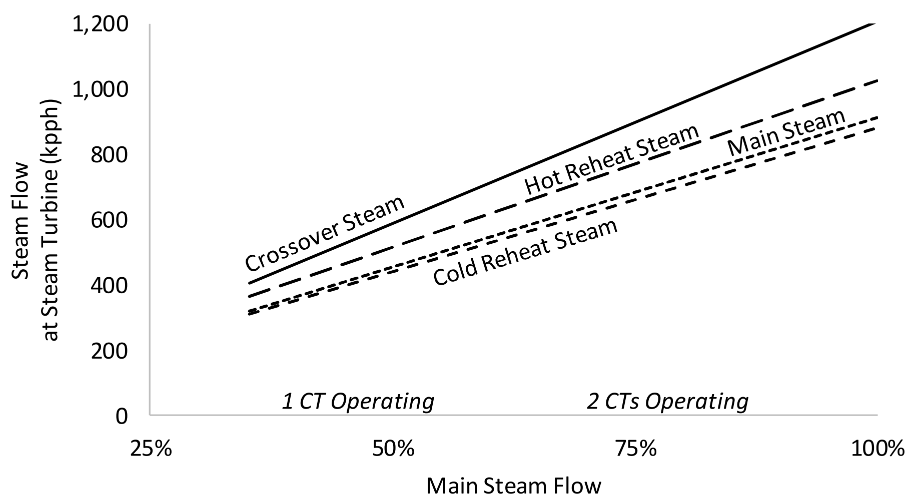



*Figure 34: Plant Daniel Unit 4 Steam Flow Ranges*

*Table 33: Plant Daniel Unit 4 Maximum Steam Operating Pressure*

| Steam Source | Maximum Pressure |
|---|---|
| Main Steam | 1950 psia |
| Cold Reheat Steam | 489 psia |
| Hot Reheat Steam | 468 psia |
| Low Pressure Admission Steam<br>LP Crossover Steam | 60 psia |

While Table 32 shows the maximum operating pressure of the steam sources, the steam cycle currently operates in a sliding pressure mode whereby steam pressure varies with steam flow. Figure 35 shows the variability of these four steam sources across the load range. Please note that the ordinate (Y-axis) in Figure 35 is not linear to capture the broad range of steam pressure available from the steam cycle.

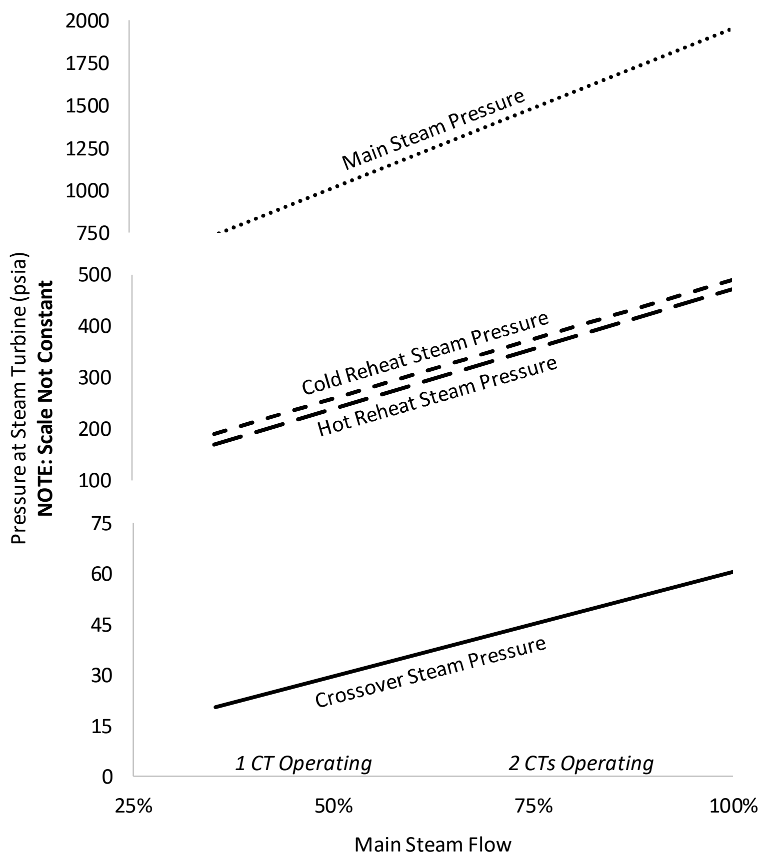



*Figure 35: Plant Daniel Unit 4 Steam Pressure Ranges*

## Steam and Condensate Interface Conditions

The PCC process' steam pressure and temperature requirements were determined collaboratively between Linde and SCS. Linde provided minimum and maximum steam parameters and the project team determined the optimal source and conditions for the overall integrated process.

As shown in Table 32, the LP crossover pressure was estimated to be ~60 psia at full load conditions on the NGCC. Pressure drop between the LP crossover and the PCC regenerator reboilers was estimated at approximately 5 psi resulting in a steam pressure of ~55 psia at the reboilers. This reference point was chosen to assess the impact of varying steam pressure. Based on simulations of PCC and NGCC performance, increasing steam pressure by 10 psia resulted in a slight beneficial reduction in steam demand for the reboilers but was offset by reduced power output from the IP turbine caused by extracting a portion of hot reheat steam (IP turbine inlet) to increase steam pressure. Alternatively, reducing steam pressure by 10 psia resulted in a beneficial increase in power output due to greater expansion across the IP turbine but was offset by higher $CO_2$ compression costs due to lower regenerator pressure and significantly increased reboiler heat transfer surface area requirements (capex). Further review of reduced LP crossover supply pressure below full load on the NGCC highlighted similar significant impacts on reboiler heat transfer surface area, so the project team incorporated a pressure control valve into the LP crossover to provide constant pressure to the PCC process. For the current FEED, ~55 psia was chosen as the optimal, constant steam supply pressure at the reboilers.

The $CO_2$ capture process utilizes the latent heat of the steam, requiring no superheat. A small amount of superheat was included to avoid two-phase flow in the piping systems. Thus, the minimum steam temperature at the source was set at 314°F.

Unlike pressure and temperature, the steam demand for the $CO_2$ capture process changes with operating condition. Two configurations for the PCC process regenerators were evaluated that influence the steam demand - a standard configuration and a lean vapor compression (LVC) configuration. The standard configuration utilizes a steam-heated thermosyphon reboiler to vaporize a portion of the solvent to provide stripping vapor to the regenerator column. The LVC configuration also utilizes a reboiler but includes equipment to produce hot lean vapor by flashing lean solvent leaving the regenerator. The hot lean vapor is subsequently compressed and returned to the regenerator to offset the reboiler steam requirements, slightly increasing the gross MW output of the combined cycle.

Simulations performed over the range of steam parameters used in the FEED determined the LVC configuration's incremental compressor power demand exceeded the performance benefit from the power cycle. Further, the LVC configuration had a slightly higher steam pressure requirement which may limit the steam source options available to meet the steam demand. The key LVC effects on the overall facility are summarized in Table 33. The standard configuration was selected for the FEED study as it offers slightly better performance and a slightly lower interface steam pressure. Figure 36 shows the estimated range of steam demand as a function of $CO_2$ capture with the chosen configuration and steam interface conditions.

*Table 34: PCC process options (at base load operation)*

| | **Standard Configuration** | **Lean Vapor Compression** |
|---|---|---|
| Combined Cycle Gross Power Output (MW) | Base | + 1.8 MW |
| Auxiliary Power (MW) | Base | + 2.8 MW |
| Steam Flow | Base | - 6.6% |
| Steam Pressure | Base | + 2.5 psia |

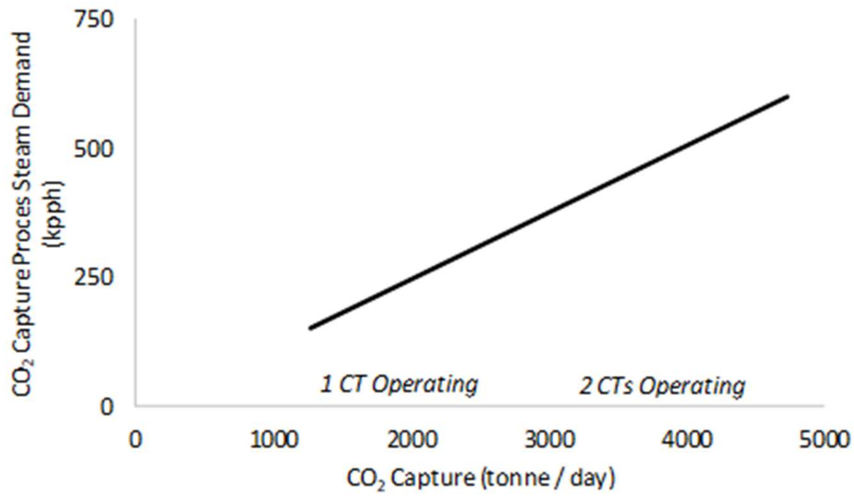



*Figure 36: PCC process steam demand*

After the steam is condensed in the $CO_2$ capture process, the condensate is returned to the steam source at a temperature between 280°F and 290°F. Table 34 presents a summary of the steam and condensate interfaces.

*Table 35: Summary of steam/condensate interfaces*

| **Parameter** | **Value** |
|---|---|
| Minimum Steam Source Pressure | ~61 psia |
| Minimum Reboiler Steam Pressure | ~55 psia |
| Steam Source Temperature | 314°F (20°F superheat) |
| Steam Flow | Varies according to Figure 12-5 above** |
| Condensate Return Temperature | 280°F – 290°F |

## Steam Source Screening

With the interface requirements defined, the next step was selecting and developing the source to supply the required steam to the $CO_2$ capture process. This steam source study was conducted in two phases. For the initial phase, options were identified and qualitatively screened to select a single option for further development. During the second phase, the preferred option was refined for use as the steam source for the FEED study. Table 35 lists eight options that were qualitatively screened based on performance, cost, and operational impacts.

