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CARBON CAPTURE PLANT FRONT-END ENGINEERING DESIGN STUDY FOR CEMENT MANUFACTURING

Final Scientific/Technical Report – Unlimited Rights

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1 Executive Summary

1.1 Introduction

1.1.1 FEED Objectives, Conclusions and Recommendations

The objective of this project was to conduct a Front-End Engineering Design (FEED) study for capturing carbon dioxide (CO_2) from cement plant flue gas using non-aqueous solvents (NAS) with a 95% capture efficiency. The study aimed to develop AACE (Association for the Advancement of Cost Engineering) Class 3 cost estimates for a commercial-scale CO_2 capture system with a capacity of 2.4 million tonnes of CO_2 per year (t-CO_2/yr). The results will provide Cemex and the U.S. Department of Energy with reliable data to support investment decisions, evaluate economic feasibility, and guide future project development and implementation.

The study was led by RTI International, the CO_2 capture technology developer, with KBR Inc. serving as the engineering, procurement, and construction (EPC) contractor, and SLB Capturi acting as the Owner's Engineer and technology licensor. The project was funded by the U.S. Department of Energy, with cost-sharing contributions from RTI International, Cemex, and SLB Capturi.

The proposed capture facility is designed for a nominal CO_2 capture capacity of 2.4 million tonnes per year, based on a 95% capture efficiency from both kiln flue-gas streams and the natural gas–fired boiler that supplies steam to the capture process. Actual CO_2 recovery will vary with the cement plant's operating hours and capacity utilization.

The estimated total capital expenditure (CAPEX) for the NAS CO_2 capture plant integrated with Cemex's Balcones cement plant is $849 million. This includes $558 million in direct costs, $54 million in indirect costs, $51million in engineering costs, $24 million in Owner's costs, and $104 million in contingency. Another $18 million accounts for miscellaneous freight and hauling costs and $42 million for escalation.

Fixed operating costs include annual operations and maintenance (O&M) labor, administrative and support staffing, as well as costs associated with maintenance materials, property taxes, and insurance. The total annual fixed operating costs were estimated at $11.4 million.

The total annual variable operating costs were estimated at $35.8 million. In addition, fuel and purchased power costs were estimated at $61.6 million annually. Total annualized operating costs were estimated to be $109 million, resulting in a breakeven CO_2 capture cost of $101.6 per tonne of CO_2.

The RTI NAS CO_2 capture plant requires 46 MW of electrical power and approximately 610 MMBtu/hr of natural gas for steam generation.

The current design includes an acid wash system to control emissions requiring ongoing amine makeup and RTI International has developed an amine recovery process that is planned for inclusion in standard design packages for future projects. It was not incorporated into the current FEED design, as its development progressed in parallel with the FEED. When the amine recovery is implemented, the levelized cost of capture is projected to decrease by at least ~9%.

The FEED study did not identify any major project risks. The solvent reclamation process, which remains under development, was not included in the current design but its integration into the system is planned for the detailed design phase.

The current design employs a hybrid air and water cooling system. This configuration significantly affects both capital cost and electricity consumption. The cost of CO_2 capture could be substantially lower by 13% at sites where cooling water is readily available. These savings are primarily driven by lower CAPEX for exchangers, reduced fan power consumption, and shorter flue gas ducting, while additional CAPEX and power for the larger cooling tower partially offset these benefits. Note: The cost of capture comparison is conservative, as it does not account for potential reductions in civil works and structural steel associated with the smaller plot area required for water cooling. Including these savings would likely further reduce the total cost of capture for water-cooled system.

1.1.2 Host Site and Design Considerations

The Balcones plant is in New Braunfels, Comal County, TX. Total cement production at Balcones is 2.5 million tons per year. The plant has 2 kilns. Kiln #1 has 4 preheater stages with a design capacity of 3,125 tons clinker/day and kiln #2 has 5 preheater stages with an inline calciner with a design capacity of 3,600 tons clinker/day. The flue gas from the preheater section is used for drying the raw materials in the raw grinding mill before sending it to the baghouse filter for dust removal and then to the stack. The CO_2 capture system takes flue gas from the process location after the baghouse. Total CO_2 emissions at nominal capacity is 2.2 MTPA. The CO_2 capture plant captures 95% of the CO_2 in the combined flue gas from the cement kilns and the natural gas-fired boiler used to generate steam for solvent regeneration.

The project employs RTI's NAS solvent process, selected for its low regeneration energy requirements and high CO_2 regeneration pressure, which together reduce overall operating costs. The design basis was established using measured site data, including two years of Continuous Emissions Monitoring System (CEMS) measurements of flue gas flowrates, compositions, temperature and pressure conditions, as well as site-specific weather data and regulatory environmental limits. A single train can treat the total flue gas from the cement plant.

The CO_2 capture facility is designed to operate using electricity supplied from the grid, while steam generated on site by the natural gas–fired boiler provides the thermal energy required for the solvent regeneration process.

1.2 Process Overview, Host Site Integration and Schedule

1.2.1 Process Overview

A schematic of the process flow diagram is provided in Figure 1. RTI's CO_2 capture process uses RTI-NAS, a formulation of hydrophobic amine in an organic diluent with low water content (<10 wt.%). The CO_2 capture plant consists of a direct contact cooler (DCC) with integrated SO_2 polishing, a flue gas blower, an absorption column with intercoolers, an advanced emissions control technology and acid wash to control amine emissions, a regeneration column, associated pumps, storage and receiver vessels, and a CO_2 compression, dehydration, and polishing train. The solvent is continuously recirculated between an absorber and a regenerator column. Flue gas from a cement plant and the natural gas-fired boiler used to generate steam for solvent regeneration for the capture plant, after scrubbing SO_2 and cooling the flue gas, enters the absorber column where 95% of the CO_2 is captured. CO_2 absorption occurs at low temperatures in the absorber column. The amine in the NAS solvent reacts with CO_2. The CO_2-rich solvent is regenerated in the regenerator using LP steam from the natural gas-fired boiler. During the solvent regeneration process,

the solvent is heated, and the reverse reactions predominate to release CO_2. The CO_2 released in this process at 65.3 psia (4.5 bar), is dried, compressed to 2215 psia (152.7 bar) and sent for sequestration. The process is water-balanced by operating the water wash temperatures close to the dew point temperature of the gas leaving the DCC, such that the total water entering the CO_2 capture process is balanced by the total water leaving with the treated gas and the CO_2-product gas. There is no makeup water required for the NAS process.

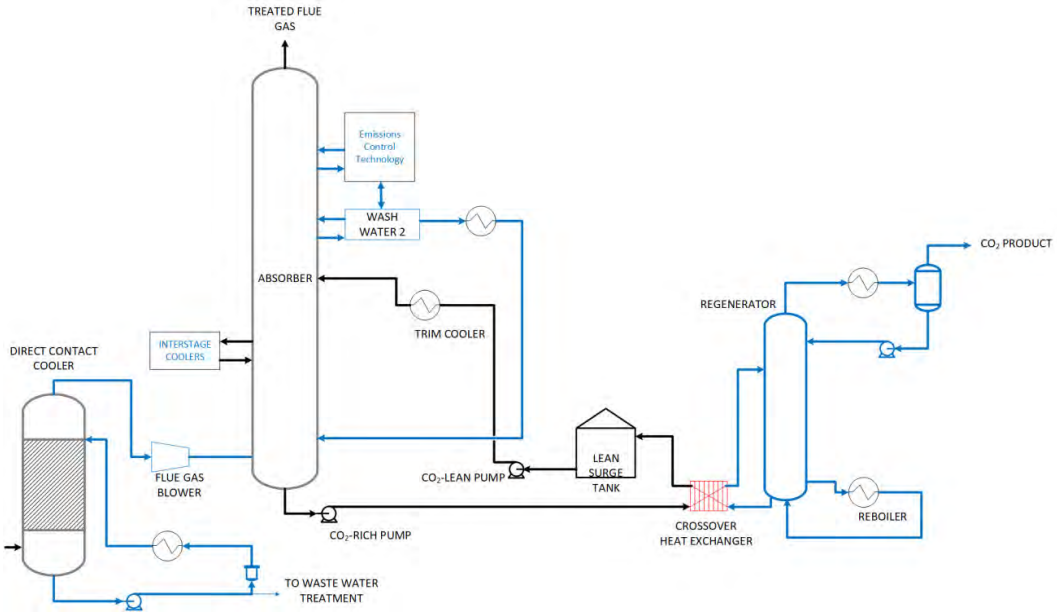


Figure 1: Schematic of the RTI NAS Process

1.2.2 Technical Design and Integration Challenges

The CO_2 capture plant at Cemex Balcones faced several design challenges that were reviewed and resolved during the FEED phase. A primary process design constraint was the limited availability of raw water, which significantly influenced the selection of cooling systems. The amount of water recovered from the DCC and the supply from the Balcones Cement Plant is able to supply 20% of the requirement for cooling water makeup. Following an evaluation of various cooling options, a hybrid system combining air cooling and water cooling was selected. Water cooling is applied in the absorber wash section and DCC trim cooler, while air coolers—sized for 80°F ambient temperature—handle the majority of the heat rejection. The use of alternative cooling systems to compensate for limited water availability, has an impact on the overall cost of CO_2 capture, as detailed in the cost analysis section of this report.

To further minimize water consumption, the design incorporates a steam-integrated CO_2 compression system, in which boiler feed water is used to generate steam instead of relying on water-cooled interstage compressors. This configuration eliminates the need for cooling tower makeup water but results in higher interstage temperatures and a corresponding 33% increase in compression power demand.

1.2.3 Site Arrangement

The inclusion of air-cooled heat exchangers, which require approximately four acres of space, necessitated relocating the capture facility from its originally identified location closer to the main plant. The proposed CO_2 capture plant will be located on a greenfield site situated south of the New Braunfels facility, occupying a plot of approximately 15 acres. Additional Cemex-owned property to the south and west of the proposed site may be utilized for construction laydown and staging areas. Figure 2 presents a 3D model of the existing cement plant, including the flue gas duct routing over the rail spurs and Wald Road.

Figure 2: 3D model view with integrated scan of the existing cement plant, showing the flue gas duct routing over the rail spurs and Wald Road.

Figure 3 shows the plant with the proposed plot area for the capture plant across the road from the cement plant. The flue gas ductwork will be routed over both the rail spurs and the Wald road to connect the cement plant to the new CO_2 capture unit.

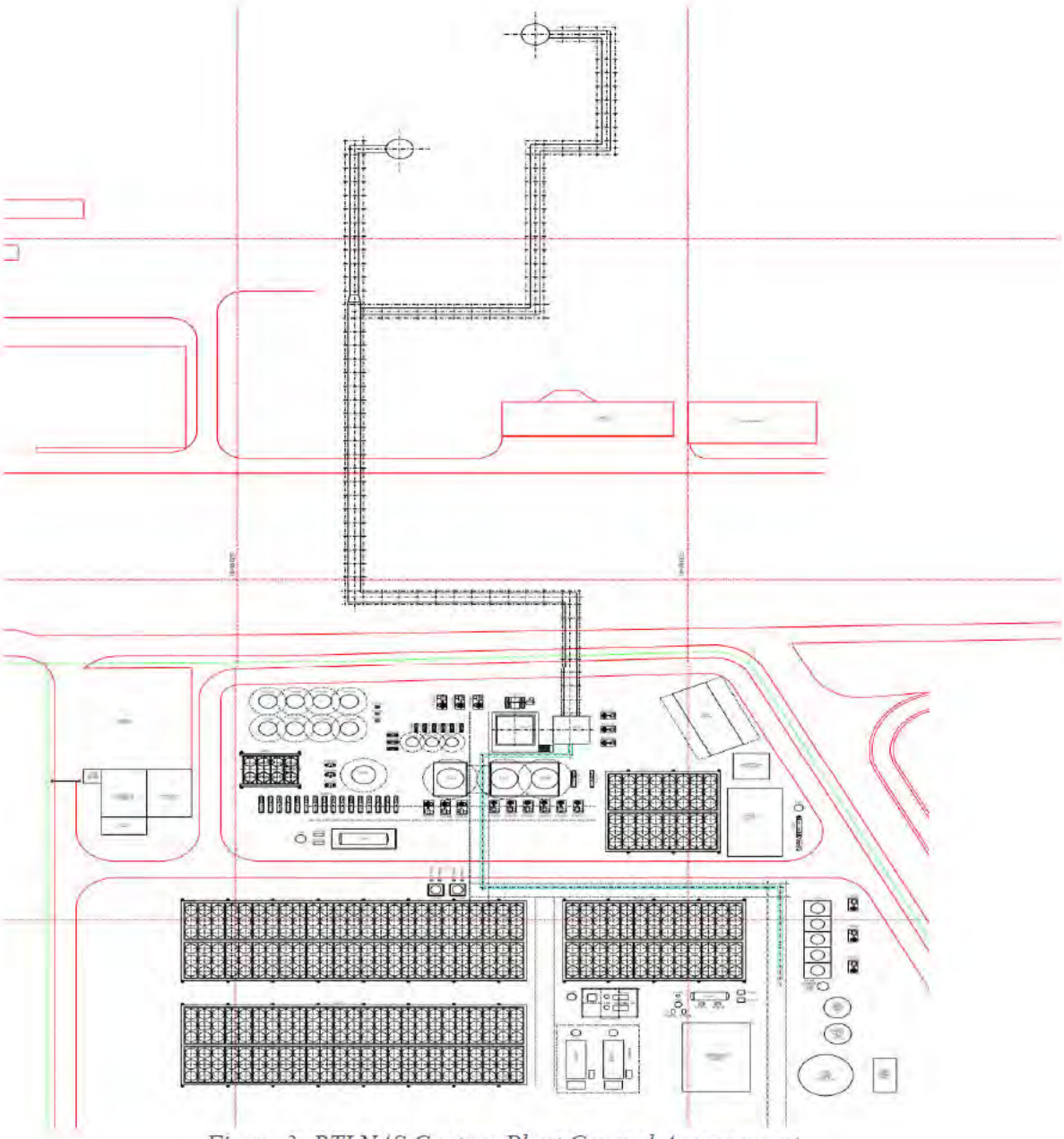
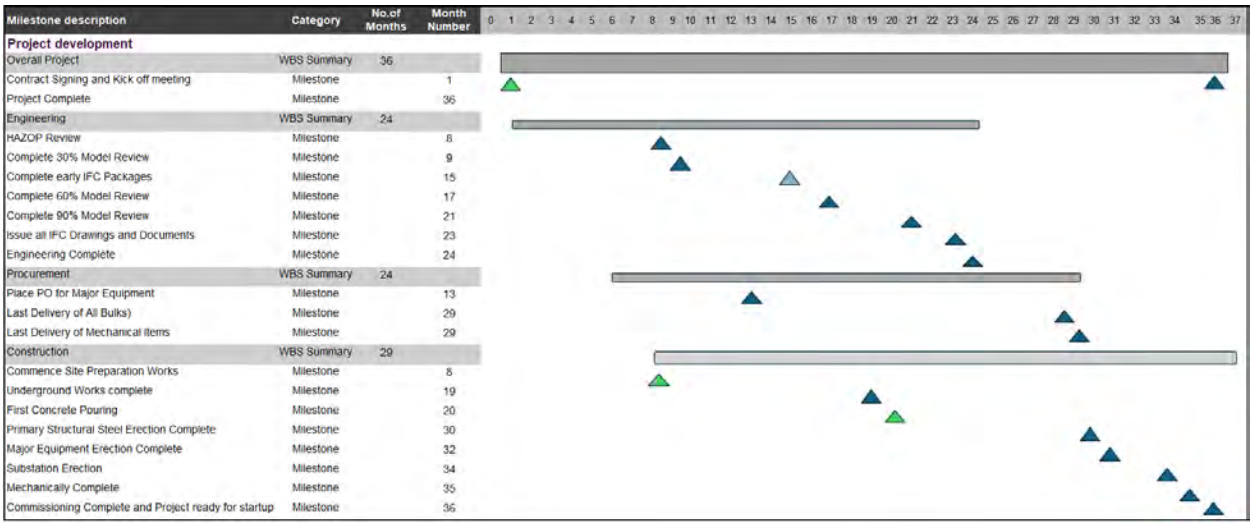


Figure 3: RTI NAS Capture Plant General Arrangement

1.2.4 Schedule

The Level 1 project schedule is presented in Figure 4. The overall project duration is estimated at approximately 36 months, from engineering authorization through commissioning. Detailed engineering is expected to continue for approximately 24 months. Construction is scheduled to begin about eight months after detailed engineering starts, extending for 24 months and overlapping with engineering activities for roughly 16 months to enable early field execution. The project would conclude with a three-month commissioning phase, resulting in a total anticipated duration of approximately 36 months.



Milestone description	Category	No.of Months	Month Number
Project development			
Overall Project	WBS Summary	36	
Contract Signing and Kick off meeting	Milestone		1
Project Complete	Milestone		36
Engineering	WBS Summary	24	
HAZOP Review	Milestone		8
Complete 30% Model Review	Milestone		9
Complete early IFC Packages	Milestone		15
Complete 60% Model Review	Milestone		17
Complete 90% Model Review	Milestone		21
Issue all IFC Drawings and Documents	Milestone		23
Engineering Complete	Milestone		24
Procurement	WBS Summary	24	
Place PO for Major Equipment	Milestone		13
Last Delivery of All Bulks)	Milestone		29
Last Delivery of Mechanical Items	Milestone		29
Construction	WBS Summary	29	
Commence Site Preparation Works	Milestone		8
Underground Works complete	Milestone		19
First Concrete Pouring	Milestone		20
Primary Structural Steel Erection Complete	Milestone		30
Major Equipment Erection Complete	Milestone		32
Substation Erection	Milestone		34
Mechanically Complete	Milestone		35
Commissioning Complete and Project ready for startup	Milestone		36

Figure 4: Level 1 Schedule for the RTI NAS CO_2 Capture Project

1.3 Project Cost Estimate

1.3.1 Capital Cost Estimates

The total estimated project costs for the Carbon Capture Plant have been calculated based on material quantities, labor hours, wage rates, vendor quotes, and indirect cost allowances. The estimate includes Total Direct Costs (TDC), indirect field costs, owner's indirect costs, escalation, and contingency.

The direct field costs encompass labor hours, average wage rates, labor costs, material costs, and their respective contributions as percentages of the Total Direct Cost (TDC). In addition to these direct costs, the estimate includes indirect field costs, owner’s indirect costs, and engineering/home office services. To arrive at the Total Installed Cost (TIC), the estimate was further adjusted for escalation and contingency.

The CAPEX cost estimates were developed by KBR based on detailed technical documentation, including datasheets, requisition packages, specifications, and other relevant materials, to support the procurement of vendor budgetary quotes. These quotes were evaluated against the associated design specifications to determine scope inclusions and exclusions. For any excluded items, appropriate allowances were applied to complete the estimate. Vendor quotes were obtained for all critical mechanical equipment, representing 94% of the total mechanical equipment cost. Additional quotes were also gathered for most electrical and instrumentation equipment.

Generally, the lowest technically acceptable vendor quotes were selected for inclusion. However, in cases where there was uncertainty regarding the accuracy or completeness of quotes, average pricing was used as a conservative approach. Contractor quotations were also included for various infrastructure components such as the power overhead feeder, gatehouse, warehouse, ECR building, control and change room building, maintenance building, laboratory, and compressor sheds. The combined value of vendor budgetary quotes and contractor estimates makes up approximately 66% of the total project equipment and material costs. The remaining bulk materials and equipment costs were estimated using the ACCE (Association for the Cost Engineering) methodology, with adjustments based on KBR's historical cost data. Capital spares were also incorporated into the estimate in accordance with KBR's projections.

The project area south of Wald Road and the length of the low duct supports area will need to be over-excavated by 9' since the soil (expansive soils) is not suitable for structural backfill, as per the Geotechnical Report. This excavated soil will need to be disposed of at an approved landfill off-site. Imported non-expansive soil fill will need to be brought into the site and compacted to replace the over-excavated expansive soil. The costs for the imported fill, soil transportation, and soil disposal cost were estimated by KBR based on previous projects in the area.

The estimated total capital expenditure (CAPEX) for the NAS CO_2 capture plant integrated with Cemex's Balcones cement plant is $849 million. Summary of the major cost breakdown is presented in Table 1.

Table 1: Summary of the Cost Breakdown

Cost Item	**Cost ($MM)**
Direct Field Cost	$ 557.3
Indirect Field Cost	$ 54.3
Engineering	$ 50.6
Misc. Project Expenses (Freight /Heavy Lift / Haul)	$ 18.0
Contingency	$ 104.0
Owner's Cost	$ 23.6
Escalation	$ 41.5
Total Project Costs	$ 849.4

The breakdown of total direct costs by major subsystems is presented in Table 2 .

Table 2: Total direct costs by Subsystem

Description	**Equipment Cost**	**Material Cost**	**Labor**	**TDC**
CO_2 Carbon Capture	$ 175,047	$ 60,884	$ 71,674	$ 307,606
CO_2 Compression & Dehydration	$ 22,845	$ 1,939	$ 2,812	$ 27,596
Balance of Plant	$ 32,393	$ 115,388	$ 74,629	$ 222,409
TOTAL	**$ 230,285**	**$ 178,211**	**$ 149,115**	**$ 557,611**

Air cooling system makes up the largest share, accounting for 27.3% of the total cost. The absorber column, which is traditionally the largest cost item, now accounts for 9.3% of the total cost. CO_2 conditioning and compression accounts for ~5% of the total cost.

The Total Direct Costs (TDC) for the Carbon Capture Plant capture the core field construction expenditures across all major engineering disciplines. These costs include both labor and material components for equipment installation, piping systems, civil works, structural steel, electrical and instrumentation, insulation, and painting activities. Labor costs were developed based on detailed man-hour estimates and a composite wage rate reflective of local labor conditions. Material costs were derived from material take-offs, vendor quotes, and engineering quantities.

Breakup of the TDC by disciplines is provided in Figure 5.

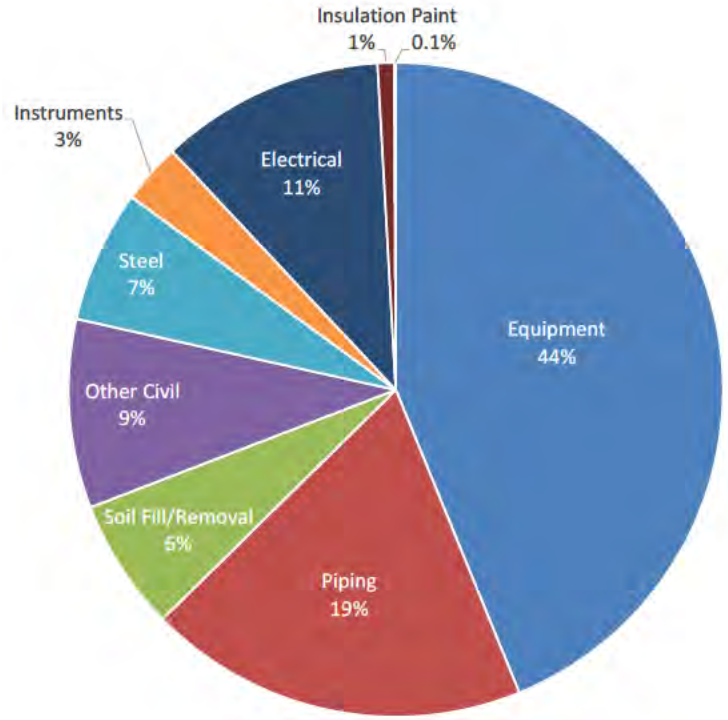


Figure 5: Breakup of the TDC by disciplines

As part of the FEED phase, the project team conducted a targeted value engineering review to identify cost-saving opportunities without compromising technical integrity or operational performance. The review focused solely on capital cost reduction. Two key opportunities were evaluated:

1. Combined heat and power (CHP) integration – replacing the existing low-pressure steam boiler with a larger medium-pressure unit to generate electricity via a steam turbine while supplying low-pressure steam for solvent regeneration.

2. Increased flue gas CO_2 concentration – reducing air in-leakage into the kiln system to prevent dilution of the flue gas. This improvement would lower flue gas flow rates, potentially reducing capture plant size and improving efficiency.

Both opportunities show strong potential for cost and efficiency improvements and are recommended for further evaluation and optimization during the detailed design phase to confirm their technical and economic viability.

1.3.2 Operating Cost Estimates

Operating cost estimates were developed from FEED data, incorporating detailed projections for consumables, waste treatment, and utilities such as natural gas and electricity for CO_2 capture and compression. Energy costs were escalated using Cemex's internal forecasts, while labor costs were based on required operations and maintenance staffing levels and local wage rates, capturing both fixed and variable components.

Fixed operating costs include annual operations and maintenance (O&M) labor, administrative and support staffing, as well as costs associated with maintenance materials, property taxes, and insurance. The total annual fixed operating costs were estimated at $11.4 million.

Total annual variable operating costs include all consumables necessary for the operation of the facility, such as NAS solvent, makeup amine, water and wastewater treatment chemicals, caustic soda, sulfuric acid, activated carbon, de-oxo catalyst, and triethylene glycol (TEG). For other consumables—including sulfuric acid, caustic soda, and TEG—unit prices were sourced from the U.S. Department of Energy's baseline study on retrofit CO_2 capture processes at cement plants [1]. The variable operating costs also include the disposal of waste materials, including spent TEG, used adsorbents, and spent catalysts.

The total annual variable operating costs were estimated at $35.8 million. In addition, fuel and purchased power costs were estimated at $61.6 million annually. Total annualized operating costs were estimated to be $109 million.

With implementation of the process for amine recovery from the acid wash, the total annual variable operating costs are estimated to be reduced by 36% to $26.9 million.

1.3.3 Economic Analysis

A comprehensive pro forma financial analysis of the CO_2 capture project was conducted by Cemex to evaluate the project's economic viability and long-term financial performance. CAPEX estimates were derived from the AACE Class 3 cost assessment conducted during the FEED study performed by KBR.

Operating cost projections were developed using data from the FEED phase, including detailed estimates for consumables, waste treatment, and utility consumption. This includes natural gas requirements for steam generation and electricity usage for the operation of the CO_2 capture and compression systems. To reflect future operating conditions, natural gas and electricity costs were escalated based on internal Cemex forecasted rates. Labor costs were estimated by identifying the required operational and maintenance staffing levels and applying prevailing wage rates for each role. This methodology allowed for the development of both fixed and variable labor cost projections that reflect local labor market conditions and the technical complexity of operating the facility.

Plant availability was assumed to be 90%. The CO_2 capture plant was designed with a capture capacity of 2.4 million metric tonnes per year, based on the nominal production capacity of the cement kilns and expected variations in process flow rates. The average operating capacity of the plant is assumed to be 86%, which, when accounting for the 90% availability, results in an overall capacity factor of 74%.

Overall cost of capture, excluding transport was estimated to be \$101.6/t-CO_2. This does not include the cost for transportation and sequestration. Inclusion of the amine recovery from acid wash waste stream technology reduces the cost of capture to \$93.0/t-CO_2.

CO_2 transportation costs were estimated using a recent internal quote from a comparable pipeline infrastructure project. This baseline was adjusted to reflect the specific conditions of the Balcones CO_2 capture project, including the proximity of the proposed sequestration site. For the purposes of this analysis, a conservative assumption of 20 miles of pipeline was used to estimate associated transportation costs.

CO_2 storage costs were derived from SLB's internal estimates based on analogous storage projects. These estimates include the cost of CO_2 injection and the installation and operation of measurement, monitoring, and verification (MMV) systems in accordance with regulatory and environmental compliance requirements. However, the storage cost estimate excludes financing costs, long-term liability provisions, and pore space fees, which are expected to vary based on final site selection and future regulatory frameworks.

Together, the transportation and storage cost estimates inform the broader calculation of the levelized cost of CO_2 capture and storage (CCS), supporting a comprehensive financial evaluation of the carbon management value chain for the Balcones project.

The analysis incorporates the benefit of federal 45Q tax credits, which offer a per-metric-ton incentive for captured and permanently sequestered CO_2. Under the most recent guidance provided by the Inflation Reduction Act, the value of the 45Q credit has been increased to \$85 per metric ton for CO_2 stored through secure geological sequestration, which is the basis used in this analysis.

To complete the analysis, Cemex incorporated company-specific financial assumptions related to financing structure, cost of capital, and tax considerations to model project cash flows over its operational lifespan. These inputs were used to determine the levelized cost of capture, as well as key financial metrics, including the internal rate of return (IRR), net present value (NPV), and payback period.

Results from the business case analysis (BCA) indicates a negative value for the project net present value (NPV); therefore, further incentives to make the project feasible will be needed in the future. Additional incentives could be achieved through a combination of (1) further DOE/similar grants to fund carbon capture plant construction and reduce exposure to high CAPEX, and (2) higher tax incentives to mitigate project OPEX and/or other endeavors outside of taxes. The BCA indicates that for the project to break even, given the current 12-year 45Q period, the credit value would need to be approximately \$175/MT sequestered compared to the current \$85/MT. Levelized revenues of 45Q credits do not reflect their full value due to intermediation costs and the fact that the project is evaluated over 25 years while the tax credit is only valid for 12 years. If the 45Q period were extended to 24 years, the required credit value would be around \$120/MT for the project to break even.

The cost of cement production is projected to increase with the addition of the capture plant. At present, there is no green premium for decarbonized cement in the United States.

1.4 Lifecycle Analysis

A life cycle assessment (LCA) was conducted for the RTI-NAS carbon capture and sequestration (CCS) system retrofitted to the Cemex Balcones Cement Plant, based on results from the FEED study targeting 95% capture of direct CO_2 emissions. The cradle-to-gate system boundary included cement plant operations, CCS infrastructure, and capture and sequestration processes. Environmental impacts were normalized per metric tonne of cement produced for ASTM Type I/II and Type IL cement products.

This project was modeled using OpenLCA software, utilizing the EcoInvent 3.10 Cutoff System Processes and NETL databases for life cycle inventory (LCI) data. The study employed the TRACI 2.1 impact assessment method, incorporating the latest global warming potential (GWP) factors from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5).

Figures 6 and 7 present the 100-year GWP (AR5) results for both Type IL and Type I/II cement products. Each figure compares the baseline system (without CCS) and the proposed system (with CCS):

- Baseline direct CO_2 emissions are shown in orange and indirect CO_2 emissions in blue.
- The proposed system includes gray for additional CCS-related emissions and green for CO_2 captured.
- The final proposed product system (last column) shows direct emissions in orange and indirect emissions in light blue.

The proposed CCS configuration achieves:

- 66.1% reduction in total GHG emissions for Type IL cement, and
- 66.5% reduction for Type I/II cement.

Under current grid conditions, the proposed CCS system alone reduced cradle-to-gate greenhouse gas emissions by approximately 66%. Incorporating co-generation increased reductions to 74%, while renewable power use achieved 76%-77% reductions.