*Table 36: Evaluated Steam Sources*

**Standalone Sources**

| | |
|---|---|
| Option 1 | Standalone Auxiliary Boiler |

**Sources Integrated with the Daniel Unit 4 Steam Cycle**

| | |
|---|---|
| Option 2 | Low Pressure Admission Steam supplemented by Auxiliary Boiler |
| Option 3 | Low Pressure Admission Steam supplemented by Crossover Steam (modifications to the LP steam turbine) |
| Option 3B | Low Pressure Admission Steam supplemented by Crossover Steam (modifications to the LP steam turbine and HRSG LP pressure level) |
| Option 4 | Low Pressure Admission Steam supplemented by Main Steam |
| Option 5 | Low Pressure Admission Steam supplemented by Cold Reheat Steam |
| Option 6 | Low Pressure Admission Steam supplemented by Hot Reheat Steam |
| Option 7 | Low Pressure Admission Steam supplemented by Crossover Steam (minimal modifications to the LP steam turbine) |

The qualitative impacts of each option to base load, heat rate, capital costs, and operational costs are detailed in Table 36 below. The results of the screening are summarized with the following:

- Options 1 and 2, with an auxiliary boiler, increase operational flexibility, but also increase the $CO_2$ produced on-site and do not achieve 90% $CO_2$ capture unless the incremental flue gas from the boiler is routed to the PCC process, increasing capital costs. The auxiliary boiler increases heat rate and reduces the efficiency of the overall site.
- Options 3 and 3B, utilizing LP and crossover steam, are the most efficient but incur significant capital costs to modify the LP steam turbine and LP steam section of the HRSG.
- Options 4-6, with steam supplied from high energy sources, minimize cost, but the impact on performance is substantial.
- Option 7, Low Pressure Admission Steam supplemented by Crossover Steam, was selected given the low cost, relatively low performance impact, high $CO_2$ capture, and limited effect on operational flexibility.

*Table 37: Steam Source Options and Impacts*

| Option | Description | Base Load CC Capacity[1] (MW) | Base Load CC Heat Rate[1] (Btu/kWh - HHV) | $CO_2$ Captured | Capital Cost (qualitative) | Operational Flexibility (qualitative) |
|---|---|---|---|---|---|---|
| Base | No Capture | Base | Base | N/A | Base | Base |
| Option 1 | Standalone Auxiliary Boiler | 0 | +1113 | <90% | $$ | No Change |
| Option 2 | Low Pressure Admission Steam supplemented by Auxiliary Boiler | -10 | +908 | <90% | $$ | Minor Reduction |
| Option 3 | Low Pressure Admission Steam supplemented by Crossover Steam (modifications to the LP steam turbine) | -35 | +437 | ~90% | $$ | Reduction |
| Option 3B | Low Pressure Admission Steam supplemented by Crossover Steam (modifications to the LP steam turbine and HRSG LP pressure level) | -35 | +424 | ~90% | $$ | Reduction |
| Option 4 | Low Pressure Admission Steam supplemented by Main Steam | -63 | +816 | ~90% | $ | Minor Reduction |
| Option 5 | Low Pressure Admission Steam supplemented by Cold Reheat Steam | -49 | +617 | ~90% | $ | Minor Reduction |
| Option 6 | Low Pressure Admission Steam supplemented by Hot Reheat Steam | -52 | +657 | ~90% | $ | Minor Reduction |
| Option 7 | Low Pressure Admission Steam supplemented by Crossover Steam (minimal modifications to the LP steam turbine) | -42 | +520 | ~90% | $ | Minor Reduction |

Note 1 – Performance differences are provided for the combined cycle and steam supply only, excluding any auxiliary loads for the CO2 capture process (e.g. CO2 compression).

### Steam and Condensate Configuration Refinement

Through the screening effort, a combination of LP steam from the HRSG and LP crossover steam from the turbine was selected as the steam source for the FEED study. With the screening phase complete, further refinement and definition of the steam supply was required.

By integrating the steam extraction into the existing combined cycle, the operating condition of the steam turbine was changing to meet the following requirements:

- The steam turbine must operate with a large extraction flow.
- The steam turbine extraction must meet the minimum interface pressure.

The IP section of the steam turbine is affected when steam is supplied to the $CO_2$ capture process from the crossover. The IP steam turbine was designed for sliding pressure operation at the inlet and outlet of the turbine, resulting in a relatively constant pressure ratio across the turbine over the operating range. When extracting steam from the crossover for use in the $CO_2$ capture process, the exhaust pressure is held constant, as described previously, to match the steam source interface pressure. This limits the expansion of the steam within the IP turbine, reducing the energy extracted from the steam, resulting in higher steam temperatures at the exhaust of the IP steam turbine. With less expansion, the thrust developed by the IP turbine is reduced, affecting the thrust balance of the HP / IP steam turbine. The deviation from the original design becomes more pronounced at lower steam flows. Figure 37 shows how the IP steam turbine operating range changes when steam is extracted for use in the $CO_2$ capture process.

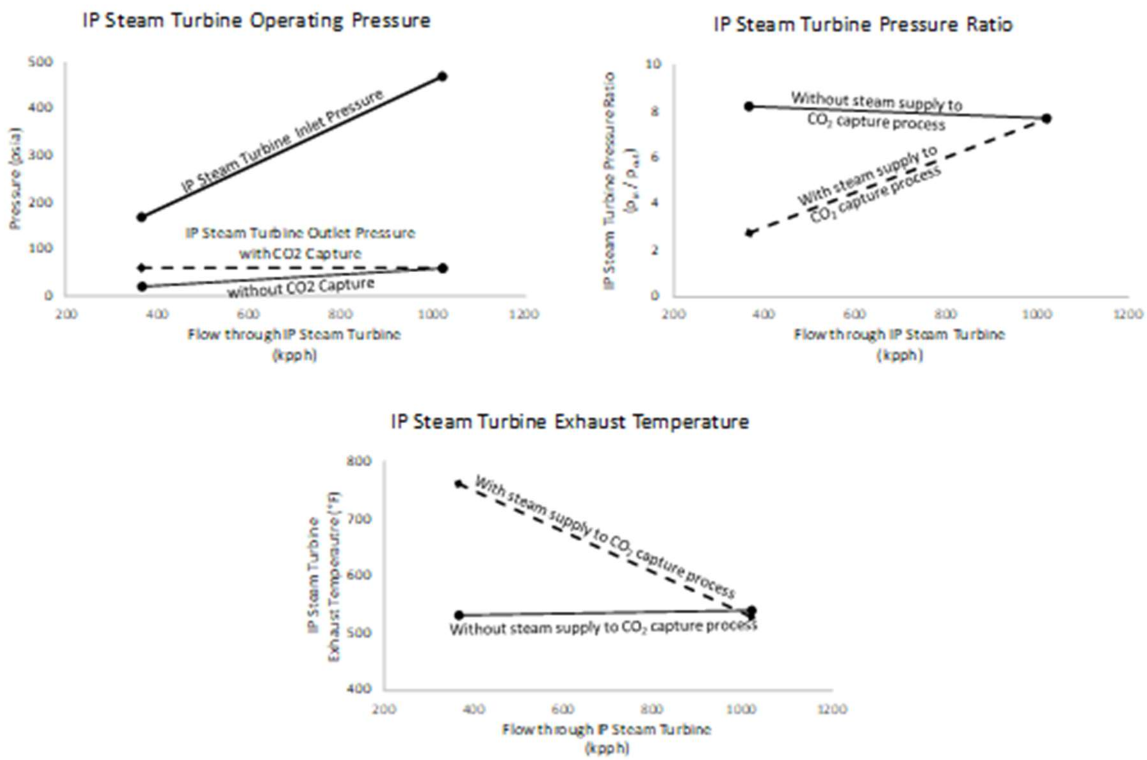



*Figure 37: IP Steam Turbine Operating Range*

While supplying steam to the $CO_2$ capture process, the operation of the LP section of the steam turbine shifts to a narrower range. While most of the operating conditions are within the current design, the operating range does extend to lower flows and pressures outside the current design. As mentioned above, the IP exhaust temperature is higher as steam flow declines since less energy is extracted in the IP turbine section. Although mixing with the cooler LP admission from the HRSG dampens this effect, the result is elevated steam temperatures at the LP inlet, especially as flow decreases. Figure 38 shows how the LP steam turbine operating range changes when steam is extracted for use in the $CO_2$ capture process.

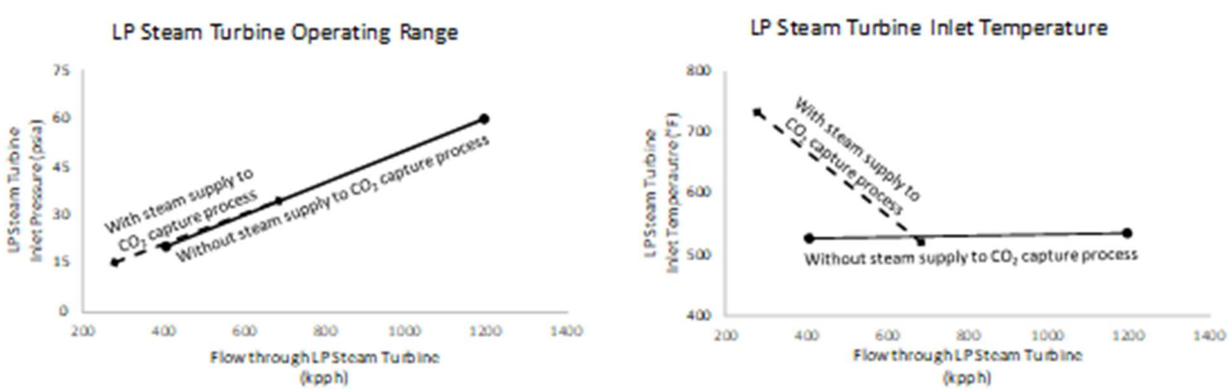



*Figure 38: LP Steam Turbine Operating Range*

The steam turbine OEM was approached with these observations in hopes of confirming their accuracy, identifying problems, and developing potential mitigation strategies. Unfortunately, the OEM was not able to provide significant support for the project effort at that time. Instead, Southern Company reviewed the steam turbine design and operation using knowledgeable internal and external experts to determine the feasibility of adapting it for use with these changes. The areas of the steam turbine affected by the process interfaces and evaluated as part of this FEED effort are described below.