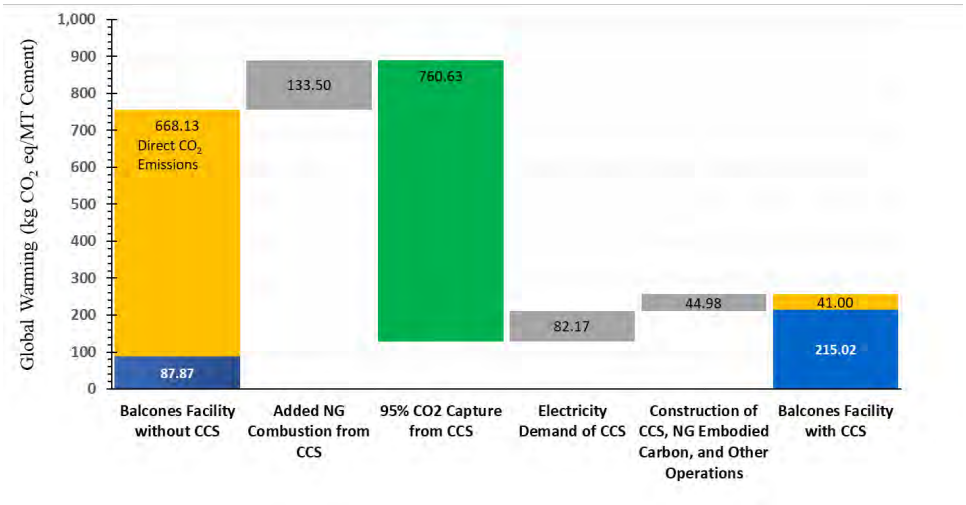


Figure 6:GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type IL cement

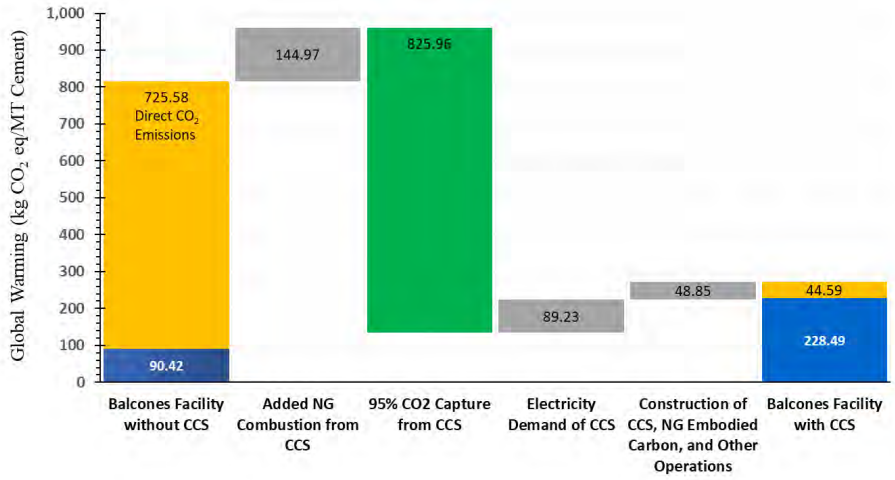


Figure 7: GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type I/II cement

The FEED CCS system is estimated to save ~500 kg CO_2e/MT of Type IL cement and ~543 kg CO_2e/MT of Type I/II cement compared to baseline operations. As the electrical grid and transportation systems continue to decarbonize, additional GHG reductions are anticipated. Decreasing embodied carbon in supporting processes will further enhance the overall environmental performance of the CCS-enabled cement production system.

1.5 Technoeconomic Analysis

A detailed technoeconomic analysis (TEA) was conducted for CO_2 capture at Cemex's Balcones plant using RTI-NAS technology, based on data from the AACE Class 3 level FEED study. The TEA follows the DOE methodology for estimation of levelized cost of capture for retrofit applications in cement plants.

Key results for the base cases and the Cemex Case are summarized in Table 3. Two scenarios are presented for each case: without amine recovery and with amine recovery, highlighting the impact of amine solvent recovery on capture costs. All DOE cases use DOE assumptions for financial and operational parameters; the Cemex Case uses Cemex-specific financial and utility parameters. Costs exclude transport and storage (T&S).

Table 3: Summary of TEA results

Case	**Assumptions**	**Cost of Capture ($/t-$CO_2$) w/o amine recovery**	**Cost of Capture ($/t-$CO_2$) w/ amine recovery**
Base Case	DOE	112.9	104.2
Water constraint relaxed	DOE	98.3	89.6
Co-generation	DOE	103.9	95.3
Base Cemex Case	Cemex	101.6	93.0

Sensitivity analysis identified the most influential parameters:

- Capacity factor and CAPEX had the highest impact, with a ±15% change significantly affecting the cost of capture.
- Utility prices (natural gas and electricity) had the lowest impact; a 30% increase raised the cost of capture by only 4%.
- Solvent price (NAS) also had a minor impact, with a 30% increase resulting in a 5% rise in capture cost.

These results highlight the economic viability of the RTI-NAS CCS retrofit, the potential benefits of co-generation, and the importance of plant utilization and capital investment on capture cost.

2 Project Overview

2.1 Introduction

RTI International, with Cemex Inc., SLB, and KBR Inc., participated in a joint effort to perform a Front-End Engineering Design (FEED) study for carbon dioxide (CO_2) capture from cement flue gas utilizing the Non-Aqueous Solvent (NAS) CO_2 capture process developed by RTI. The FEED study evaluated the integration of RTI's CO_2 capture system at an existing cement plant, the Cemex Balcones cement plant at New Braunfels, Texas.

The CO_2 capture plant is designed to remove at least 95% of CO_2 from the flue gas from the Balcones cement plant kilns K1 and K2, and the associated natural gas-fired boiler for steam generation. The plant is designed for a nominal capacity of 2.4 MPTA (million tonnes per annum) scale CO_2 capture system integrated with a cement facility. The captured CO_2 has a purity of > 95% CO_2, and is dried, polished to meet pipeline specifications, and compressed to 2215 psia (152.7 bara) to be made ready for sequestration.

The CO_2 capture plant consists of a direct contact cooler (DCC) with integrated SO_2 polishing, a flue gas blower, an absorption column with intercoolers, a regeneration column, associated pumps, storage and receiver vessels, and a CO_2 compression, dehydration, and polishing train. CO_2 product end use (sequestration, EOR, etc.) will be determined in future phases.

The primary objective of the FEED was to develop an Association for the Advancement of Cost Engineering (AACE) Class 3 cost estimate for a nominal 2.4 million tonnes per annum (MTPA) CO_2 capture system integrated with a cement production facility.

The purpose of this report is to summarize the project design basis, the key design decisions reviewed and implemented during the FEED study and the resulting engineering design package and cost-estimation.

2.2 Project Team and Organizational Structure

RTI International served as the prime contractor to DOE-NETL, responsible for overall project leadership and CO_2 capture technology integration. Other partners on the project included Cemex, KBR and SLB. Cemex acted as the host site partner, providing critical input on plant operations and site-specific integration requirements. KBR led the front-end engineering design (FEED), while SLB served as the Owner's Engineer, offering independent technical oversight and feedback throughout the study. SLB is also the technology licensor for RTI's NAS technology for CO_2 capture. Cost-share for the project was provided by RTI International, Cemex and SLB.

Figure 8 presents the organizational structure for the overall project, while Figure 9 outlines the structure specific to the FEED study, including the discipline leads.

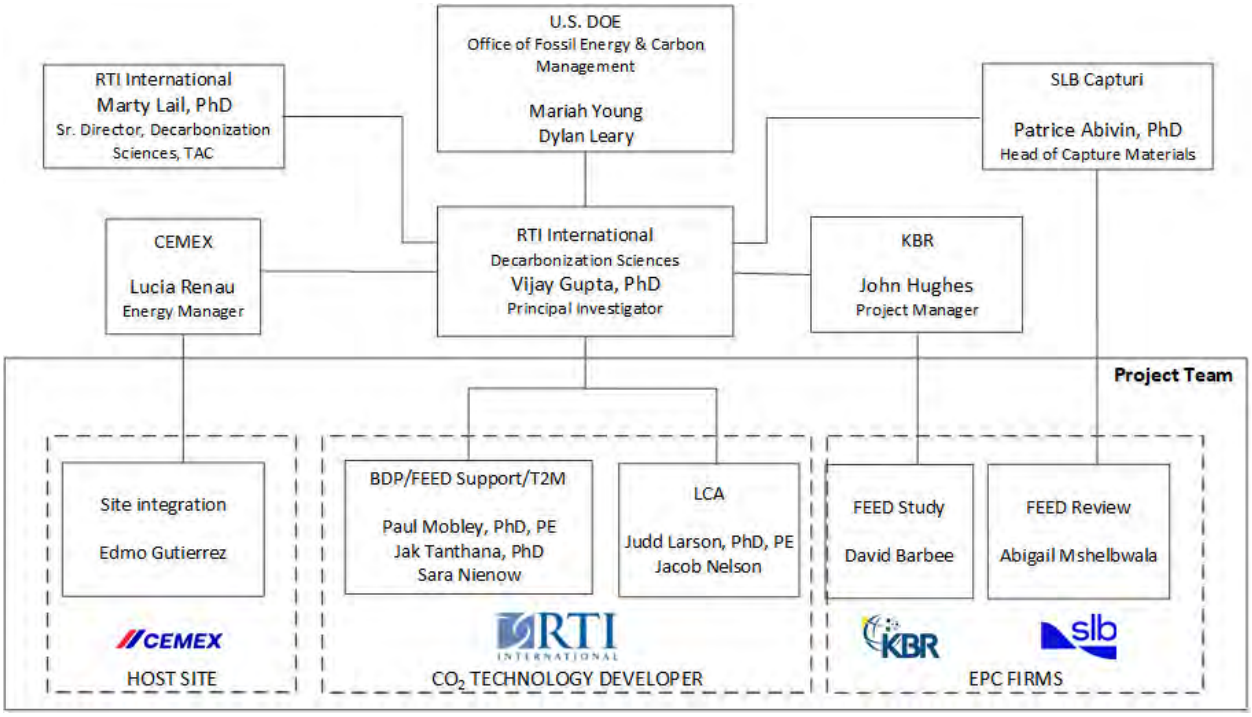


Figure 8: Organizational Structure for the Project

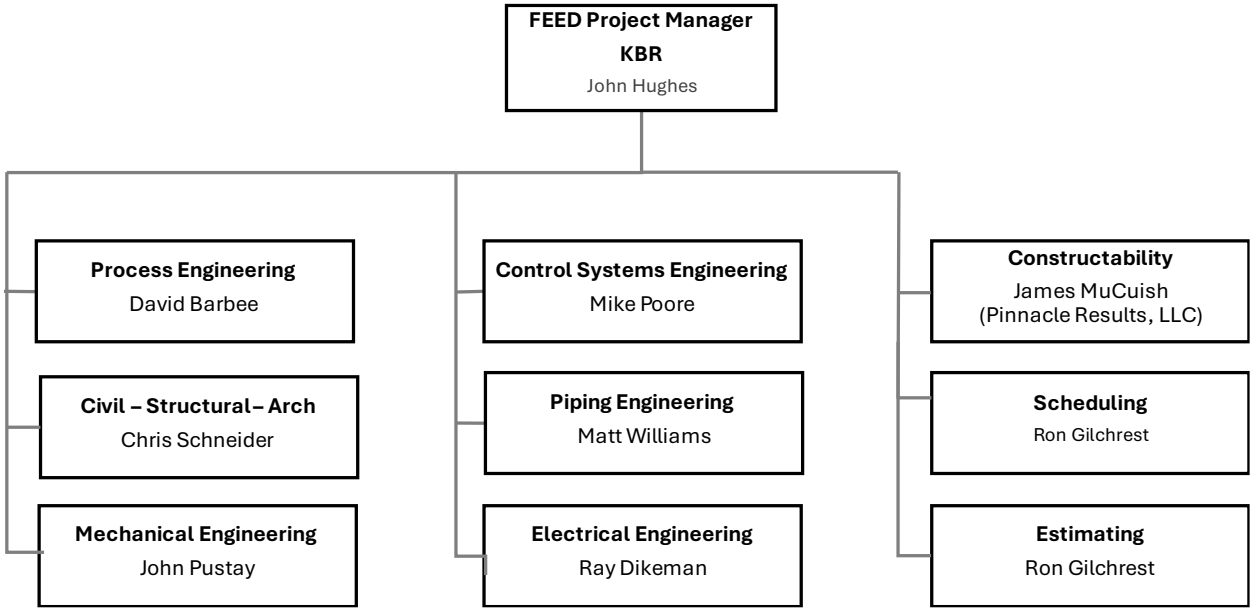


Figure 9: Organizational Structure for the FEED Study

The project was executed under a single budget period and comprised five main tasks:

- Task 1 – Project Management and Planning
- Task 2 – Project Design Basis Definition

- Task 3 – Basic Design Package (BDP)
- Task 4 – Front-End Engineering Design (FEED) Study
- Task 5 – Technology-to-Market (T2M) Strategy

Task 1: Project Management and Planning
Task 1 encompassed all project management and coordination activities. RTI International served as the prime contractor and was responsible for ensuring that the project met its technical, schedule, and budgetary objectives. Biweekly meetings were held with all project partners (Cemex, KBR and SLB) to monitor progress, align on priorities, and make decisions regarding project direction. Additionally, RTI maintained regular communication with the DOE Project Manager to provide formal status updates and report on project milestones.

Task 2: Project Design Basis Definition
In Task 2, RTI worked with Cemex to establish a unified design basis for the FEED study. This task also involved identifying any permitting requirements, environmental reviews, and internal or corporate approvals necessary to initiate construction of the CO_2 capture facility.

Task 3: Basic Design Package (BDP)
The objective of Task 3 was to develop a Basic Design Package (BDP) for the proposed CO_2 capture plant, which would serve as the foundation for the FEED effort in Task 4. RTI worked closely with KBR to complete the BDP. Key deliverables included process flow diagrams (PFDs), heat and material balances (H&MBs), preliminary equipment sizing based on the balance of plant, a process simulation model, and supporting technical data. These were informed by prior solvent development work and CO_2 capture technology evaluations.

Task 4: Front-End Engineering Design (FEED) Study
The EPC contractor led the execution of the FEED study, which included the development of detailed discipline-specific engineering documents and an AACE Class 3 capital cost estimate (CAPEX). An independent third party, Saltegra LLC, was selected to conduct a Hazard and Operability (HAZOP) analysis. A constructability review was performed by Pinnacle Results LLC, with active participation from all project partners.