### Thrust Bearing

With the expansion ratio reduction in the IP steam turbine section, the rotor thrust forces will change. It is likely that the additional force on the thrust bearing can be mitigated by a design change in thrust bearing, cage, supports, and/or the addition of balance pistons on the rotor if the existing bearing cannot handle the added load.

IP Steam Turbine, Crossover, and LP Steam Turbine Materials

The elevated IP steam turbine exhaust temperatures likely exceed the design conditions of the IP steam turbine exhaust, crossover, and LP steam turbine materials at lower loads. Material changes are likely required to resolve this.

### Last Stage Blades

The last stage blades of the LP steam turbine will operate at lower mass flow, increasing steam recirculation at the last stage. Since this steam is recirculating without being exhausted to the condenser, frictional (windage) heating of the steam can occur. There are alarms and unit trips associated with this frictional heating, typically referred to as LP exhaust hood temperature alarms/trips. LP exhaust hood spray nozzles spray condensate into this area as the temperature increases to help limit the impact of frictional heating. Excessive steam recirculation and spray nozzle operation can cause damage to the last stage blades known as trailing edge erosion. Blades with excessive trailing edge erosion will need to be monitored and replaced to prevent blade failure. This is more concerning at the lower loads, as estimated new conditions are further outside of the existing design and operating range.

For this FEED, it was assumed that the last stage blades of the LP turbine are capable of long-term operation. This assumption was made without an OEM confirmation and without a detailed study evaluating new operating conditions. To ensure the blades can withstand the change in conditions, an evaluation of the last stage blades should be performed during detailed design, including a Finite Element Analysis (FEA) and frequency analysis based on the new thermodynamic and flow conditions.

### Steam Turbine Expansion

When steam is admitted through the gland steam system and then through the main stop & control valves and reheat stop & intercept valves, the turbine will heat and expand in the axial direction. The LP turbine section remains fixed above the condenser while the HP-IP section expands and slides toward the front standard. The crossover pipe connects the IP turbine exhaust to the LP turbine inlet. A metal bellows expansion joint in the crossover pipe allows for axial expansion and contraction between the turbine sections. If expansion is greater than allowed by the expansion joint, damage could occur to the expansion joint resulting in crossover steam leaks and a potential forced outage. Also, as crossover temperatures are higher, the overall expansion of the turbine is expected to be slightly greater. This could impact internal axial clearance between the LP turbine blading and the LP turbine stationary components. Typically, there is sufficient axial clearance between rotating and stationary components in the LP section, so a slight increase in expansion of the turbine is assumed to be acceptable for the FEED.

### LP Steam Temperature Mismatch

The elevated steam temperature from the IP turbine may also exceed the allowable temperature mismatch with the LP admission steam from the HRSG due to concern of material distortion at larger temperature gradients. Possible solutions to evaluate during detailed design include material changes, re-directing the LP steam around the steam turbine and directly into the $CO_2$ capture process, or dumping the LP steam into the condenser when it does not meet the minimum temperature requirement.

### Conclusion

It is likely that the above issues can be addressed by steam turbine equipment modifications, operating constraints, or a combination of the two. Detailed steam turbine modifications should be investigated during a subsequent project phase by the OEM or a contractor capable of designing and supplying the necessary modifications.

Minimum operating constraints may also be required to maintain the steam turbine in an acceptable range, possibly operating no lower than 1 CT at 100% load. Possibilities include:

1) Limiting thrust bearing loading to as close to normal as reasonably possible.

2) Limiting crossover temperature to a more reasonable range.

3) Limiting temperature differential between LP admission and IP exhaust to ~200°F.

For this FEED study, a conservative cost allowance of $15 MM has been included assuming extensive steam turbine modifications as described above.

### Condensate Return

For the screening evaluation, condensate from the $CO_2$ capture process was returned to the deaerators / integral LP steam drums in the combined cycle, providing approximately 45% of the required flow at base load. The balance of the condensate flow to the deaerators / integral LP steam drums was provided from the condenser, flowing through the LP economizer. Finally, an LP economizer bypass is likely required to manage the LP economizer outlet temperature at reduced flow. This configuration requires complex controls to balance the almost equal flow streams to the deaerators / integral LP steam drums while also being split appropriately between the two HRSG trains. While this arrangement enhances efficiency by recovering the heat from the returned condensate, controller tuning may be problematic and susceptible to instability during upset and transient conditions. Figure 39 shows the condensate system, which incorporates this condensate return arrangement, in more detail.

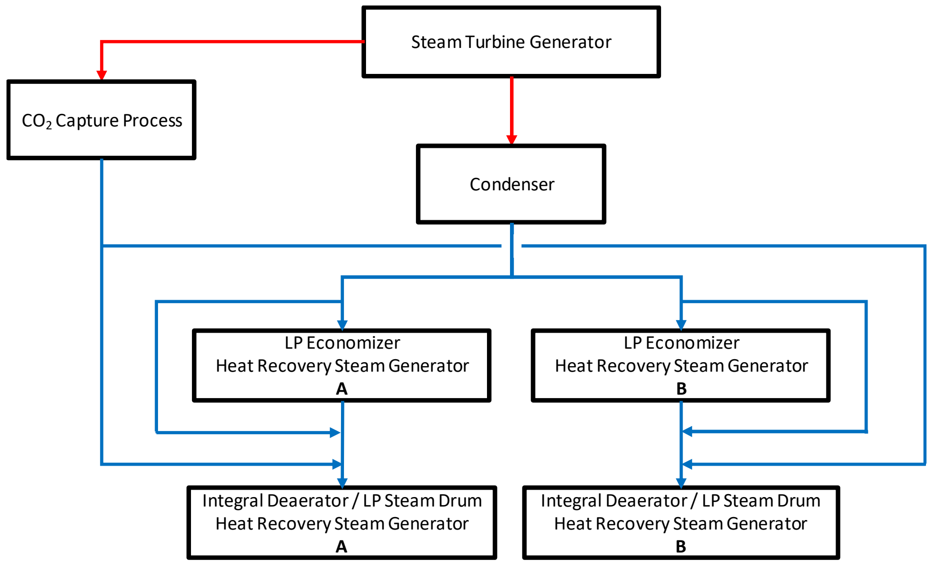



*Figure 39: Condensate configuration for screening evaluation*

After further review, it was determined that a simpler condensate return arrangement is preferable as shown in Figure 40. The condensate from the $CO_2$ capture process is returned directly to the condenser, maintaining the existing condensate flow path and control scheme within the combined cycle. This reduces the piping scope, control complexity, and the size of the condensate return pump from the $CO_2$ capture process. The stack temperature is lowered by approximately 55°F, providing margin to the $CO_2$ capture process DCC. There is a slight, negative impact on performance (1-2 MW) at base load.

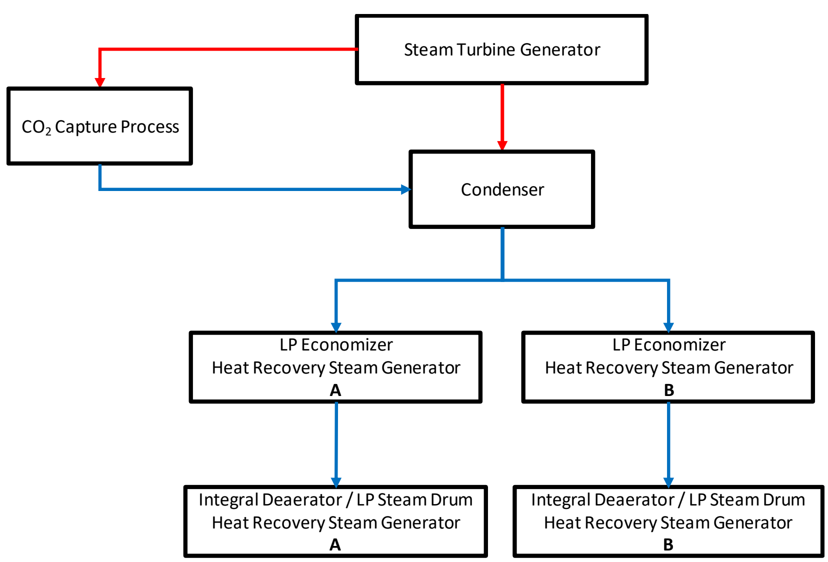



*Figure 40: Condensate configuration for FEED*

### Backup Steam Source

In the screening evaluation, a connection to the main steam system was included for use when the LP system was unavailable. This could be used, for example, when the steam demand of the $CO_2$ capture process exceeds the operating capability of the IP / LP steam turbine. This also provides a method to slightly increase capacity for peaking by increasing flow through the LP steam turbine.