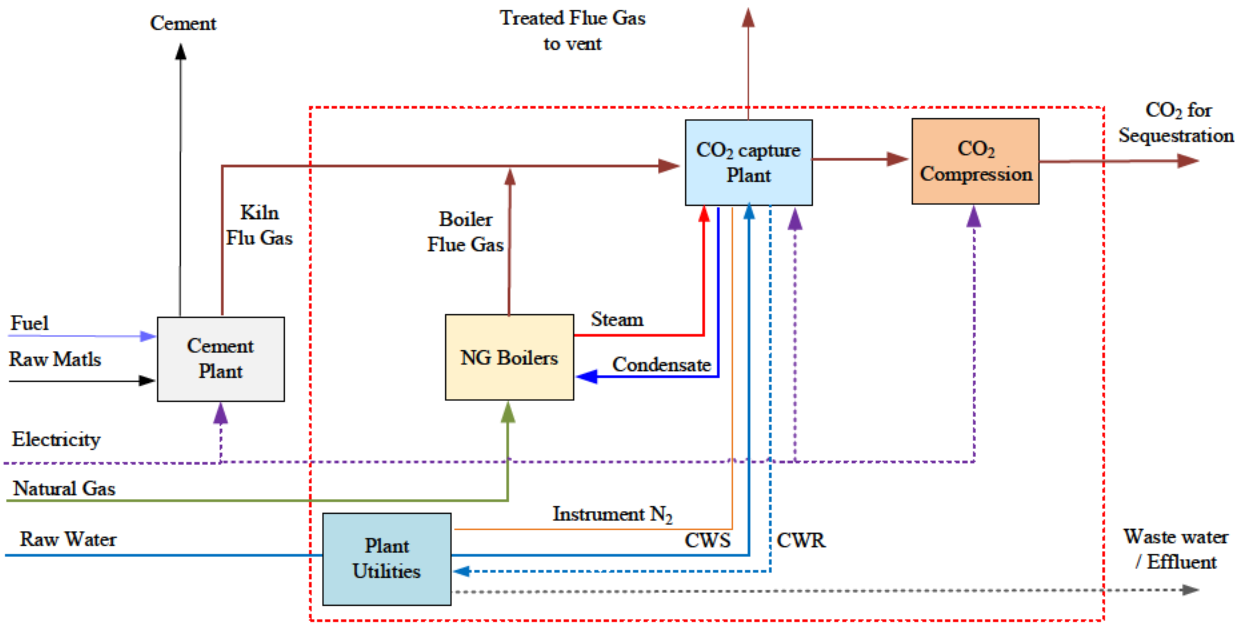
Task 5: Technology-to-Market Strategy
In Task 5, RTI used the FEED deliverables and cost estimates to develop operational expenditure (OPEX) projections and conduct a techno-economic analysis (TEA) of the proposed CO_2 capture system. RTI collaborated with Cemex to perform a life cycle analysis (LCA), accounting for CO_2 emissions produced, captured, and avoided—including emissions from steam production required to operate the capture facility. The project team also conducted an environmental, health, and safety (EH&S) risk assessment for the capture system. Finally, Cemex developed a business case analysis (BCA) to evaluate the commercial viability of the proposed process.

2.3 Host site and Design Considerations

The Balcones plant is in New Braunfels, Comal County, TX. Total cement production at Balcones is 2.5 million tons per year. The plant has 2 kilns. Kiln #1 has 4 preheater stages with a design capacity of 3,125 tons clinker/day and kiln #2 has 5 preheater stages with an inline calciner with a design capacity of 3,600

tons clinker/day. Fuels used are petroleum coke, natural gas, biomass, oil containing materials, plastics, and tire-derived fuel. The flue gas from the preheater section is used for drying the raw materials in the far grinding mill before sending it to the baghouse filter for dust removal and then to the stack. The CO_2 capture system takes flue gas from the process location after the baghouse. Total CO_2 emissions at nominal capacity is 2.2 MTPA. The CO_2 capture plant captures 95% of the CO_2 in the combined flue gas from the cement kilns and the natural gas-fired boiler used to generate steam for solvent regeneration. The schematic of the integrated cement and CO_2 capture plant is shown in Figure 10.

Figure 10: Schematic of the integrated cement and CO_2 capture plant



The temperatures in the burning zone of a cement kiln are high (> 1,200 °C), and the long residence time of the exhaust gases in the process favors formation of nitric oxide (NO) over nitrogen dioxide (NO_2). The plant uses a selective non-catalytic reduction to reduce NOx down to < 230 ppmw. Less than 1% of NOx exists as NO_2, as determined using stack testing at the Balcones plant by Mostardi Platt. The plant uses a dry sorbent injection to control SO_2 emissions in the exhaust gas to approximately 0-5 ppm and uses fabric filter baghouse for control of particulate matter. The SO_2 is further reduced to < 1 ppm by scrubbing the flue gas with caustic solution in the direct contact cooler upstream of the absorber column. The NOx content is not affected by the caustic solution and passes through the DCC column.

The Balcones Plant is in a hot humid subtropical region and has limited water availability. Cemex can provide, on average, 191 GPM of water for the capture plant. This presents some challenges as the CO_2 capture process requires cooling of the solvent in the absorber intercooler, as well as absorber wash columns and direct contact cooler to cool and condition the flue gas. In addition, the CO_2 compression process also requires intercooling between the compression stages. The lack of cooling water availability was addressed by using hybrid cooling with air cooling for most part and water-cooling for trim cooler in the DCC and

the water wash for the treated gas leaving the absorber. However, using alternative cooling due to the lack of cooling water impacts the overall capture cost" as shown in the cost analysis sections of this report.

2.4 Process Overview

2.4.1 Overview of Process Design

A schematic of the process flow diagram is provided in Figure 11. RTI's CO_2 capture process uses RTI-NAS, a formulation of hydrophobic amine in an organic diluent with low (<10 wt.%) water content to capture >95% of CO_2 from a cement plant and the associated natural gas-fired boiler for providing steam for solvent regeneration. The solvent is continuously recirculated between an absorber and a regenerator column. Flue gas from a cement plant and the natural gas-fired boiler used to generate steam for solvent regeneration for the capture plant, after scrubbing SO_2 and cooling the flue gas, enters the absorber column where 95% of the CO_2 is captured. CO_2 absorption occurs at low temperatures in the absorber column. The amine in the RTI-NAS solvent reacts with CO_2. The CO_2-rich solvent is regenerated in the regenerator using LP steam from the natural gas boiler. During the solvent regeneration process, the solvent is heated, and the reverse reactions predominate to release CO_2. The CO_2 released in this process at 65.3 psia (4.5 bar), is dried, compressed to 2215 psia (152.7 bar) and sent for sequestration.

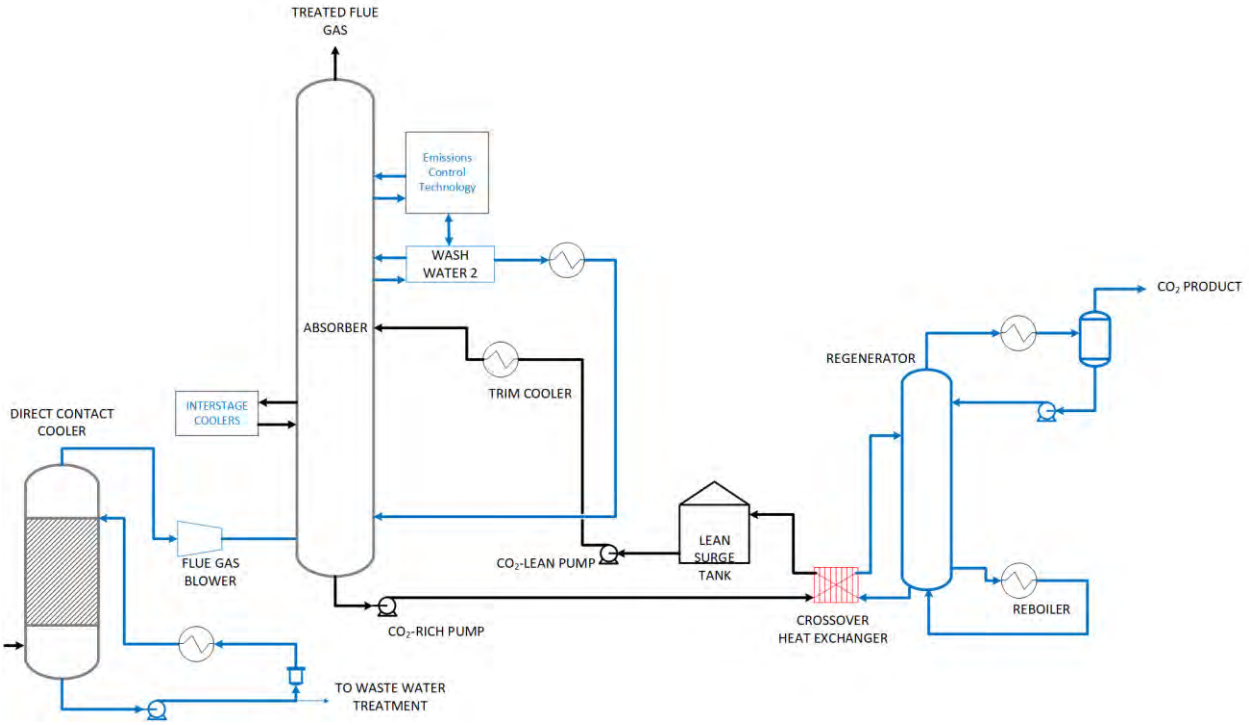
The process is water-balanced by operating the water wash temperatures close to the dew point temperature of the gas leaving the DCC, such that the total water entering the CO_2 capture process is balanced by the total water leaving with the treated gas and the CO_2-product gas. There is no makeup water required for the NAS process.

RTI'S NAS technology has the potential to reduce the thermal regeneration energy demand to ~2.1-2.3 GJ/t-CO_2 captured. Key attributes of the RTI-NAS solvent are:

- Low energy required for solvent regeneration resulting in low steam consumption
- High working capacity resulting in low liquid/gas ratio
- High solvent thermal and oxidative stability resulting in longer service life
- Low corrosivity

A single train is needed to treat the flue gas from the cement plant. The process equipment comprises an integrated direct contact cooler (DCC) and a SO_2 polisher, a flue gas blower, the absorption column with the intercoolers, an advanced emissions control technology and acid wash to control amine emissions, the regeneration column, associated pumps, storage and receiver vessels, and a CO_2 drying and compression train.

Figure 11: Schematic of the RTI CO_2 Capture Plant



The CO_2 capture facility is organized into three main process units, encompassing both Inside Battery Limits (ISBL) and Outside Battery Limits (OSBL) areas.

- ISBL includes the core process systems responsible for CO_2 separation, solvent regeneration, and product gas compression.
- OSBL includes supporting utilities, chemical storage, wastewater treatment, and systems required for safe and continuous operation of the ISBL.

A high-level representation of the process architecture is shown in the Block Flow Diagram (BFD) in Figure 12, with further detail provided in:

- **Appendix B.1** – Process Area Descriptions
- **Appendix B.2** – Block Flow Diagram
- **Appendices B.3 to B.6** – Process & Utility Flow Diagrams and Heat & Material Balances

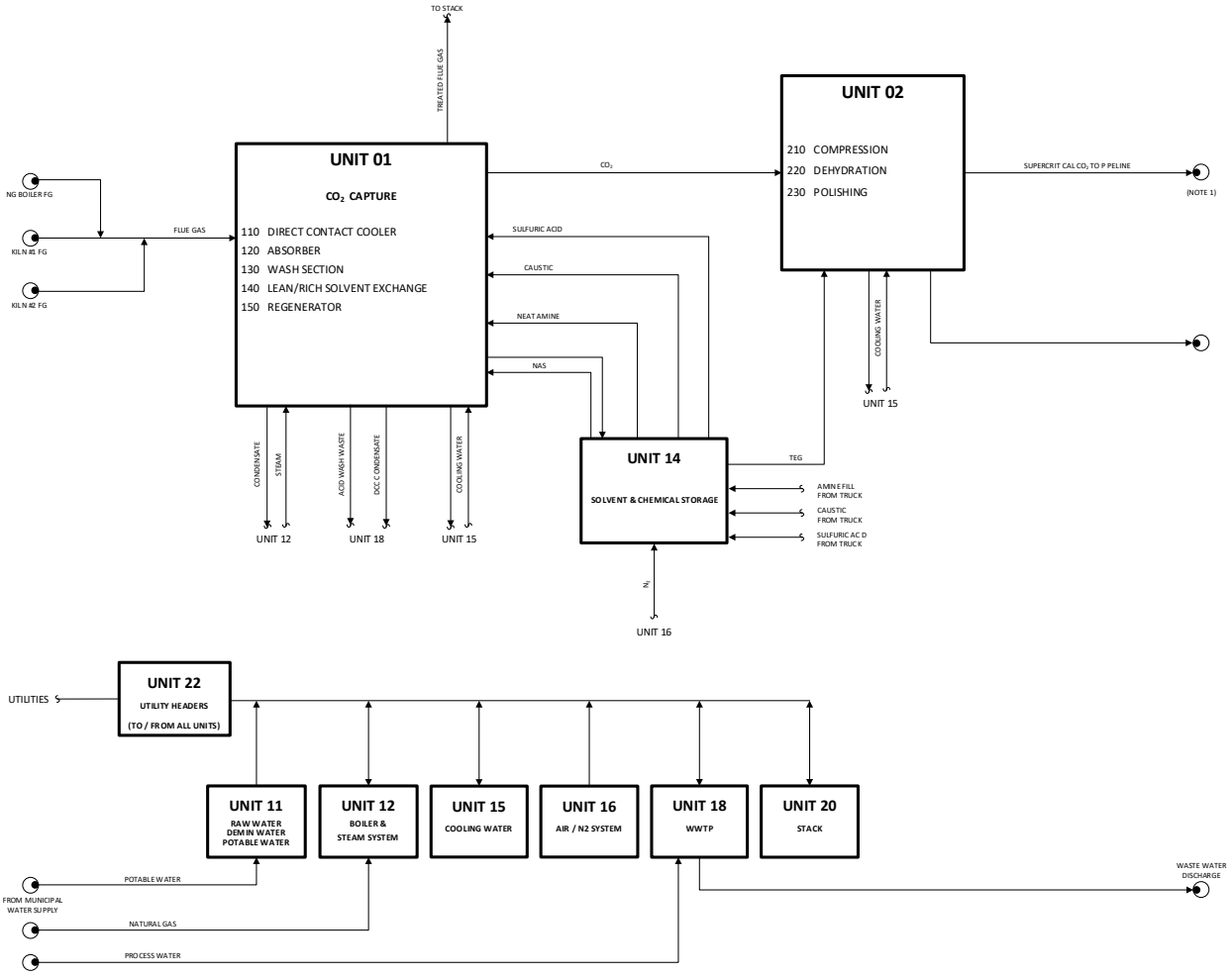


Figure 12: Block Flow Diagram for the Capture Plant

The three major process units are:

- Unit 01 – CO_2 Capture (ISBL): Flue gas conditioning, solvent absorption, and regeneration
- Unit 02 – CO_2 Compression and Polishing (ISBL): Multi-stage compression, dehydration, and final conditioning
- Unit 03 – Utility and Offsite Systems (OSBL): Steam generation, water treatment, chemical storage, cooling systems, air/nitrogen, and effluent handling

To clearly delineate project scope and interfaces with the host site, the battery limits and system boundaries are defined in the following section.

2.4.2 Battery Limits and System Boundaries Process:

This section defines the physical and operational boundaries between the CO_2 capture facility and the host site, identifying all points of interface for utilities, raw materials, products, and effluents. These boundaries help establish:

- Ownership and responsibility

- Integration requirements
- Utility provisioning assumptions

The battery limits are divided into ISBL and OSBL areas, with detailed stream parameters summarized in **Appendix B.7** – Battery Limit Summary.

Inside Battery Limits (ISBL)

The ISBL encompasses all equipment, piping, and controls required for:

- Flue gas conditioning and CO_2 absorption (Unit 01)
- Solvent regeneration and heat recovery in the lean-rich heat exchanger
- CO_2 compression, dehydration, and final polishing (Unit 02)

ISBL battery limits terminate at the following tie-in points:

- Flue gas inlet from the host plant
- CO_2 product outlet, ready for pipeline delivery or storage
- Utility tie-ins: steam, electricity, water, instrument air, and nitrogen

Outside Battery Limits (OSBL)

The OSBL includes all systems that support ISBL operations, including:

- Unit 11 – Water Systems: Raw, potable, and demineralized water, with limited makeup water from the host and internal recycling
- Unit 12 – Boiler and Steam System: Powered by natural gas
- Unit 14 – Solvent and Chemical Storage
- Unit 15 – Cooling Water System: Hybrid cooling towers designed for reduced water use
- Unit 16 – Instrument Air and Nitrogen Supply
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack and Emissions Relief System
- Unit 22 – Utility Header and Distribution

Key OSBL interfaces include:

- Water supply point from host (limited)
- Electricity supply from grid (not from host)
- Natural gas supply for steam generation
- Effluent discharge point to wastewater treatment
- Material receiving points for bulk chemicals and solvents

Host Site Interfaces

To minimize integration risk and ensure project independence, the following operational interfaces are clearly defined:

- Flue gas feed: Delivered at the ISBL battery limit
- CO_2 product: Sent to pipeline or storage at defined export point
- Steam is self-generated on-site. Electricity is supplied from the grid, and the host plant provides a limited amount of water.
- Operations: The CO_2 capture facility is operated by dedicated personnel, separate from host plant staff

2.4.3 Major Process Blocks (ISBL):

Each unit described in this section is summarized for clarity and overview purposes. Process descriptions for each main block are provided in the **Appendix B.1**.