However, the decision to include this backup steam source was deferred until the detailed design phase for the following reasons:

- The steam turbine modifications identified during the detailed design will define the operating range of the IP / LP steam turbine and any benefits that the backup steam source may provide for operating conditions outside of this range. Any benefits will have to be compared to the cost of the main steam connection as well as other alternatives, such as operational restrictions.
- The value of peaking capacity may be minimal, as the incremental capacity is small (less than 10 MW), and the incremental heat input is high (>18,000 Btu/kWh – HHV).

### LP Admission Piping (through STG, not separate)

The LP steam generated by the HRSG is cooler than exhaust steam from the IP steam turbine. Since superheat is not a requirement for the steam supply to the $CO_2$ capture process, this steam was directly routed to the capture process for the screening evaluation. The existing flow path to the steam turbine remained, leaving a path for the steam when not needed by the PCC process. This provides a slight performance benefit by delivering cooler steam to the $CO_2$ capture process and hotter steam to the LP steam turbine while maintaining flexibility to operate the combined cycle when there is no steam supply to the $CO_2$ capture process.

After further review, it was determined that the LP steam would remain unchanged for the FEED study for the following reasons:

- Eliminates the need to modify the existing LP steam piping to optionally deliver steam to the process or to the steam turbine.
- Eliminates a complex control to determine the LP steam path
- Maintains one steam path for controlling the steam supply to the $CO_2$ capture process
- Provides some cooling of the IP exhaust steam at lower loads
- Impact on performance is negligible.

### FEED Study Configuration

Based on the above evaluations and decisions, the steam supply / condensate return configuration for the $CO_2$ capture process adopted for this FEED is shown in Figure 41.

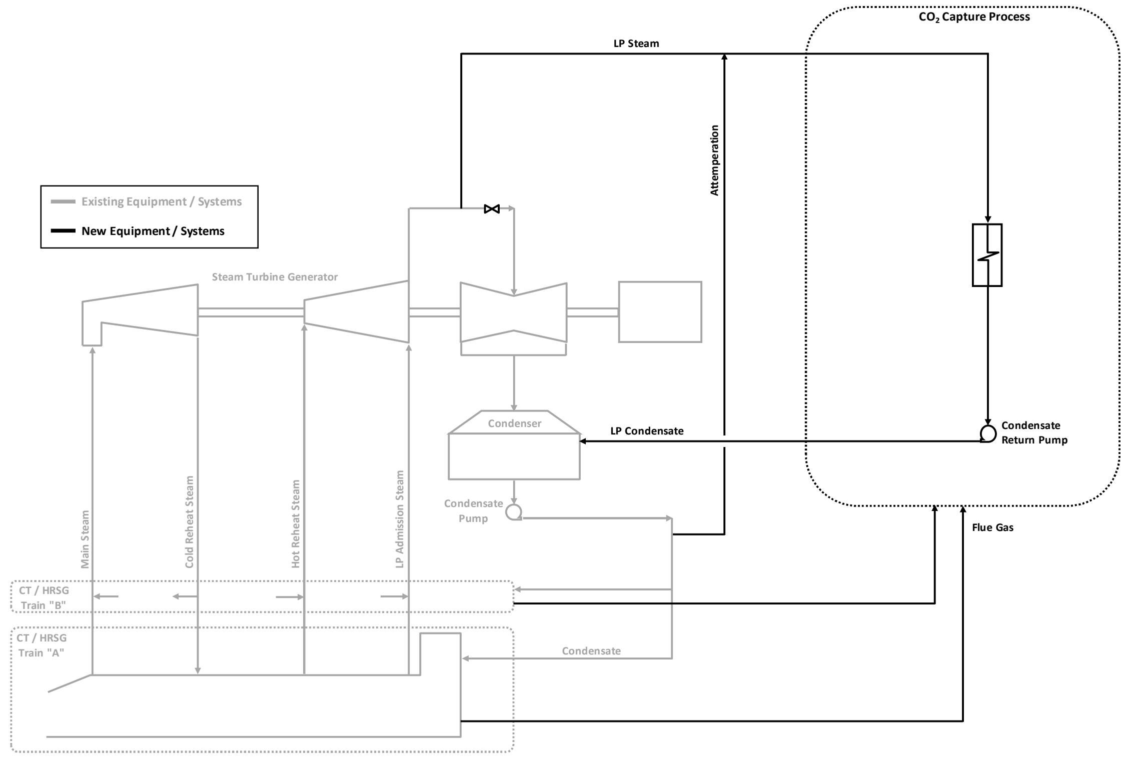



*Figure 41: Steam/Condensate configuration for FEED*

## Future Investigations

During the FEED effort, several items were identified for future evaluation.

1. The existing condensate pump discharge from the combined cycle was chosen as the source to attemperate the steam to the $CO_2$ capture process. In future assessments, the project team should consider using the condensate return from the $CO_2$ capture process for attemperation. The condensate return is at an elevated temperature which would reduce the steam extracted from the combined cycle and recover some of the heat being returned from the PCC process.
2. A pressure control valve was added to the LP crossover to provide constant pressure steam to the PCC process reboilers. Fixing steam supply pressure avoided significantly larger regenerator reboilers needed at conditions below full load or at lower steam pressures but resulted in lower gross MW output from the steam turbine across the load range due to limiting expansion across the IP turbine. It also introduced material and operating issues for the steam turbine due to operation outside existing design parameters. This balance of higher capital cost (reboiler size) versus increased gross output and efficiency may be worthy of further investigation during a detailed design phase.
3. A steam turbine allowance has been included for modifications to the steam turbine. The background for this approach and its associated allowance were described previously. Any modifications will be defined, evaluated, and selected once a steam turbine designer has been selected during the detailed design phase.

### *3.4.9 Site Security*

Because the PCC process will be inside the fence of the existing site, no additional major site security features were included in the FEED estimate.

### *3.4.10 Logistics*

The addition of $CO_2$ capture to Plant Daniel is not expected to add significant logistic challenges to the current operations. The $CO_2$ capture equipment outages would be planned to coincide with the current outage schedule of the combined cycle. Plant Daniel has an existing warehouse system and site access policies. Pipe bridges and ductwork crossing plant roadways were designed to avoid impeding normal delivery traffic.

### *3.4.11 Constructability*

Constructability reviews were conducted as part of the FEED following Southern Company's Technical and Project Solutions (T&PS) standard procedures. These reviews include the items listed below which are detailed in the subsequent sections.

*Table 38: Constructability Review per T&PS procedures*

| | |
|---|---|
| 1. Constructability Assessment | 11. Installation Contracting Methodology |
| 2. Modularization, Pre-fabrication, & Pre-Assembly | 12. Installation QA/QC Plan |
| 3. Project Safety Plan | 13. Security Plan |
| 4. Site Improvement Plan and Logistics | 14. Outage Work Integration Plan |
| 5. Construction Equipment Access | 15. Construction Management Plan |
| 6. Heavy Haul/Lifting Plan | 16. Construction Installation Estimate |
| 7. Impacts to Existing Facilities | 17. Regional Craft Labor Availability Forecast |
| 8. Project Installation Risk Assessment | 18. Craft Worker Productivity Improvement |
| 9. Construction Work Package List | 19. EPC Summary Level Schedule |
| 10. Permitting Requirements | 20. Post-Construction Site Restoration Plan |

#### *Constructability Assessment*

The initial constructability assessment considers:

- Safety: There are no extraordinary safety requirements, other than those typically associated with heavy construction.
- Scope: The scope of this project can be achieved for the estimated cost within the schedule provided using normal means and methods.
- Quality: There are no extraordinary quality requirements identified at this time that would directly impact the scope, schedule, budget, and risk.
- Risk: The risks associated with this project are typical for work on this scale requiring ordinary means and methods of mitigation.

#### *Modularization, Pre-fabrication, and Pre-assembly*

There are several advantages to using a modular construction approach. One significant advantage is overall project schedule compression. Traditional construction requires completed foundations before structural assembly, pipe assembly, insulation, electrical, instrumentation, etc. can begin. Modular construction allows these activities long before the civil and foundation work is completed. Additionally, all these activities require manhours on a busy jobsite with inherent risks. Employing modular construction allows many manhours to be removed from the jobsite. Activities performed at a modular assembly facility are completed in a more controlled environment. Many safety concerns on a busy jobsite are mitigated in the module assembly yard such as less moving equipment, drastically reduced work at elevation, fewer people, and fewer concurrent activities. This controlled environment also allows for more efficient work.

The biggest challenge with modular construction is the front-end planning required. It is very difficult to modularize items designed to be stick-built, so design engineers must always keep the modular approach in mind. However, modules can be assembled using the same engineering deliverables that would be used to field assemble onsite. Standard structural steel erection drawings are used for steel assembly. Piping is assembled from isometric drawings, using coordinates referenced to an established zero point. No special module drawings are required. The biggest changes in engineering caused by a modular approach are the compressed engineering design schedule and the additional need to analyze modules for transportation.

Based on the location and accessibility of the jobsite, there will be size limitations associated with transporting modules. These constraints are typically shipping size limitations and/or site access limitations. Size constraints must be considered from the beginning of the modular design process. Modules are shipped by either truck or barge, each having their own size limitations. Truck shipments are typically limited to a 14'W x 14'H x 50'L maximum shipping envelope. Larger modules can be shipped via truck, but the shipping gets much more complex and less cost effective. Additional Department of Transportation restrictions will apply and police and utility escorts will be required. Barge transportation allows for the shipment of much larger modules. Based on logistics studies from multiple parties, it appears larger modules can be shipped to the Plant Daniel site using a combination of barges, trucks, and possibly rail.