2.4.3.1 Direct Contact Cooler

The combined flue gas from Kiln 1, Kiln 2, and the natural gas-fired boiler, at 272 F and 14.36 psia, is routed to the Feed Direct Contact Cooler (V-0111), where it is cooled and conditioned prior to CO_2 absorption. In this unit, the gas stream is contacted with a caustic solution, which facilitates the removal of sulfur dioxide (SO_2). The water in the recirculation loop passes through the DCC Circulation Filter (F-0111), the Feed Scrubber Wash Air Cooler (E-0112), and the Feed Scrubber Wash Cooler (E-0111) before returning to the top of the DCC. During the cooling process, excess water vapor condenses from the flue gas. This condensate is collected and sent to the Wastewater Treatment Plant (WWTP), where it is treated and reused elsewhere in the process. The combination of gas cooling and moisture removal significantly reduces the specific volume of the flue gas, thereby lowering the power demand of the downstream Flue Gas Blowers (K-0111 A/B). The cooled and conditioned flue gas exits the top of the DCC and is conveyed by the blowers to the Absorber Column (C-0121) for CO_2 capture.

2.4.3.2 Absorber Column

The Absorber Column (C-0121) is a vertically packed, integrated unit designed for CO_2 removal from flue gas. It consists of three main sections: the CO_2 absorption section, followed by a water wash section and an acid wash section for downstream treatment. Cooled flue gas from the Flue Gas Blowers (K-0111 A/B) enters the bottom of the absorber and flows upward in a counter-current direction to the lean amine solvent, which is introduced at the top of the CO_2 absorption section. As the gas rises through the packed Absorption beds, CO_2 is absorbed into the solvent. Interstage cooling is applied between the beds to remove the heat of absorption and maintain optimal solvent loading efficiency. The partially loaded solvent is collected in the Absorber Interstage Surge Tanks (T-0121, T-0122), from which it is circulated by the Absorber Interstage Circulation Pumps (P-0121 A/B/C and P-0122 A/B/C) through the Absorber Interstage Air Coolers (E-0121, E-0122). These air coolers reduce the solvent temperature before it is reintroduced into the column above the next packed stage. At the bottom of the column, the CO_2-rich solvent is collected and discharged by the Rich Solvent Pumps (P-0124 A/B/C). The treated flue gas, now with significantly reduced CO_2 content, continues upward into the water wash and acid wash sections for final cleanup before exiting the absorber.

2.4.3.3 Absorber Wash Sections and Acid Wash

The upper section of the Absorber Column (C-0121) is designed to minimize amine emissions through a multi-stage gas cleaning sequence. This section consists of: two water wash sections, an activated carbon bed located between the two wash sections and a final acid wash section for polishing.

First Water Wash Section - The first water wash section is located directly above the CO_2 absorption zone. It captures the bulk of entrained amines from the treated flue gas through contact with a circulating water stream. The amine-rich condensate from this section is returned to the absorber sump for recovery and reuse.

Activated Carbon Bed - The water from the second wash section is routed through this carbon bed in a recirculation loop, effectively removing dissolved amines from the system. The carbon bed is regenerated with steam, which desorbs the captured amines. The resulting steam condensate and recovered amines are cooled via the Activated Carbon Bed Cooler (E-0133) and returned to the absorber sump for reuse.

Second Water Wash Section - The second water wash section, supplied with water purified by the activated carbon bed, achieves deeper scrubbing of the treated gas. The improved water quality enhances amine removal efficiency and reduces solvent losses.

Acid Wash Section - The final stage in the gas treatment sequence is the acid wash section, where the flue gas contacts sulfuric acid-dosed wash water. This step chemically neutralizes any remaining amine vapors via acid-base reaction. The pH of the acid wash is maintained to ensure effective amine removal.

After this final polishing step, the fully treated flue gas is routed to the stack (Unit 20) for atmospheric discharge, compliant with environmental emissions limits.

2.4.3.4 Lean/Rich Solvent Exchanger

CO_2-lean solvent from the Regenerator Column (C-0151) is routed through the Lean/Rich Solvent Heat Exchanger (E-0141), where it transfers heat to the incoming CO_2-rich solvent from the Absorber, delivered by the Rich Solvent Pumps (P-0124 A/B/C). This integration reduces reboiler duty and improves energy efficiency. After heat exchange, the lean solvent flows to the Lean Solvent Surge Tank (T-0141), and from there, it is cooled in the Lean Solvent Air Cooler (E-0142) before being sent to the top of the Absorber Column (C-0121). During normal operation, approximately 10% of the lean solvent flow is diverted through the Particulate Filter (F-0141) and Carbon Filter (F-0142) to remove solids and degradation products, maintaining solvent quality. The filtered stream is then recombined with the main flow upstream of the absorber.

2.4.3.5 Regenerator

A slipstream of CO_2-rich solvent from the Absorber Column enters the upper packing stage of the Regeneration Column (C-0151), along with reflux from the column top. The remaining CO_2-rich solvent flows through the Lean/Rich Heat Exchanger (E-0141) and enters the lower packing stage of the Regeneration Column. The regenerated CO_2-lean solvent from the column bottom is partially sent to the Lean Solvent Surge Tank (T-0141) via the Lean/Rich Heat Exchanger, while the remainder is sent to the Regenerator Reboilers (E-0152 A/B/C/D), which use LP steam for solvent regeneration. Vapors from the reboilers return to the column, and CO_2 gas from the column top is cooled in the Regenerator Overhead Condenser (E-0151) before entering the Condensate Drum (V-0151). Captured CO_2 is sent to the Unit 02 CO_2 Compressor Package, while reflux is recycled to the column. In the event of downstream upsets, vented gas is routed to the stack.

2.4.3.6 CO_2 Compression, Dehydration and Polishing

The CO_2 Compressor Package (K-0211) compresses CO_2 from the Unit 01 Regenerator Column and integrates polishing and TEG dehydration to meet pipeline specifications. The system consists of a five-stage integrally geared compressor with heat exchangers and suction/knock-out drums. Heat from the intercoolers is recovered using boiler feedwater (BFW), generating LP steam for the utility header.

Intermediate process steps include O_2 Polishing and TEG Dehydration between stages 3 and 4 of compression.

The O_2 Polishing Reactor (V-0221) reduces O_2 content in the CO_2 stream to <10 ppmv using a catalyst that reacts with hydrogen. Hydrogen is supplied via electrolysis in the vendor-provided Electrolyzer Package (A-0232), which uses demineralized water sourced from OSBL.

The TEG Dehydration Package (A-0221) removes moisture from the CO_2 stream, with TEG. The polished and dehydrated CO_2 is returned to stage 4 of the compressor for final cooling and compression before being delivered to the pipeline.

2.4.4 Major Process Blocks (OSBL):

This section provides a summary of the OSBL units that supply utilities to the CO_2 capture plant. Process descriptions for each main block are provided in the **Appendix B.1**.

2.4.4.1 Unit 11 - Water Treatment Unit

The Water Treatment Unit supports plant operations by supplying raw, demineralized, and potable water through three main systems:

- Raw Water System: Receives treated wastewater and raw well water, stored in the Service Water Tank (T-1101). It supplies water to the service water header, cooling water system, and the Demineralized Water Package. The system includes fire protection pumps (P-1102 A/B) compliant with NFPA 20, with one diesel-driven and one motor-driven pump, and a jockey pump (P-1103 A/B) for maintaining pressure during normal operation.
- Demineralized Water System**:** Treats service water in the Demineralized Water Package (A-1101) to remove salts, reducing corrosion risk. The treated water is stored in the Demineralized Water Tank (T-1102) and distributed to the Deaerator, Electrolyzer Package. The system includes nitrogen blanketing and internal recycling for backwash and neutralization.
- Potable Water System**:** Supplies potable water from an offsite municipal source, stored in the Potable Water Tank (T-1103) and pumped to users via the potable water header.

2.4.4.2 Unit 12 - Boiler and Steam System

Boiler and Steam System provides low-pressure (LP) steam to various plant users and includes a Deaerator system, boiler feedwater (BFW) treatment, and steam generation.

- Boiler Feedwater System**:** Demineralized water from Unit 11 is chemically treated for oxygen scavenging and introduced into the Deaerator (V-1201), where LP steam and steam condensate strip dissolved gases. The deaerated BFW is pumped by BFW Pumps (P-1201 A/B) to the Natural Gas Boiler Package (A-1203) and other BFW users. Additional chemical injection is used for pH and scaling control.
- Boiler System**:** The boiler produces LP steam using natural gas and BFW. The generated steam is routed to the LP steam header. Boiler blowdown is sent to the Blowdown Drum (V-1202), where flashed steam is recovered to the LP steam header, and liquid blowdown is sent to the wastewater treatment unit (Unit 18). Flue gases are directed to the Unit 01 Direct Contact Cooler.

- Condensate Recovery**:** Steam condensate from the LP system is collected in the Condensate Flash Drum (V-1203). Flashed gases are vented, and the recovered condensate is returned to the Deaerator via the Condensate Pumps (P-1203 A/B), improving water efficiency.

2.4.4.3 Unit 14 – Solvent and Chemical Storage Utilities

Solvent and Chemical Storage Utilities provides storage, transfer, and handling of solvents and key chemicals required for plant operation. It includes three main subsystems:

- Solvent Storage System: Amine solvent and formulated solvent are delivered by truck and stored in the Solvent Storage Tank (T-1401) and Solvent Sump (V-1401), respectively. Both vessels are nitrogen-blanketed using backpressure regulators. Solvent is filtered and transferred via Solvent Transfer Pumps (P-1401 A/B and P-1402) to the Lean Solvent Surge Tank in Unit 01. Internal solvent drains also feed into the Solvent Sump for reuse.
- Caustic Storage System:
  Caustic solution, delivered by truck, is stored in the Caustic Storage Tank (T-1402) and transferred via Caustic Transfer Pumps (P-1403 A/B) to the Unit 01 Direct Contact Cooler for SO_2 neutralization. The tank includes provisions for safe venting.
- Sulfuric Acid Storage System:
  Sulfuric acid is trucked in and stored in the Sulfuric Acid Storage Tank (T-1403), then pumped by Sulfuric Acid Transfer Pumps (P-1404 A/B) to the acid wash section of the Unit 01 Absorber Column.

2.4.4.4 Unit 15 – Cooling Water System

Cooling Water System consists of a vendor-supplied Cooling Water Package (A-1501), featuring a cooling tower that uses makeup water from the Unit 11 Service Water Tank. The cooled water is distributed via the utility cooling water header to various users across the facility. Blowdown from the cooling system is routed to Unit 18 for wastewater treatment.

2.4.4.5 Unit 16 – Air and Nitrogen Systems

Air and Nitrogen Systems provides compressed air and nitrogen gas for plant operation and safety functions. It includes two subsystems:

- Air Compressor System:

Compressed air is generated by two vendor-supplied packages: the Primary Air Compressor (K-1601) and Secondary Air Compressor (K-1602), managed by a split header pressure control system. The Secondary Compressor automatically starts if header pressure drops below a setpoint. Air is stored in the Air Receiver (V-1601), which also serves as an emergency backup for instrument air. The compressed air is then dried via the Instrument Air Dryer Package (A-1602) before distribution to the plant and instrument air headers.

- Nitrogen Gas System:

Nitrogen is produced by the Nitrogen Generation Skid (A-1601) and supplied to high-pressure users at 145 psia. A pressure control valve reduces pressure to 45 psia for low-pressure nitrogen users. Nitrogen is used for inerting and blanketing applications throughout the facility.

2.4.4.6 Unit 18 – Wastewater Treatment Plant

Unit 18 treats wastewater from both ISBL and OSBL sources using a vendor-supplied Wastewater Treatment Package (A-1801). The system handles various streams, including:

- Boiler blowdown (Unit 12),
- Demineralizer waste and backwash (Unit 11),
- Cooling water blowdown (Unit 15),
- Acid wash effluent (Unit 01),
- Process water from the Direct Contact Cooler,
- Electrolyzer blowdown (Unit 02),
- Knock Out Drum aqueous phase (Unit 20),
- General contact sewer drains.

Treated water is either recycled to the Unit 11 Service Water Tank (T-1101) or discharged offsite at battery limits.

2.4.4.7 Unit 20 – Stack

Unit 20 manages non-routine gas releases through a dedicated stack system. Relief and depressurization gases from across the facility are routed via the main relief header to the Knock Out Drum (V-2001), which prevents liquid carryover.

Separated gases flow to the Stack (A-2001), which is connected to the treated flue gas outlet from the Unit 01 Absorber Column—making the Absorber stack the sole emission point. A Continuous Emissions Monitoring System (CEMS) at this location tracks emissions from both Unit 01 and Unit 20. During Unit 02 upsets, captured CO_2 is also vented via this stack.

Aqueous liquids from the KO Drum are intermittently pumped to Unit 18 for treatment, based on level control.

2.5 Operating and Contracting Strategy

The ownership and operational arrangements for the CO_2 capture facility are currently under evaluation and have not been finalized. The following outlines the current considerations and assumptions used for the purposes of the Front-End Engineering Design (FEED) study.

Ownership and Operations

- For the purposes of this FEED, the facility has been modeled as a stand-alone plant operated by a dedicated team, separate from host plant personnel.

Utility and Water Supply

- The capture facility's utilities are largely self-supplied.
- Steam will be generated on-site using a dedicated natural gas-fired boiler.
- Electric power will be supplied from the grid, independent of the host site.
- Water supply is partially provided by the host site.
- The majority of process water is recycled within the capture facility to minimize fresh water usage.
- A hybrid cooling system is incorporated to optimize water consumption and reduce reliance on makeup water.

Operations and Staffing

- The capture plant is assumed to operate independently of the host facility.
- A dedicated operations and maintenance (O&M) team will be responsible for day-to-day operation, monitoring, and maintenance.
- Staffing assumptions for the O&M team are reflected in the operating cost estimates

Commercial and Contractual Considerations

- Final decisions on ownership, O&M contracting, and commercial agreements (e.g., site lease, utility connections) will need to be addressed prior to detailed engineering or final investment decision (FID).
- The FEED package is designed to support a range of ownership models, including:
    - Independent third-party owner/operator model
    - Special purpose vehicle (SPV) structure
    - Build-Own-Operate-Transfer (BOOT) arrangements

3 Design Basis and Scope Definition

The project design basis is provided in **Appendix A1**. Details of the site-specific conditions and environmental requirements are provided in this section.

3.1 Site Characteristics

The Balcones Plant is in a hot humid subtropical region and has limited water availability.

The proposed location for the CO_2 capture plant is on a greenfield plot, South of the New Braunfels facility, with a plot plan of about 15 acres. Additional Cemex property is available to the south and west of the plot plan for potential laydown areas. Figure 13 shows an aerial view of the Balcones plant and Figure 14 shows the plant with the proposed plot area for the capture plant across the road from the cement plant. The flue gas ducting will need to go over the rail spurs and the road. Figure 14 provides another view of the proposed plot.

Figure 13: Image of the Balcones plant showing the plot area for the CO_2 capture plant

Figure 14: Proposed Plot for the CO_2 capture plant

3.2 Site Ambient Conditions

New Braunfels, TX, sits at an elevation of approximately 645 feet and experiences a humid subtropical climate with hot summers and mild winters. Average temperatures range from lows of ~40°F in January to highs near 97°F in July and August. Annual rainfall averages around 35 inches, with wetter months in spring and fall. The region sees occasional frost but rarely experiences snow.

Key ambient conditions for the capture plant are provided in Table 4. The design basis document in **Appendix A.1** provides further details.

Table 4: Ambient conditions for the Capture plant

Ambient Conditions	**Units**	**Maximum (Summer)**	**Minimum (winter)**
Average Dry Bulb Temperature	°F	85.3	51.8
Extreme Dry Bulb Temperature	°F	108	21.9
Mean Coincident Wet Bulb Temperature	°F	74.5	61.9
Annual Cooling One Percentile DBT	°F	98.6	
Annual Evaporation One Percentile WBT	°F	77.5	
		Design	**Normal**
Barometric Pressure	psia	14.70	14.36
Annual wind speed, average	ft/s	12.8	

3.3 Fuel Feedstock and Flue Gas Characteristics

Characteristics for the kiln exhaust gas, the boiler flue gas and the natural gas and air to the boiler for the Design case are provided in Table 5 below:

Table 5: Characteristics for the kiln exhaust gas, the boiler flue gas and the natural gas and air to the boiler for the Design case

	Kiln Exhaust Gas	Natural Gas	Air	NG boiler flue gas	Combined flue gas to CC plant
V-L mole fraction					
CO_2	0.1404	0.0100	0.0003	0.0869	0.1284
H_2O	0.135	0.0000	0.0099	0.1758	0.1442
O_2	0.1057	0.0000	0.2074	0.0204	0.0864
N_2	0.6189	0.016	0.7732	0.7083	0.6391
Ar	0.0000	0.0000	0.0092	0.0085	0.0019
SO_2	4.80E-06				3.70E-06
NOx	1.24E-04			5.0E-05	1.07E-04
CH_4		0.9310			
C_2H_6		0.0320			
C_3H_8		0.0070			
C4H10		0.0040			
Total	1	1	1	1	1
Flowrate (kmol/hr)	39,716	962	10,584	11,574	51,290
Flowrate (kg/hr)	1,164,950	16,675	305,413	322,089	1,487,039
Temperature (°C)	128.5	26.7	15	150.6	133.4
Pressure (MPa, abs)	0.099	0.101	0.101	0.1	0.099
Enthalpy (kJ/kg)	-2887.6	-4475.1	-97.6	-2619	-2829.4
Density (kg/m^3)	0.87	0.71	1.22	0.79	0.85
Molecular Weight	29.33	17.33	28.86	27.83	28.99

The CO_2 product specifications at the plant battery limit is provided in Table 6.

Table 6: CO_2 Specifications for pipeline transport

Component	Unit	Value
CO_2	Vol % (min)	95
H_2O	ppmv	100
N_2	Vol % (max)	4
O_2	Vol % (max)	0.001
Ar	Vol % (max)	4
CH_4	Vol % (max)	4
H_2	Vol % (max)	4
CO	ppmv	35
SO_2	ppmv	100
NO_X	ppmv	50

3.4 Environmental Requirements

Cemex identified all permits expected to be required for construction and operation of the CO_2 capture plant. Since this is a FEED study, the permitting process was not initiated and no regulator organizations were contacted. Instead, all permitting concerns were evaluated, and a comprehensive list was created with the required permit and the permitting agency. The list of permits/approvals expected is provided in Table 7.

Table 7: List of expected permits/approvals

Category	Agency	Permit or Approval
NEPA Compliance	N/A	NEPA Review
Wetlands	U.S. Army Corps of Engineers (USACE)	Section 404 Permit
Risk Management Plan Rule	U.S. Environmental Protection Agency (USEPA)	Risk Management Plan (RMP)
Air Emissions	TCEQ Air Permits Division	New Source Review Permit Amendment
	TCEQ Air Permits Division	Significant Revision to Existing Title V Federal Operating Permit
Stormwater	TCEQ Water Quality Division	TPDES Stormwater General Permit for Construction Activities
Wastewater	TCEQ Water Quality Division	TPDES Permit to Discharge Wastes
Water Use	TCEQ	Edward's Aquifer Protection Plan (EAPP)
Waste Disposal/Storage	TCEQ Industrial and Hazardous Waste	Updated Solid Waste Registration (SWR)
	TCEQ Industrial and Hazardous Waste	Industrial and Hazardous Waste Permit
Water Use	TCEQ Water Quality Division	Water Rights
Wetlands	TCEQ	Section 401 Water Quality Certification
Comal County Engineer's Office	Comal Trinity Groundwater Conservation District (GCD)	Drilling Authorization and Well Registration
Comal County Engineer's Office	Comal County	Floodplain Development Permit
Comal County Engineer's Office	Comal County	Private Improvement within the Public Right-of-Way (PIROW) Permit
Comal County Engineer's Office	Comal County	Camp Bullis Dark Skies Zone Outdoor Lighting Permit
Comal County Engineer's Office	Comal County	Fire Marshal Building Permit and Certificate of Compliance
Planning and Development	City of New Braunfels	Commercial Building Permit
Railroad	Railroad Owner	Encroachment Coordination

TCEQ: Texas Commission on Environmental Quality
TPDES: Texas Pollutant Discharge Elimination System

4 Design Challenges and Key Decisions

This section identifies the challenges and important design decisions incorporated in the FEED study.

4.1 Limited Water Supply

One of the process design challenges is the lack of raw water availability and its impact on cooling systems. The Cemex Balcones Cement Plant is able to supply 191 GPM of raw water from the on-site wells. An additional ~400 GPM of condensate from the Feed Direct Contact Cooler (DCC) is available for use as cooling water. This presents some challenges as the CO_2 capture process requires cooling of the solvent in the absorber intercooler, as well as absorber wash columns and direct contact cooler to cool and condition the flue gas. In addition, the CO_2 compression process also requires intercooling between the compression stages. The lack of cooling water availability was addressed by using hybrid cooling with air cooling for most part and water-cooling for trim cooler in the DCC and the water wash for the treated gas leaving the absorber.

The dry bulb temperature (DBT) for New Braunfels, TX for 2021-2022 is shown in Figure 15. The high summer design temperature presents a challenge, as both air and water cooling are constrained by the limitations of the log mean temperature difference (LMTD). Figure 16(a) shows the monthly mean coincident wet bulb temperature (MCWBT) plotted against the ambient dry bulb temperature (DBT) for New Braunfels, TX in 2022. The maximum MCWBT observed was 80°F, which, with an approach temperature of 15°F, indicates that process streams could be cooled to approximately 95°F using water cooling alone. However, due to limited water availability, a hybrid cooling strategy incorporating both wet and dry cooling would be required. Figure 16(b) presents the DBT distribution and cumulative distribution for the same year.

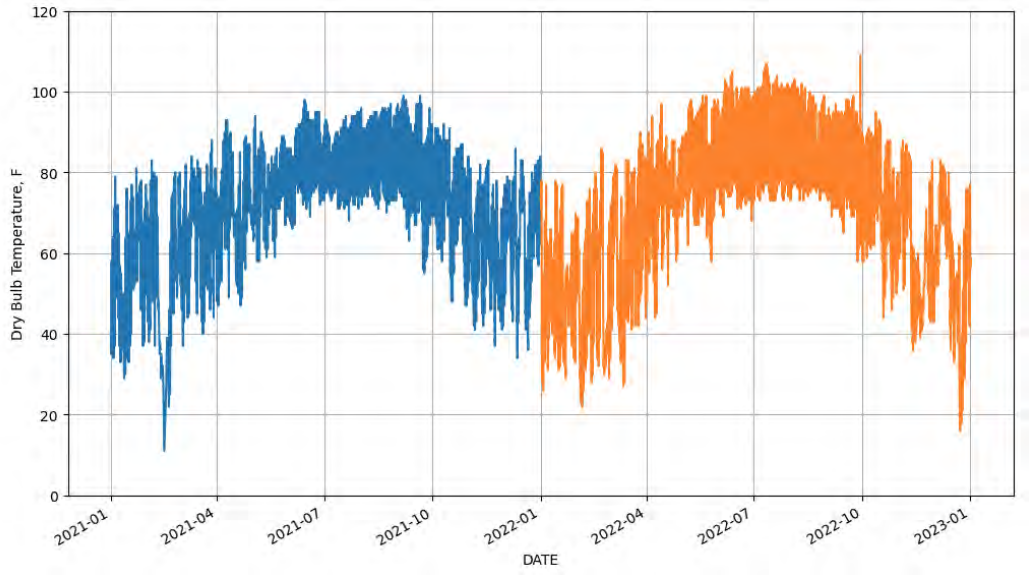


Figure 15: Dry Bulb Temperatures for 2021-2022

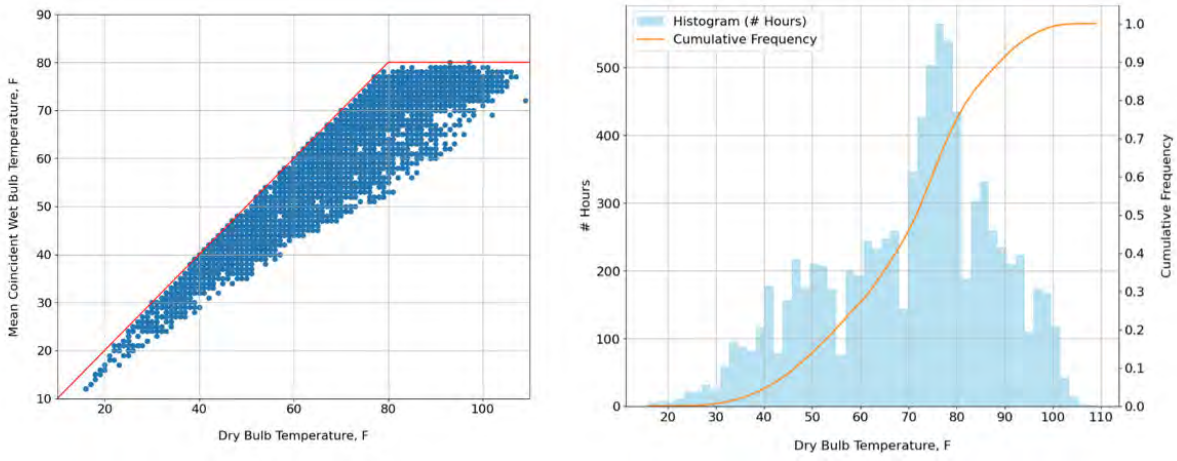


Figure 16: (a)) Mean coincident wet bulb and dry bulb temperature distribution (2022) (b) DBT histogram and cumulative frequency (2022)

The facility was originally designed for the ASHRAE 99.6% dry bulb temperature of 106.7 °F, resulting in high cooling requirements and increased equipment costs. To reduce cooling loads and associated capital expenditures, alternative ambient air temperatures were evaluated for the design of the air coolers.

The CO_2 capture rate is affected by the temperatures of the absorber intercoolers and the trim cooler. For the air-cooled heat exchangers, these temperatures are determined by the selected approach temperature and the ambient dry bulb temperature. An approach temperature of 15°F (9.4°C) was used in the design.

A computationally efficient surrogate process model, based on a rate-based model using NAS technology was developed to predict plant operation based on historical dry/wet bulb temperatures and kiln flue gas data as inputs. Under design conditions the model predicted a 96.4% average capture rate. The results of the optimization study using the 80°F (26.7 °C) design temperature and the 2021–2023 hourly data are shown in Figure 15.

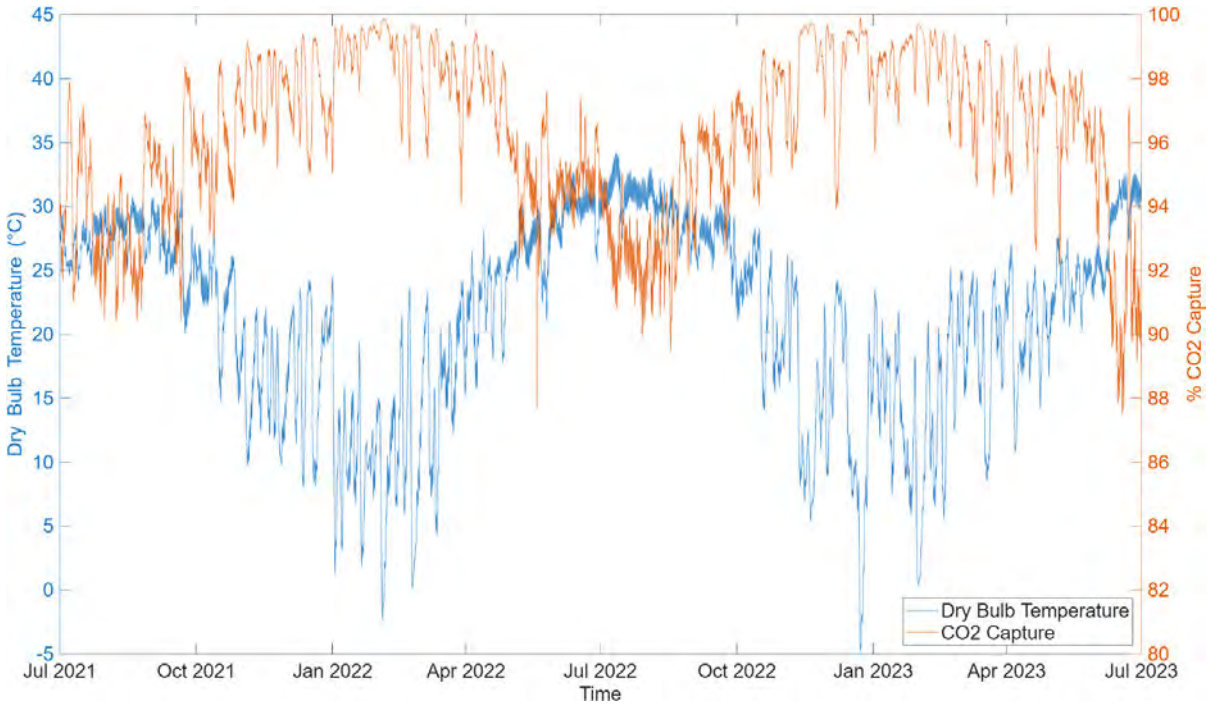


Figure 17: Results of the optimization study depicting the mean capture rate of 95% using the 80 °F (26.7 °C) design temperature for the air coolers.

A summary of the design options is provided in the below table.

Table 8: Air Temperature Options

Air Temperature (°F)	Basis
106.7	ASHRAE 99.6% Dry Bulb Temperature
104.2	ASHRAE 98% Dry Bulb Temperature
100.8	ASHRAE 90% Dry Bulb Temperature
80.0	Minimum temperature that meets the annual CO_2 capture rate of 95%

The impacts of these ambient temperatures on cooling requirements for various cooling system technologies are summarized in the next section. For more information on the facility's ambient conditions, refer to the Project Design Basis in **Appendix A.1**.

Options Considered

As a result of the cooling system design challenges mentioned above, the following cooling options were evaluated.