A Modularization Study was commissioned with a third-party construction contractor to evaluate opportunities within the PCC process. Through several 3D model review meetings, the FEED design was analyzed for modularization opportunities. Figures 42 and 43 show highlighted areas that were identified for potential modularization, including utility rack modules, vertical and horizontal process modules, and stair tower modules. Specific opportunities include:

- Process areas around the Regenerator and possibly the Absorbers may be good opportunities for large process modules.
- Utility rack modules could be utilized for the Regenerator pipe racks, the East-West crossover racks, as well as the North-South pipe racks.
- Stair towers could be pre-assembled for the Absorbers, as well as smaller stair towers identified in various process areas.

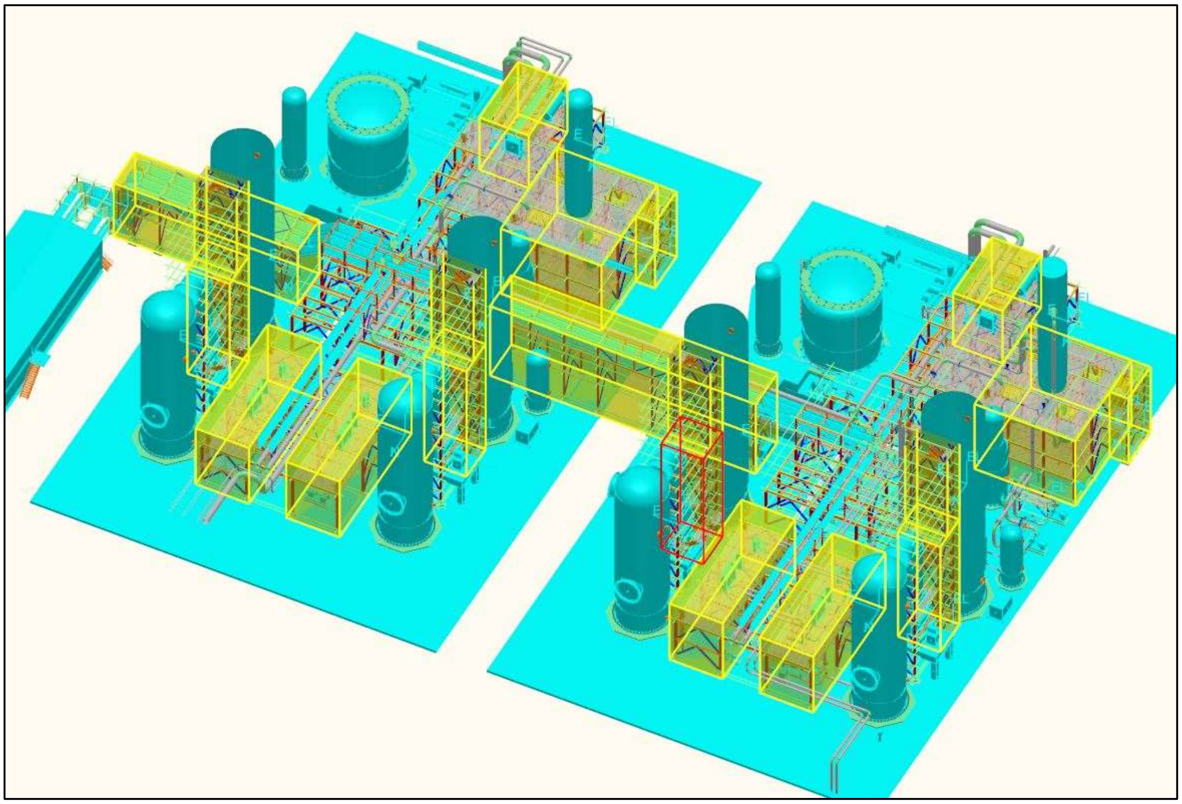


*Figure 42: Modularization opportunities ISO view*

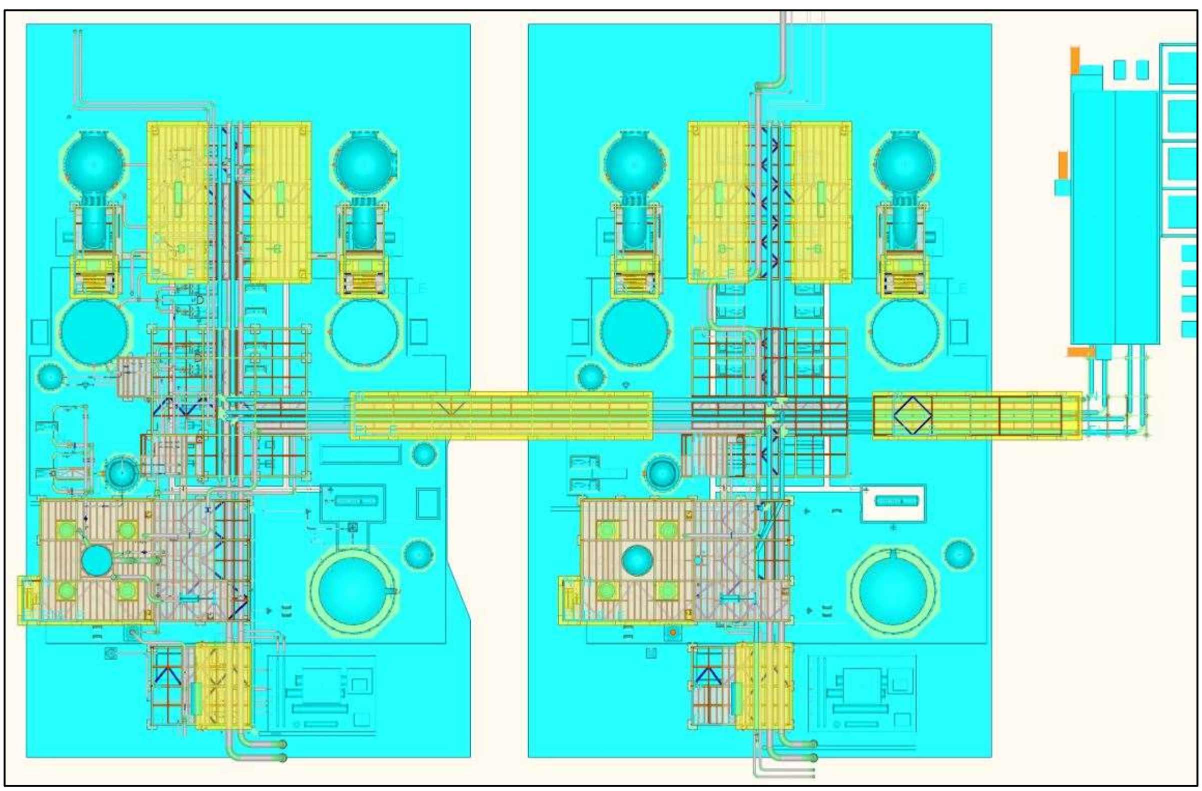


*Figure 43: Modularization opportunities plan view*

Feedback from the construction contractor indicated more detailed design of structural members and routing of small-bore piping, electrical components, and instrumentation within the PCC process must be completed to accurately estimate modularization costs so specific cost savings for this FEED estimate could not be included. Thus, the FEED cost estimate presented has been developed assuming field assembly for the $CO_2$ capture process. Further investigations will be required during a detailed design phase of the project.

However, some examples of typical cost savings provided by the contractor based on previous projects are shown in the tables below. Based on these general results, a modularization approach appears to hold promise in reducing project construction costs.

*Table 39: Potential Modularization Benefits*

| **Manhour Per Unit Comparison** | | | |
|---|---|---|---|
| **Task** | **Unit** | **Field** | **Shop** |
| Cable Tray | (LF) | 1.46 | 0.75 |
| Instruments | (EA) | 12.4 | 5 |
| Large Bore Pipe | (LF) | 5.75 | 1.5 |
| Small Bore Pipe | (LF) | 2.5 | 1 |
| Structural Steel | (TN) | 30 | 20 |
| Misc. Steel | (TN) | 45 | 25 |

*Table 40: Previous Modularization Impacts*

| **Specific Savings** | | | |
|---|---|---|---|
| **Task** | **Unit** | **Field** | **Shop** |
| Structural Steel Assembly (Labor Only) | $/ton | 1,950 | 1,300 |
| Typical CC Pipe Rack 350 Tons | $ | 682,500 | 455,000 |
| High Energy Weld (12", P91, 1'25" Wall) | $ | 4,800 | 2,250 |
| Typical CC Pipe Rack 475 High Energy Welds | $ | 2,280,000 | 1,068,750 |
| Standard Weld (3", Carbon, Sch. 40) | $ | 375 | 105 |
| Typical CC Pipe Rack 1585 Standard Welds | $ | 594,375 | 166,425 |

### *Project Safety Plan*

The FEED was completed assuming the project would adhere to the safety requirements set forth in the T&PS Environmental, Health, and Safety (EH&S) Procedures and any necessary additional site-specific safety procedures. At a minimum, the construction organization would include a safety professional dedicated to the project throughout its duration. The contractor would be required to staff the project with the necessary number of on-site safety professionals needed to monitor the work being performed. Contractor safety professionals will focus only on safety; they will not share responsibilities with quality or production.

Southern Company's behavioral based safety program, Safety Through Everyone's Participation (STEP), would be implemented by both T&PS and the contractors. New requirements would also include contractor foreman participation in the Southern Safety Trilateral Training (SST).

Gap Analysis did not reveal any additional procedures required, but the review identified the need to monitor the following areas closely:

- Haul Road Safety
- Access and Crossing Plant Roads

### *Site Improvements and Logistics*

The project would utilize existing construction entrances, gatehouses, parking facilities, and laydown areas as shown in Figure 44. Additional site improvements for lay down areas or travel routes for construction will be added as the project develops.

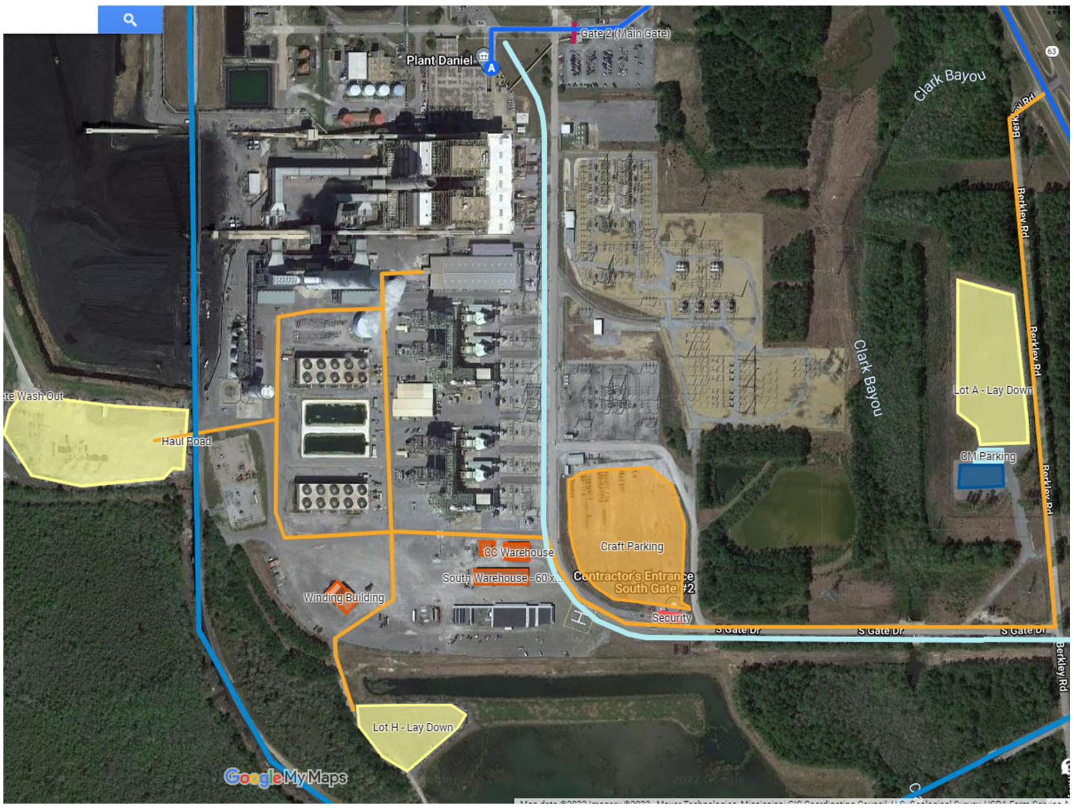



*Figure 44: Site Improvement and Logistics*

Site layout includes:

- Construction entrance
  - Gate 3 (Main Gate)
  - Gate 2 (Contractor)
- Lay Down Yards A, H, B
- Craft Parking
- Security
- T&PS Trailer
- Contractor Trailer
- Material Flow

- Relocate/Demo Buildings

### *Construction Equipment Access*

Items related to site construction equipment access identified for the FEED are listed below. No significant obstacles were identified. These items would be verified or resolved in subsequent project phases.

- Roadway marking and signs
- Equipment fueling locations
- Locations for filling water trucks
- Ground stability study of all haul roads
- Additional haul roads identified as needed
- Subsequent soil borings if required
- Equipment storage and maintenance areas
- Identify access to crew work areas and verify adequate equipment access
- Requiring contractor to verify equipment loads and overhead clearances to ensure equipment can be safely delivered and removed from the site.

### *Heavy Haul/Lifting Plan*

A Heavy Haul / Heavy Lift Study was performed by a contractor to identify challenges and begin developing plans around equipment movement and facilitating modularization opportunities. Summary recommendations from this review are listed below.

- Perform construction in a manner which minimizes lifts and rigging
- Haul path – utilize existing roadways
- Haul plan – yard dog (trailer jockey) & floats
- Crane pad – RT cranes: will have independent outrigger float
- Lift plan – will require written lift plans for all lifts. Critical lifts will require PE stamped lift plans
- Crane pad – Small cranes will be Rough Terrain only: will have independent outrigger float. 200+ Ton cranes will have full crane plan developed.
- Special lifting equipment – Forklift attachments (boom type), bottle racks, and cable reel trailers require proper name plate identification

### *Impacts to Existing Facilities*

Several impacts to existing facilities were identified during the constructability review, most notably the demo and relocation of material storage buildings and temporary construction areas in the proposed plot space. Figure 45 shows the facilities for which demo / relocation has been included in the FEED estimate. The warehouse space removed would be rebuilt elsewhere on site to maintain plant capacity.

In addition to these buildings, items such as temporary power requirements for equipment storage and construction activities, additional traffic on site access roads, work areas near an operating facility, and tie-in outages for new equipment will require close coordination with plant operations personnel.

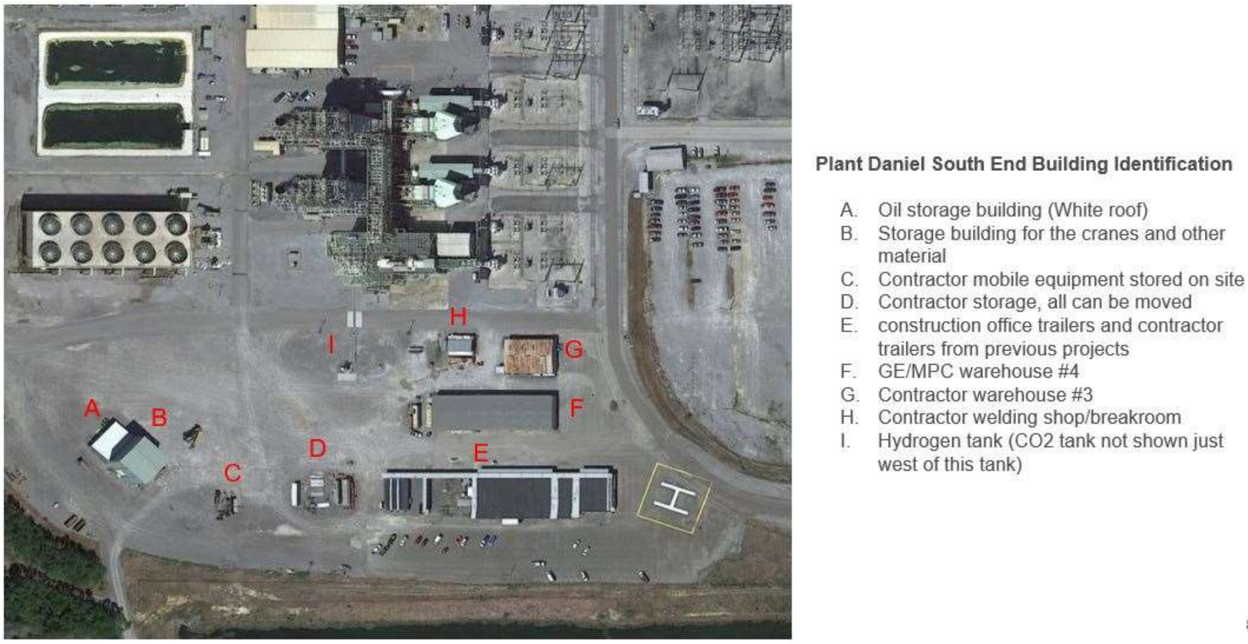



*Figure 45: Building and storage area demo/relocation*

## *Project Installation Risk Assessment*

The project team met several times during the project development process to identify, discuss, and rank risks. Figure 46 shows ranked high level risks identified during the FEED.

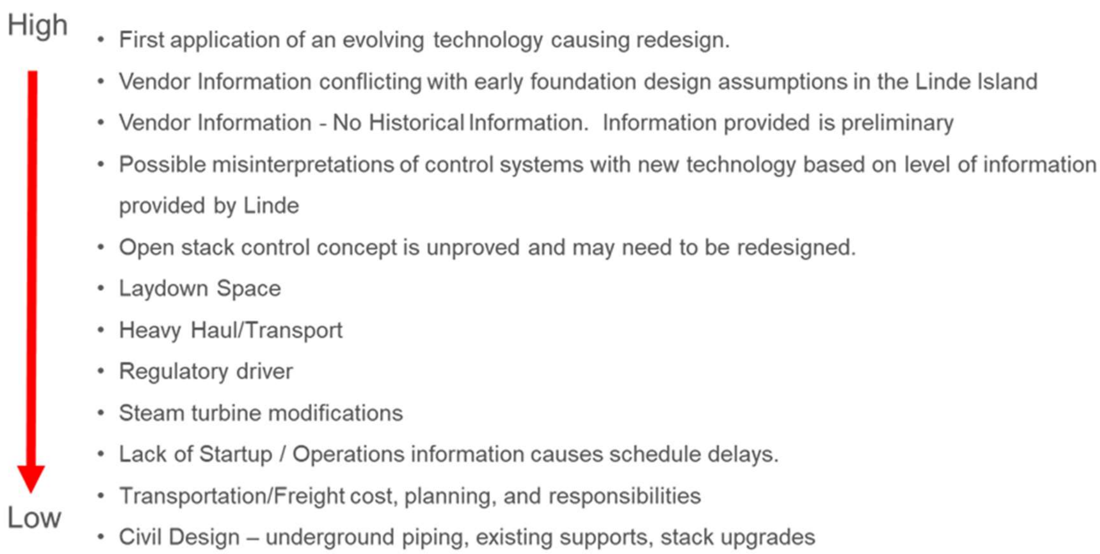



*Figure 46: Project Risk Ranking*

## *Construction Work Package List*

Table 40 lists the construction packages identified during FEED development and included in the final cost estimate. Proposed construction work areas are shown in Figure 47.