Table 9: Cooling Options Summary

Option	Name	Description
Base Case	Water Cooling via Open Wet Tower	Recirculating cooling water in an open wet tower

A	Water Cooling via Wet Surface Air Cooler (WSAC)	Process fluid goes to a WSAC
B	Air Cooling then Water Cooling (Open Wet Tower)	Air Cooler until LMTD pinch point, followed Water Cooling
C	Air Cooling then Water Cooling (WSAC)	Air Cooler until LMTD pinch point, then the process fluid goes to a WSAC
D	Heat Pump with Air Cooler Condenser	A closed loop Heat Pump with a working fluid that allows for Air Cooler Condenser (ACC)
E	"Hybrid" - Air Cooling, then Water Cooling (Wet Tower), then Heat Pump with Air Cooled Condenser	Air Cooler until LMTD pinch point, followed Water Cooling, then closed loop Heat Pump with a working fluid that allows for Air Cooler Condenser
F	Air Coolers, Cooling Tower, Design Air Coolers for 80 °F Ambient	Water Cooling in wash section and DCC trim. Air Coolers sized for 80°F. Capture rate drops in summer, but the annual average is 95%.

Other options considered but not included due technical infeasibility are:

1. Air cooling only – not feasible due to process temp cross over with design dry bulb temperature.
2. Direct contact cooling of NAS solvent with air – high losses of solvent.
3. Ground source heat pump – load is too large and would be cost prohibitive.

Evaluating these options for utilities consumption and indicative CapEx results in the following.

Table 10: Cooling Options Values and Tradeoffs

Item	Units	Base Case	A	B	C	C.1	D	D.1	E	F
	-	Water	WSAC	Air / Water	Air / WSAC 99.6% ASHRAE	Air / WSAC 98% ASHRAE	Air / Heat Pump 99.6% ASHRAE	Air / Heat Pump 98% ASHRAE	Air / CWT / Heat Pump 98% ASHRAE	Air / Water 80°F Ambient Design Temp
Heat Loads										
% to Air Cooling		0	0	24	24	32	24	32	32	84
% to Heat Pump		0	0	0	0	0	76	68	53	0
% to Water Cooling		100	0	76	0	0	0	0	15	16
% to WSAC		0	100	0	76	68	0	0	00	0
Meets Water Constraints		No	No	No	No	No	Yes	Yes	Yes	Yes
Electrical Consumption (Normalized)	MWe	1	0.2	1.3	0.7	1.3	10.6	9.4	7.7	2.5
Indicative Capex, TDC (1) (Normalized)	MMUSD	1	11.9	4.8	12.6	13.2	8.9	9.6	9.9	9.4
Footprint	acre	0.4	1.8	1.7	3.1	2.9	4.2	3.6	4.0	4.1

Notes:

1) Costs shown above are indicative and only cover direct equipment costs. These values should ONLY be used for directional comparison of one scenario against another. Total installed costs of the cooling system have NOT been estimated. No specific accuracy is assigned or implied.

Of these options, option F is the only option that meets the water constraints without consuming excessive electricity and is cost (CapEx) competitive with the other options that meet the water constraints. .

5 Discipline Design Summaries

5.1 Process Engineering

This section presents the process engineering basis and associated documentation developed for the CO_2 capture facility. It includes the design philosophies, process configuration, operating strategies, safety systems, and supporting documentation required to define the technical scope for both ISBL (Inside Battery Limits) and OSBL (Outside Battery Limits) systems.

The process design is centered around a water-lean amine-based CO_2 capture system, followed by compression, dehydration, and polishing units. Utility systems including water treatment, cooling, air systems, chemical storage, and nitrogen supply are captured in the OSBL scope.

5.1.1 Design Decisions

5.1.1.1 Process Design Rate

One of the challenges in the process design was determining the normal and maximum operating cases for the facility due to the variability in operating data provided for the Cemex Balcones Cement Plant. PI data for the Cemex site depicted daily fluctuations in plant operations and further variability from Kilns 1 and 2 tripping.

The facility is required to capture > 95% of the CO_2 produced in the cement plant kilns and natural gas boiler, as mandated by the Department of Energy (DOE). Given this CO_2 capture requirement and variability in the PI data, it was challenging to select a design rate for the facility. Designing for the peak PI data results in overdesigning the facility for most of the year, which further increases plot footprint and cooling system requirements. However, designing for the average PI data results in under capturing when the kilns are operating at instantaneous, above average rates. As a result, selecting the facility's design rate is a balance of managing peak operating rates without oversizing equipment.

Cemex provided hourly-averaged CEMS data for kiln #1 and kiln #2 over the period from July 2021 to June 2023. The data included flue gas composition, temperature and pressure conditions and flowrates. The data revealed significant variability in the flue gas flow rates for each kiln, which posed challenges in sizing the CO_2 capture plant. This variability in operating data required careful consideration to determine the normal and maximum operating cases for the facility at the Cemex Balcones Plant. In this FEED study, RTI with support from KBR selected the normal and maximum operating cases that resulted in appropriate design conditions for equipment sizing and achieved >95% CO_2 capture on an annual basis. It was determined that the capture plant should be designed to address the 90th percentile of the total flow as the design "max" case, while the "mean" or 50th percentile value would represent the "normal" case. All equipment was designed to accommodate the design "max" case conditions, and a "normal case" was adopted to provide data for the "average conditions."

The design "max" case led to the plant being sized to capture 2.4 MTPA of CO_2 emissions from both the kiln and the captive natural gas boiler. The nominal capture capacity is 86%, which, when combined with the 90% plant availability, results in an overall capacity factor of 74%.

5.1.1.2 Use of Hybrid Cooling

The Balcones Plant is in a hot humid subtropical region and has limited water availability The amount of water recovered from the Direct Contact Cooler (DCC) and the supply from the Balcones Cement Plant is able to supply 20% of the requirement for cooling water makeup. Following an evaluation of various cooling options, a hybrid system combining air cooling and water cooling was selected. Water cooling is applied in the absorber wash section and DCC trim cooler, while air coolers—sized for 80°F ambient temperature—handles the majority of the heat rejection. The use of alternative cooling systems to compensate for limited water availability, has an impact on the overall cost of CO_2 capture, as detailed in the cost analysis section of this report.

5.1.1.3 Choice of Compressor Type

Due to limited site water availability, an integrally geared CO_2 compressor with heat integration was selected in place of a conventional water-cooled unit. In this configuration, the heat of compression is recovered and used to raise low-pressure steam (LPS), thereby eliminating the need for a dedicated cooling water system. While the heat-integrated compressor requires approximately 33% higher power than a conventional design, it significantly reduces cooling water demand. Compressor power requirements can be optimized by increasing the number of compressor stages with accompanying intercooling. In collaboration with the compressor suppliers, it is recommended that this aspect be further evaluated to determine the optimum number of stages and intercoolers.

5.1.1.4 Choice Deoxygenation and Dehydration

To meet pipeline CO_2 purity specifications, the design incorporates a regenerable oxygen adsorbent system to remove trace oxygen impurities from the CO_2 product gas. The adsorbent is periodically regenerated using hydrogen produced by the electrolyzer. In parallel, triethylene glycol (TEG) dehydration is employed to control moisture content and ensure that the treated CO_2 meets water specification limits for pipeline transport.

5.1.1.5 Particulate Management and Filtration

The feed flue gas streams contain trace amounts of particulate matter that must be removed prior to downstream processing. Based on characterization data indicating low particulate loading, a gas filter upstream of the DCC was not included in the design, but instead, particulate removal is achieved through the Feed Scrubber Circulation Filter. The filter is an automatic self-cleaning unit installed on the process water discharge from the DCC bottoms. The circulation filter receives process water from the Feed Scrubber Wash Circulation Pump, removes entrained particulate matter, and returns the filtered water after cooling to the DCC. A small slipstream from the pump discharge is sent to Wastewater Treatment Plant (WWTP). This configuration provides reliable removal of residual particulates while minimizing equipment count and pressure drop in the flue gas path.

A few other filter designs were considered during the FEED study but ultimately not pursued for the reasons described below.

1. Locating the filter on the flue gas overhead from the DCC, upstream of the Flue Gas Blower. Potential disadvantages of this design are:
    - The filter will need to be large to handle the flue gas flow rate and be designed for minimal pressure drop.

- The filter may need to be designed as a bag house filter, which is already employed by the cement plant so a second bag house filter may provide minimal benefit.

2. Designing the filter as a cartridge filter instead of an automatic self-cleaning filter. Initial discussions with vendors reviewed the following cartridge filter designs.
    - A single filter housing containing multiple cartridge filters in parallel designed to treat the full process water stream from the DCC. This design required frequent filter changeouts and several filters in parallel and therefore was considered an impractical design.
    - Another design option located the cartridge filter on a slipstream (e.g., 10%) of the DCC bottoms process water instead of treating the full stream. While this option reduces the number of filters, there are potential clogging issues in the downstream plate and frame exchanger if the filter does not adequately remove solids to meet the exchanger's particulate matter limitations.

The final option using an automatic self-cleaning filter was selected as the most suitable design since this type of filter can treat the full DCC process water stream. Although the collection efficiency is less than that of a cartridge filter, the automatic self-cleaning filter design has a larger capacity and requires less parallel equipment so it was considered the preferred design option.

5.1.2 Process Engineering Summary

Process Flow Diagrams (PFDs) were developed for the major CO_2 capture systems, including the Direct Contact Cooler (DCC), Absorber, and Regenerator. Utility Flow Diagrams (UFDs) were also prepared for the Outside Battery Limit (OSBL) systems to capture supporting infrastructure such as water, steam, nitrogen, and chemical handling systems. The full set of PFDs and UFDs is included in **Appendices B.3 and B.5**, respectively.

Heat and Material Balances (HMBs) for the Inside Battery Limit (ISBL) systems were developed using RTI's process simulation model. Two design cases were evaluated: the **Normal Case** and the **Max Case**. These HMBs were subsequently updated by KBR to reflect refined estimates of pressure drops and equipment performance. The updated ISBL HMBs are provided in **Appendix B.4**. Utility and mass balances for the OSBL systems were also developed by KBR and are presented in **Appendix B.6**, capturing utility consumption, generation, and recycling rates across the facility.

A ISBL/OSBL **Equipment List** was also developed to define the major process and utility equipment identified in the FEED scope. This list reflects the equipment associated with both ISBL process units and OSBL utility systems, as shown in the PFDs and UFDs. The complete equipment lists are provided in **Appendix B.8** (ISBL) and **Appendix B.9** (OSBL).

A summary of utility demands, design cases, and supply sources is included in **Appendix B.10 – Utility Summary**, which supports sizing and design of the OSBL utility systems.

Operating requirements for catalysts and chemicals, are provided in **Appendix B.11 – Catalyst and Chemical Summary**.

5.1.3 Hazard and Operability Study/Process Hazard Analysis (HAZOP)

5.1.3.1 Introduction

An independent firm, Saltegra Consulting LLC, specializing in Process Hazard Analysis (PHA), was selected to facilitate the PHA for the Balcones CO_2 Capture Plant. The PHA was held over a total of six days, combining both in-person and remote sessions. The PHA team include representatives from RTI , KBR, SLB, Cemex as well as a facilitator and scribe familiar with the HAZOP methodology. The in-person workshop was held at the Research Triangle Park, North Carolina on May 20 – 24, 2024 followed by remote sessions on May 29, 2024. The analysis utilized both the **HAZOP (Hazard and Operability Study)** and **Checklist** methodologies to systematically identify and evaluate potential hazards associated with the design and operation of the CO_2 capture process.

The primary objectives of this review were to:

- Identify events, which potentially have a significant impact on the safety of personnel and operations. These concerns included effects on surrounding populations as well as on operating personnel and equipment damage.
- Assess the risk level associated with each safety hazard.
- Suggest changes or further study to overcome the potential unsafe deviations with unacceptable risks.
- Record the causes, risk level, and considerations of the safety hazards in a report and submit this report to location management.

The HAZOP process followed a node-based approach, using preliminary **Piping and Instrumentation Diagrams (P&IDs)** as the basis for identifying logical system divisions. Each node typically corresponded to a major unit operation, subsystem, or piping section where distinct flow, pressure, or control behaviors could occur. The nodes covered both ISBL and OSBL systems, including the absorber, regenerator, compression train, and utility tie-ins.

5.1.3.2 PHA Scope

The PHA was conducted as part of the FEED phase to identify and evaluate potential process safety hazards associated with the proposed facility design. The scope of the assessment included:

- All process units, equipment, and associated systems within the defined FEED battery limits.
- Normal operating conditions as well as non-routine modes such as startup, shutdown (normal and emergency), maintenance, and transient conditions.
- Interfaces with existing facilities where tie-ins or operational dependencies are present.
- Potential loss of critical utilities, including firewater, steam, nitrogen, instrument air, and power.
- Instrumentation failure modes and their contribution to potential process upsets or hazardous conditions.
- External event impacts, such as high ambient temperatures, seismic events, or other natural hazards relevant to the region or site conditions.
- Review of relevant historical incidents from similar facilities or industry sources.

In addition to standard HAZOP analysis, the PHA also included the following supplemental evaluations:

- Human Factors Checklist – assessing working conditions and potential human error risks.
- Facility Siting Checklist – evaluating equipment placement and layout against applicable safety standards and siting criteria.

- External Events Checklist – considering exposure to and resilience against natural or external hazards.

The analysis addressed potential consequences to personnel safety, public health, and equipment integrity, assuming failure of safeguards for consequence development purposes. A qualitative assessment of existing or proposed safeguards was carried out for each identified scenario.

The PHA was organized around 28 process nodes, defined according to system functionality and process boundaries.

5.1.3.3 HAZOP Methodology

The PHA was conducted using the HAZOP Guideword methodology, supplemented with What-if analysis for general issues, to ensure comprehensive hazard identification and risk analysis (HIRA).

The evaluation included:

- Application of standard HAZOP deviations such as No/Low Flow, High Flow, Reverse Flow, Misdirected Flow, Low/High Level, Pressure, Temperature, and Contamination.
- Consideration of special deviations relevant to abnormal or transitional operations, including startup, shutdown (planned and emergency), maintenance, and transient conditions.
- Review of existing or proposed engineering and administrative safeguards for each deviation scenario.
- Evaluation of potential failure modes, including instrumentation malfunction, utility loss, and external events (e.g., extreme weather, seismic activity).
- Use of supplemental checklists to address broader risk considerations:
    - Human Factors – Evaluation of ergonomic, procedural, and cognitive risks.
    - Facility Siting – Assessment of hazard proximity, equipment spacing, and layout-related risks.
    - External Events – Analysis of resilience to site-specific natural hazards.

Possible causes for each deviation were identified, followed by an assessment of the worst credible consequences, assuming failure of safeguards. The team qualitatively assessed the severity and likelihood of each consequence using a project-specific risk matrix. Existing safeguards were reviewed for adequacy and effectiveness and a risk ranking was assigned based on the severity and likelihood. Where risks were deemed unacceptable or where safeguards could be enhanced, recommendations were developed. This

structured process was repeated for all relevant deviations and nodes to ensure comprehensive coverage of the facility's design.