*Table 41: Construction work packages*

| |
|---|
| COCIN150 - T&PS - Construction Management |
| COCIN151 - Temporary Construction |
| COCPK001 - Underground Investigations / Site Work |
| COCPK003 - Deep Foundations |
| COCPK004 - Foundations and Structural Concrete |
| COCPK005 - Structural Steel |
| COCPK006 - Mechanical |
| COCPK007 - Electrical |
| COCPK008 - Instrumentation & Controls |
| COCPK009 - Insulation, Coatings & Linings |
| COCPK012 - Demolition |
| COCPK017 - Buildings / Architectural |
| COCPK020 - Switchyard, Distribution & Transmission |
| COCPK021 - Underground Mechanical & Electrical |
| COCPK023 - Fire Detection |
| COCPK028 - Large Cranes and Heavy Hauls |
| COCPK029 - Scaffolding |
| COCPK030 - Contractor Indirects |

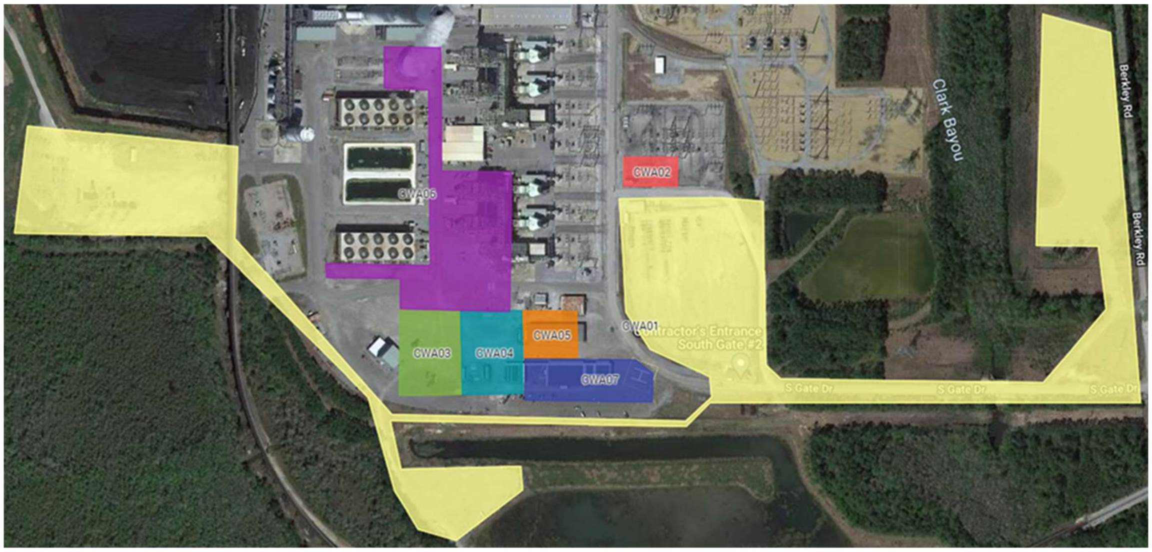


*Figure 47: Proposed construction work areas*

### *Permitting Requirements*

Primary air, water, and waste permits required for project execution are discussed previously. Permit requirements reviewed in addition to the primary permits are listed below.

- Environmental
  - SPCC (EPA) (Spill Prevention, Control & Counter Measures)
  - SWPPP (EPA) (Stormwater Pollution Prevention Plan)
- Wetlands/Threatened & Endangered Species/Cultural Resources
  - No permits identified at this time.
- Archaeological & Historical
  - No permits identified at this time.
- Local
  - No permits identified at this time.

### *Installation Contracting Methodology*

- Lump Sum Contracts – Multi-Prime Independent
  - Sitework, Foundations, and Undergrounds
  - Electrical, Mechanical, Instrumentation, Scaffold, Insulation, Coatings, and Structural Steel
- Specialty Contractors
  - Deep Foundations
  - Switchyard
  - Continuous Emissions Monitoring Systems (CEMS)
  - Pre-engineered Metal Building Installation
  - Tank Installation
  - Heavy Haul and Transportation
  - Modularization
  - Inspection and Testing – Welding
  - Inspection and Testing – Concrete/Site Work
  - Inspection and Testing – Crane/Monorail/Hoist Certifications

### *Installation QA/QC Plan*

Projects managed by Southern Company's T&PS follow a documented internal implementation procedure to establish the project's quality program. T&PS projects also document the quality program to be followed and the alignment of the site's staffing plan to the contracting strategy in the Project Quality Assurance Plan (PQAP) checklist.

Day to day quality activities listed in the procedures are managed and performed by the site project team with oversight by the assigned T&PS Construction Quality lead. Roles and responsibilities are discussed during PQAP meetings and contractor mobilizations. Training may be provided upon request. The contractors for this project will comply with the requirements of their contract documents and their accepted site-specific quality program. The contractors are required to manage and submit to T&PS the following:

- A site-specific quality program for review and acceptance.
- Applicable inspection and test plans (ITPs) or process control procedures to address how special conditions will be met, explain key inspection areas and hold points, identify special equipment needs, and define acceptance criteria.
    - ITP examples include the following: Survey Control, Concrete and Grout Placement, Electrical Installation, Welding, Bolting, etc.
    - ITPs shall be reviewed and accepted by T&PS Construction Quality Lead and applicable T&PS Discipline Leads per organization procedures.
- Submittals of qualifications / certifications for quality personnel and 3rd party test agency including their personnel.
- Quality Document Submittal Plan.

The contractor shall designate an onsite quality professional(s) who is qualified to properly inspect and evaluate the work being performed. T&PS reserves the right to accept and reject quality professional(s).

The Site Team shall routinely monitor the effectiveness of the site-specific quality program using T&PS's Construction Quality Surveillance (CQS) process to capture quality activity performed by contractor personnel. Increased Site Team participation for CQS is encouraged. Contractor is required to update the Site Team on quality per the Quality Update Report (QUR) guideline.

### *Security Plan*

The project will utilize Site Security for processing craft personnel onsite. The project will provide funding for supplemental security staff as necessary including nights & weekends. All contractor personnel will be verified by a Site Safety Professional for ability to legally work in the U.S. on Southern Company Projects. All vehicles entering the site will be subject to random security searches. Contractors are also responsible for conducting random drug screening as outlined by T&PS contracts.

### *Outage Work Integration Plan*

Outage work integration planning will be coordinated with site personnel and includes the following elements:

- **Scope of work**: Identify scope early as possible to allow for scheduling and minimizing impact to existing facility.
- **Sequencing**: Placement of large components such as the absorbers and the DCCs will significantly impact working construction space for the project.  Construction should be sequenced so the placement of

foundations (including deep foundations) maximizes construction space by allowing installation to occur from east to west.

- **Communication**: Daily plan of the day (POD) meetings would be held with contractors and site management.  Weekly plant update meetings would be scheduled to discuss logistics, schedule, and ongoing work.

### *Construction Management Plan*

The construction management team is typically organized as shown in Figure 48.

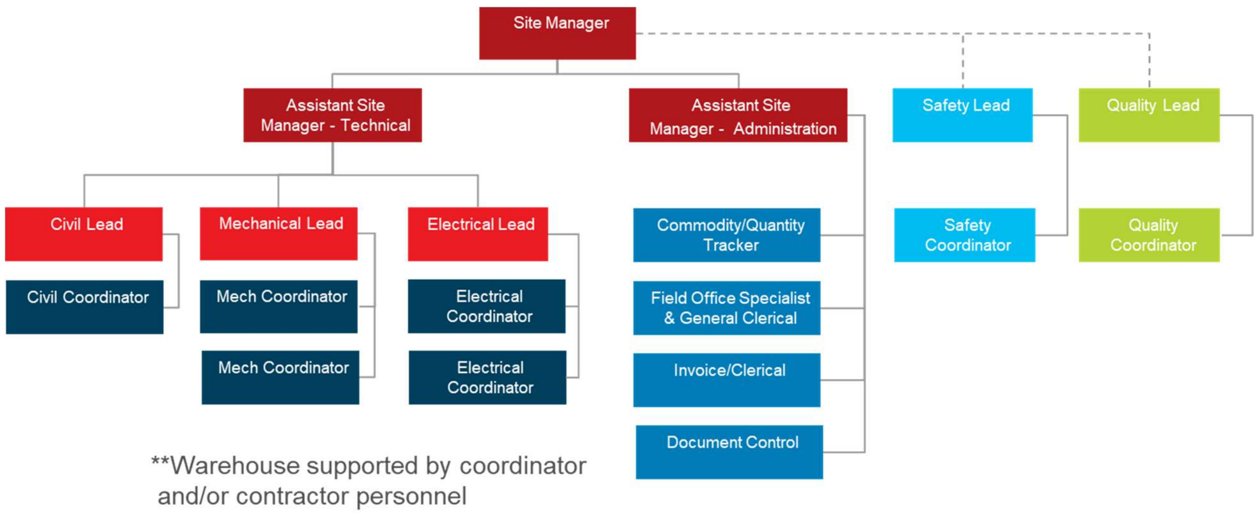



*Figure 48: Construction management organization*

### *Construction Installation Estimate*

Please see section 3.4.12 for details on the construction estimate.

### *Regional Craft Labor Availability Forecast*

Nonresidential construction demand is making significant strides in recovery from the pandemic. The data firm Dodge Construction Network reported a 12% increase in nonresidential building construction starts in 2021 over 2020. Environmental public works gained 21%. Utilities/gas plants rose 6% for the year. According to a new report from the American Institute of Architects, the nonresidential building sector is expected to see a healthy rebound through 2023. The AIA's Consensus Construction Forecast panel—comprising leading economic forecasters—expects spending on nonresidential building construction to increase by 5.4 % in 2022 and accelerate to an additional 6.1 % increase in 2023. The industrial market is expected to pace the building construction upturn this year and next, with projected gains of over 9% this year and more than 8% in 2023.

The economists and analysists with Construction Industry Resources suggest these positive trends in construction activity when factored with other economic drivers and historical trends will continue at least through 2024 with wage escalation approaching 4% per year. By 2025, however, the U.S. economy will be due for a reboot with the Federal Reserve policy even taking a hard line against inflation resulting in a contraction of the economy or recession. What comes after recession of 2025 is likely a long expansion. Through the second half of the 2020s and the earliest years of the 2030s, the outlook for the United States is for a prolonged period of growth, aided by improving productivity and rising wages. Of course, exogenous factors such as international crises, debt crises, internal dissension, and other random events would have major impacts to the economy, all of which are difficult to foresee.

Severity of labor shortages could also present significant challenges to future increases in construction activity. Demographic trends point to a declining labor force particularly for skilled construction workers. According to the Bureau of Labor Statistics (BLS), most of the “baby boomer” generation will have left the workforce by 2030. The BLS estimates that the construction workforce is currently declining 1% per year. A recent study by the Construction Industry Institute (CII) identified that an unfavorable perception of construction careers exists with new entries to the labor force compared to other industries.

In summary, a robust demand for construction labor is predicted for the next 2 – 3 years and softening for a period of 1 – 2 years before rebounding strongly. Robust construction activity coupled with declines in skilled labor availability will result in wage escalation and an increase in staffing risks for construction projects. Construction firms will continue toward an increased reliance on labor saving technologies and processes to mitigate these risks.

### *Craft Worker Productivity Improvement*

Prime contracts will include a Craft Worker Productivity Improvement Plan with reporting requirements. Some of the Productivity Plan elements include:

- Labor Productivity
  - Ensuring a safe and clean work environment
  - Material, tool, and equipment availability
  - Location of facilities, tool rooms, break areas, etc.
  - Proper and complete work task planning using tools such as Installation Work Packaging and Workface Planning
- Equipment Logistics
  - Haul route selection and marking
  - Preparation and maintenance of haul routes
  - Location of port-o-lets and other facilities
  - Dust control for driver safety and visibility
  - Proper lighting for early morning and evening hauling
- Equipment Management
  - Off hours fueling
  - Effective equipment preventive maintenance
- Peer Reviews
  - Pre-Construction Checklist
- Logistics and Site Layout focused on craft movement
- Installation Rates Used in Estimate

### *EPC Summary Level Schedule*

Please see section 3.4.13 for the project summary schedule.

### *Post-Construction Site Restoration Plan*

Development of this plan ensures the site is restored to preconstruction condition or better, removing all temporary infrastructure and returning the site to the original site conditions.  Costs for site restoration have been included in the FEED estimate. Every effort will be made to restore the site to preconstruction conditions. A post-outage site restoration plan will include all necessary activities such as grading and repaving as needed, painting, grassing, signage, removal of all nonpermanent contractor facilities and any general housekeeping to restore site to preconstruction condition.

### *3.4.12 Project Cost Estimate*

A division of work (DOW) summary of the FEED cost estimate is shown in Table 41. It is considered an overall +/- 15% estimate based on the level of engineering detail and material quantities provided by Linde and SCS. This accuracy range refers to the overall estimate, but not necessarily the individual parts. The estimate costs were in 2021 nominal dollars and escalated using a T&PS Project Controls internal tool. The cost is broken down into Division of Work (DOW) packages and cash flowed using typical cost curves for each DOW and durations based on the Level 1 schedule.

The basis for Linde's engineering cost is an engineering hour estimate. Approximately 95% of the mechanical equipment costs are supported by vendor quotes. The remaining 5% were estimated based on Linde inhouse data. Piping material quantities have been established with Linde piping material tools, based on the PID and plot plan. The pricing for piping materials is based on unit rates derived from the Linde inhouse cost database and partly supported by vendor quotes. The pricing for steel structure materials is based on unit rates derived from currently executed projects. The pricing for E&I equipment and materials is based on unit rates derived from currently executed projects. The estimate of the procurement and supply cost for all equipment, bulk materials and commodities is based on Linde inhouse cost data and supported by vendor quotes.

The PCC portion of the cost estimate was developed on a global sourcing basis. Linde prepared the cost estimate on a multi-currency basis with all items included in their expected currency based on vendor quotes, Linde's cost data base, and the assumed project execution scheme. Linde’s cost estimate was completed in EUR and converted to US dollars using an exchange rate of 1 EUR = 1.16 USD.

It should be noted that the FEED estimate currently does not include financing costs. Many variables are considered when determining the method of cost recovery for financing costs on a construction project of this size. The authority to approve cost recovery mechanisms for a regulated utility such as Mississippi Power lies with the Mississippi state public service commission (PSC). The PSC would determine what was allowed for a potential future project. Rather than speculate what the PSC would approve, the project team chose to omit financing costs from the FEED estimate

*Table 42: Division of Work Cost Estimate for Linde FEED*

| Division of Work | Total Cost ($ MM) |
|---|---|
| Front End Planning | $4.5 |
| Engineering – Including Construction and Startup Support | $47.9 |
| Engineering-Procured Materials | $18.1 |
| Construction – Including Labor, Materials, and Contracted Equipment | $497.1 |
| Startup | $31.8 |
| Project Management | $8.7 |
| Owner’s Costs | $17.8 |
| Escalation and Contingency | $126.3 |
| **TOTAL** | **$752.2** |

*3.4.13 Estimated Project Schedule*

The summary estimated project execution schedule associated with the FEED package scope is included below. The schedule includes detailed design, equipment procurement, construction, and commissioning/startup of the $CO_2$ capture retrofit. Major permitting activities are also included as they have been identified in other public analyses as potentially significant contributors to project duration. The total project duration was estimated to be just under 5 years.

SCS project controls compiled the inputs from engineering, construction, and procurement and reviewed for schedule sequencing and logic. Linde also drafted a project schedule for the ISBL scope and provided it to SCS for comparison. Both organizations produced similar first drafts and this increased confidence in the combined overall product.

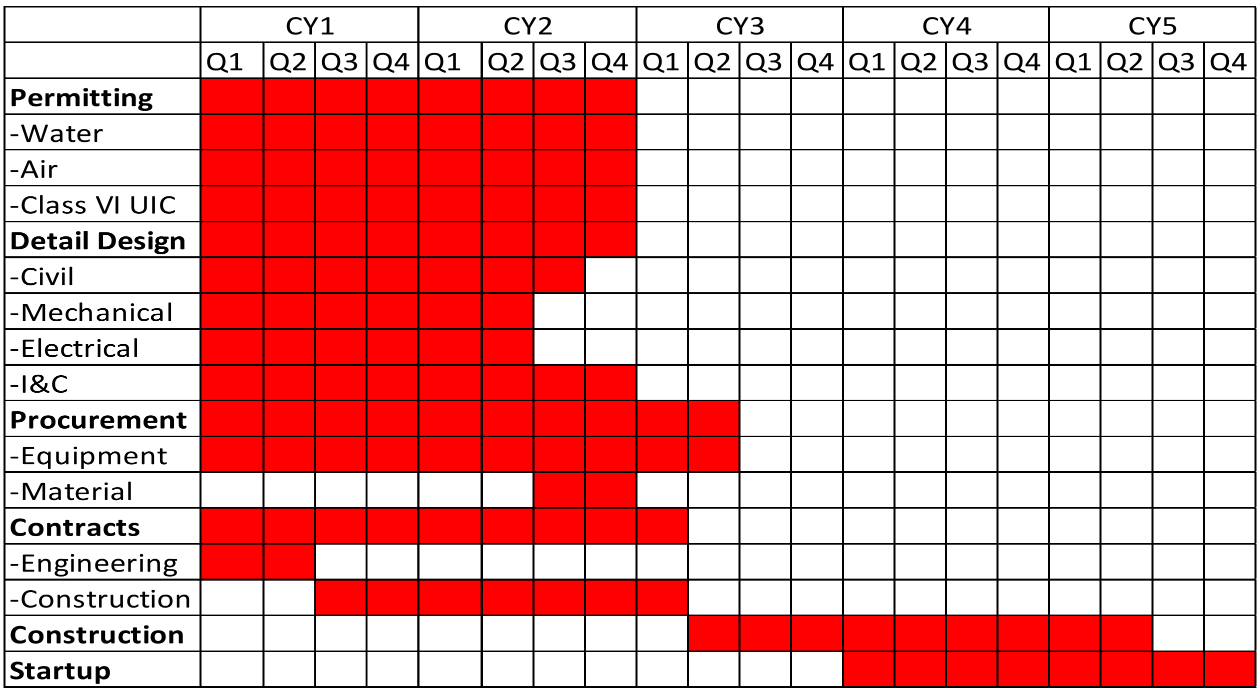



*Figure 49: Summary Project Schedule*

*3.4.14 Estimated NGCC Performance Impact*

Based on the PCC system and NGCC configuration detailed in this FEED package, the estimated performance impact on net plant MW output and heat rate are provided in Table 16-1.

*Table 43 NGCC Performance Impacts*

| Parameter | Change with addition of $CO_2$ Capture |
|---|---|
| Combustion Turbine Output (MW) | No Change |
| Steam Turbine Output (MW) | -43 |
| Facility Station Service (MW) | +36 |
| Net Plant Output (MW) | -79 |
| Net Plant Heat Rate (BTU/kWh) | +1060 |