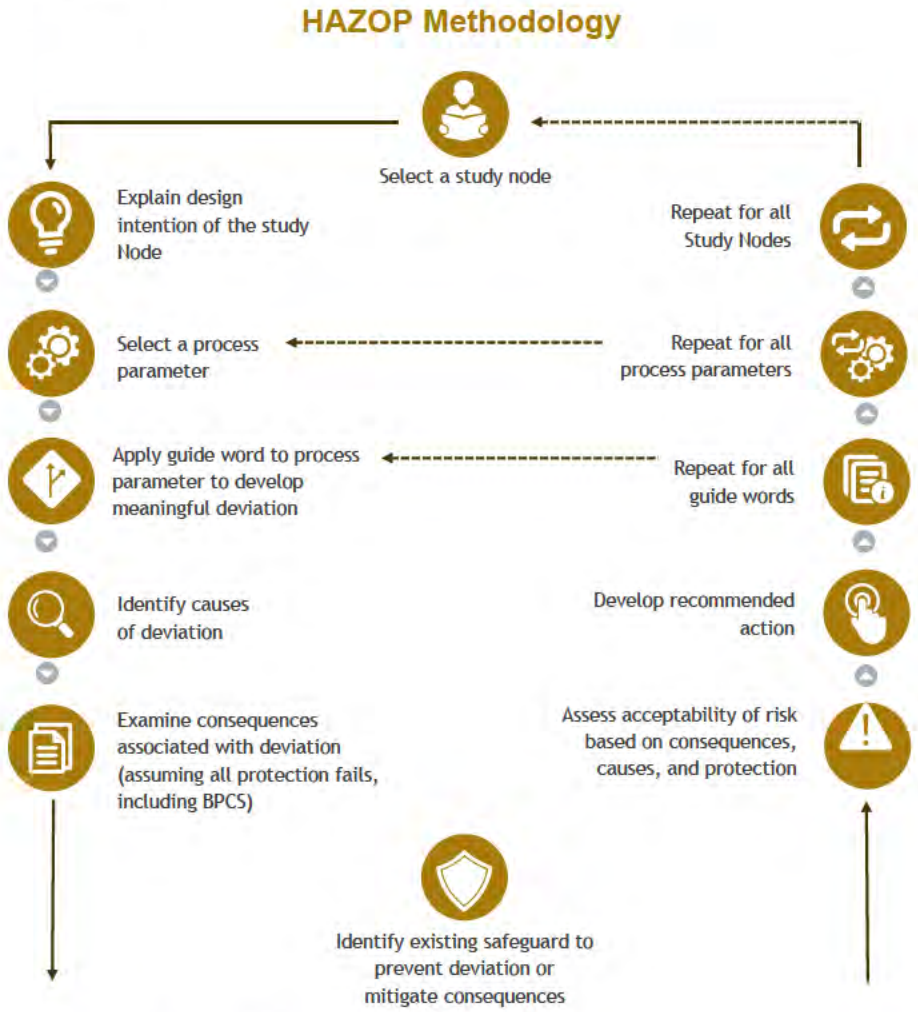


Figure 18: Risk Methodology Process

Risk ranking for each identified scenario was based on a project-specific qualitative risk matrix, which provided a consistent framework for evaluating severity and likelihood. The matrix defines six severity categories (from Minor to Catastrophic) and six likelihood levels (from Rare to Almost Certain).

An overview of the qualitative risk assessment approach is shown in Figure 18.

Figure 19: Risk Matrix

					Likelihood					
					1	2	3	4	5	6
Severity	Health and Safety	Business - Financial	Environmental	Business – Non - Financial	Rare <0.001%	Unlikely >0.001% - <0.01%	Possible >0.01% - 0.1%	Likely 0.1% - 1%	Very Likely 1% - 10%	Almost Certain 10% - 100%
A	Multiple fatalities/ >10 injuries or health effects	Disastrous damage	Widespread damage which remains for a period > 5 years	International concern						
B	Single fatality/ 10 or more injuries or health effects	Extensive damage	Extensive damage which can be restored in 1-5 years	International public attention						
C	Permanent disability/ 3 or more injuries or health effects	Major damage	Extensive damage which can be restored in 1 year	National public concern						
D	Lost time injury/ Partial disability/ Several non-permanent injuries or health effects	Local damage	Localized damage which can be restored in a period of months	Regional public concern						
E	Recordable injury or health effects from common source / event.	Minor damage	Immediate area damage which can be restored in a period of months	Some local public concern						
F	Over-exposures causing noticeable irritation but no actual health effects	Slight damage	Immediate area damage which can be restored in a period of days or weeks	No local public concern						
Level 1 - High (Intolerable)	Long term operation in high risk not allowed. Immediately identify risk mitigation according to the hierarchy of controls and implement risk mitigation to reduce the risk to ALARP within 30 days. In case of extension, an approval from relevant holding company shall be obtained. Include in Risk Register for tracking. Consider advanced Risk Analysis methodologies for further investigation. Reporting within 24hrs. Notify relevant Oil & Gas Holding Companies within 7 Days.									
Level 2 - Medium/High (Tolerable if ALARP)	Conduct an ALARP study to determine if the cost of implementing additional risk mitigation is appropriate. Include in Risk Register for tracking. Consider advanced Risk Analysis methodologies for further investigation. Reporting time within 7 Days.									
Level 3 - Medium (Tolerable if ALARP)	Conduct an ALARP study to determine if the cost of implementing additional risk mitigation is appropriate. Monitor and improve effectiveness of current controls. Include in Risk Register for tracking. Reporting time within 30 Days.									
Low (Broadly Acceptable)	Low Priority, monitor and improve effectiveness of current controls. Include in Risk Register for tracking.									

5.1.3.4 PHA Results

The method to risk rank and identify recommendations used by the PHA team was a qualitative process. The PHA Team may have developed recommendations that were not risk-driven but were made to improve operations and provide minor means.

Table 11: Risk Driven Recommendation Summary

Number of Recs	7	6	7	22	13
Scenario Risk Ranking	**Level 1 – High (Intolerable)**	**Level 2 – Medium/High (Tolerable if ALARP)**	**Level 3 – Medium (Tolerable if ALARP)**	**Low Risk (Broadly Acceptable)**	**Not Risk-Ranked / Not Applicable**

5.1.4 Overpressure / Relief Study

Overpressure protection is critical to maintaining the mechanical integrity of process equipment and piping systems. A systematic evaluation of all modes of operation and engineering design intentions was conducted to identify credible overpressure scenarios and ensure appropriate safeguards were in place.

Provisions were incorporated into the design to contain or safely relieve excess pressure under abnormal or upset conditions. Overpressure protection was based on the identification of credible single failure scenarios. The simultaneous occurrence of multiple unrelated causes (i.e., lacking mechanical, electrical, or process commonality) was not considered in accordance with standard industry practice.

Control responses and the automatic start-up of equipment were not considered substitutes for mechanical pressure relief devices in providing overpressure protection. Final protection was achieved through properly selected and sized mechanical pressure relief devices, designed to comply with applicable ASME and API standards.

Common causes of overpressure evaluated during the study included:

- Thermal expansion
- External fire exposure
- Blocked outlet (liquid and vapor)
- Inbreathing/outbreathing during filling or emptying
- Automatic control valve failure
- Inadvertent valve opening
- Check valve leakage or failure
- Abnormal heat input

Relief load calculations were performed for each credible scenario to determine individual relieving requirements for pressure-relieving devices. These calculations form the basis for the sizing and selection of relief valves and associated vent systems.

- **Appendix B.12** provides the *Overpressure and Vent Philosophy* adopted during FEED by KBR, outlining the overall approach to pressure protection and vent system design.

Sizing and relief rates for vendor-supplied package equipment will be confirmed during the detailed engineering phase.

5.1.5 Isolation Philosophy

An Isolation Philosophy has been developed to guide the specification and placement of isolation devices across process and utility systems. It provides the design basis for isolating equipment or plant sections to ensure safe maintenance, inspection, commissioning, and operational activities. The philosophy applies to both ISBL and OSBL systems and is consistent with industry standards for safe access and plant segregation.

The full Isolation Philosophy is provided in **Appendix B.13**.

5.1.6 Heat Tracing and Winterization Philosophy

A Heat Tracing and Winterization Philosophy was developed to ensure that process and utility systems are adequately protected against freezing conditions and meet operability requirements under site-specific ambient conditions. The philosophy defines the criteria for identifying lines and equipment requiring heat tracing (electrical or steam) and insulation, as well as guidelines for winter operation and maintenance.
The complete heat tracing and winterization philosophy document is provided in **Appendix B.14**.

5.1.7 Environmental Permitting

Cemex identified all permits expected to be required for construction and operation of the CO_2 capture plant. Since this is a FEED study, the permitting process was not initiated and no regulator organizations were contacted. Instead, all permitting concerns were evaluated, and a comprehensive list was created with the required permit and the permitting agency. The list of permits/approvals expected is provided in Table 7.

Under the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP), cement plants are required to report their total CO_2 emissions **before** accounting for any reductions achieved through carbon capture and storage (CCS) or other mitigation technologies. This requirement is established under 40 CFR Part 98, Subpart H – Cement Production. The EPA has proposed amendments to this subpart as part of an ongoing rulemaking process to reconsider certain GHGRP requirements; however, until a final rule is issued, facilities must continue to report gross CO_2 emission**s** in accordance with the existing regulation. Meetings were held with KBR and Cemex environmental team to discuss relocation of the CEMS upstream of the tie-in points for the two stacks to allow Cemex to monitor the emissions from the cement kilns with the CO_2 capture unit running, as required by under the National Emission Standards for Hazardous Air Pollutants (NESHAP) set by the U.S. Each kiln needs to be monitored separately as they had different emission limits. The CEMS needs to be installed at an accessible location where the pollutant concentration or emission rate measurements are directly representative of the total emissions, and the measurement location should be (1) at least two equivalent diameters downstream from the nearest control device, the point of pollutant generation, or other point at which a change in the pollutant concentration or emission rate may occur and (2) at least a half equivalent diameter upstream from the effluent exhaust or control device. The option of a combined CEMS after the two ducts join into a single duct leading to the capture plant was discarded due to requirement to monitor each kiln individually. The team reviewed various locations and identified a suitable location in the duct work from each of the kiln to the central duct before the flue gas from the natural gas boiler is added. This location is consistent with the EPA requirements listed above. Having a dedicated CEMS for each kiln meets the requirement for each kiln being monitored separately. Other options considered was to move the CEMS from the current location to

the new location but was discarded as it would present challenges to monitor the plant emissions when the CO_2 capture plant was not running Instead, it was decided to have a valve in the duct between the main baghouse and the present stack so that we can go back to the main stack when the capture plant is down. This allowed Cemex to measure the plant emissions both with and without CCS at any given time.

5.2 Mechanical Engineering

5.2.1 Design Decisions

The process design challenges manifested themselves in the mechanical equipment design. Of all the process design challenges mentioned above, the water availability and process design rates had considerable influence on equipment design / selections which are highlighted below.

The mechanical equipment costs represent approximately 45% of the Total Direct Costs, so decisions on process design margin, design rates, site constraints such as cooling water all contributed to increased equipment costs.

5.2.1.1 Air Cooler Mechanical Options Analysis

Due to the limited availability of cooling water, this project employed the use of air-cooled heat exchangers (ACHE) as noted above in the process cooling system section. This cooling system was a hybrid of two types of heat exchangers. Both air cooled heat exchangers and gasketed plate and frame exchangers were required for complete plant cooling.

The design basis of the ACHE was to utilize 1" tubes (welded 316 SS) with multiple tube passes to achieve the highest heat transfer coefficients. ACHE fans are manual adjustable pitch, preset at the factory. The maximum ambient temperature for sizing the air-cooled exchangers was set at 80°F, representing a design compromise between equipment sizing constraints and the ability to achieve a 95% annual average CO_2 capture rate. This approach balances thermal performance with capital cost and footprint, while accounting for typical site temperature profiles.

Each ACHE is provided with header walkways and ladders for access and maintenance of the heat exchanger tube bundle. Actuated Louvers were provided as an option for winter and turn down cases to aid in maintaining the process temperature. Each fan motor is variable frequency drive (VFD) compatible for additional temperature control.

Pressure drop through each exchanger was evaluated in tandem with associated pumps or applicable compressor. This was to ensure sufficient head and horsepower in the pump was available while maintaining and economical design. Refer to pump selection philosophy below for additional details.

This ACHE design may be improved by increasing the tube diameter up to 1.5" diameter, additional tube rows(layers), and increasing tube passes. By applying these modifications, the number of air-cooled heat exchanger bays and overall horsepower consumption would be reduced.

5.2.1.2 Regenerator Reboiler Design

NAS is water-lean and does not require stripping steam for regeneration. Due to its low water content, minimal steam is generated during regeneration, making a traditional thermosyphon reboiler unsuitable. To address this, a once-through forced recirculation reboiler was selected. The solvent is withdrawn from the bottom section of the regenerator packing and flows to the reboiler by gravity. The system relies on an elevation difference between the solvent withdrawal point and the reboiler return connection to the column. This elevation provides sufficient hydrostatic head to overcome pressure drops across the reboiler and ensure continuous circulation without the need for a pump.

The Regenerator Reboiler's large heat duty (685 MMBTU/hr) poses a challenge because designing the reboiler as a traditional shell and tube exchanger requires 8 parallel exchangers and results in a large plot footprint.

To reduce plot footprint and number of equipment, a welded plate and frame style exchanger was considered as an alternate design. Specifically, this project selected the Alfa Laval Compabloc exchanger, of which only 4 parallel units are needed.

The welded plate and frame exchanger design offers several advantages over the shell and tube exchanger design, including:

- High heat transfer rates and lower liquid hold-up.
- Reduced footprint and maintenance activities since shell and tube exchangers require additional plot space for pulling out tube bundles axially for maintenance and replacement.
- High shear rates, which reduce fouling, and high turbulence, which allows for effective and economical chemical cleaning in place (CIP).
- Easy accessibility of side panels, which can be removed for visual inspection and high-pressure wash cleaning, and disassembly of the plate pack, which can be immersed in chemical for cleaning.

5.2.1.3 Pump Selection Philosophy

Early in the design process, API 610 was identified as the most appropriate construction standard for pumps operating within the unit battery limits. This decision was then later supported by the pump suppliers who indicated limited references for pumps in amine service not bult to API 610. ANSI/ASME constructed pumps were also considered acceptable for services inside and outside the battery limits provided, the process conditions were compatible with available hydraulic capabilities; however, they were not used within this FEED.

The quantity of pumps for each service was determined based on rated capacity and available net positive suction head (NPSH). Minimum-flow (recycle) controllers were incorporated across services to accommodate the wide capacity range between normal and rated flow conditions. Allowable operating ranges and final selection will be confirmed by pump vendors during detailed design.

5.2.1.4 Absorber And DCC Design

The Absorber Column baseline design was based upon a concrete structure which has a long history of success in the Flue Gas Desulfurization industry and more recently CO_2 capture industry. KBR worked closely with leading manufactures of large Absorber and DCCs to validate their design offerings technically for the specific operating conditions, column footprint and height requirements.

Alternative materials of construction were evaluated and compared to the concrete construction with liner plate. Steel designs were found to be technically viable and had comparable budgetary cost estimates to the concrete option with liner plate. However, further investigation is recommended to establish a more definitive design baseline and cost comparison between concrete and steel construction options.

5.2.1.5 Cement Plant Flue Gas Mechanical Tie-In

A new flue gas duct would be installed to direct exhaust gas from Kiln #1 and Kiln #2 to the CCS. The existing flue gas duct design layouts from Kiln #1 and Kiln #2 were dramatically different which resulted in developing custom tie-in strategies for each kiln stack tie-ins. The underlying design goal was to isolate capture plant disruptions from having an impact on the reliability of the cement plant and vice versa.

Flue gas from the kilns would be directed from the existing K#1 and K#2 stacks through a large duct (10' w x 10' h). The diverter dampers would direct flue gas to either the cement plant stack or the CCS. The guillotine dampers provide positive isolation of the kilns from the CCS.

The duct work after flue gas from Kiln #1 and Kiln #2 is enlarged to 12' x 12' duct routed over the rail spurs and the road to the proposed CCS area and is approximately 1,000 ft in length from stack to the DCC blower. The ductwork would be constructed of ¼" carbon steel. The ductwork would be constructed in sections along its length and expansion joints would be employed at strategic locations to manage thermal growth and external loads on stack breaching and / or blowers.

5.2.2 General Site Plan

Figure 20 shows the 2D plot plan and general layout of the CO_2 capture plant and is also provided in **Appendix C.1**. Additional 3D model snapshots (Figure 21 and Figure 22) are included here to illustrate the spatial arrangement of major equipment, the routing of flue gas ductwork (including crossings over rail spurs and Wald Road). These visuals help integrate the mechanical layout into the site context and highlight key routing and elevation challenges.

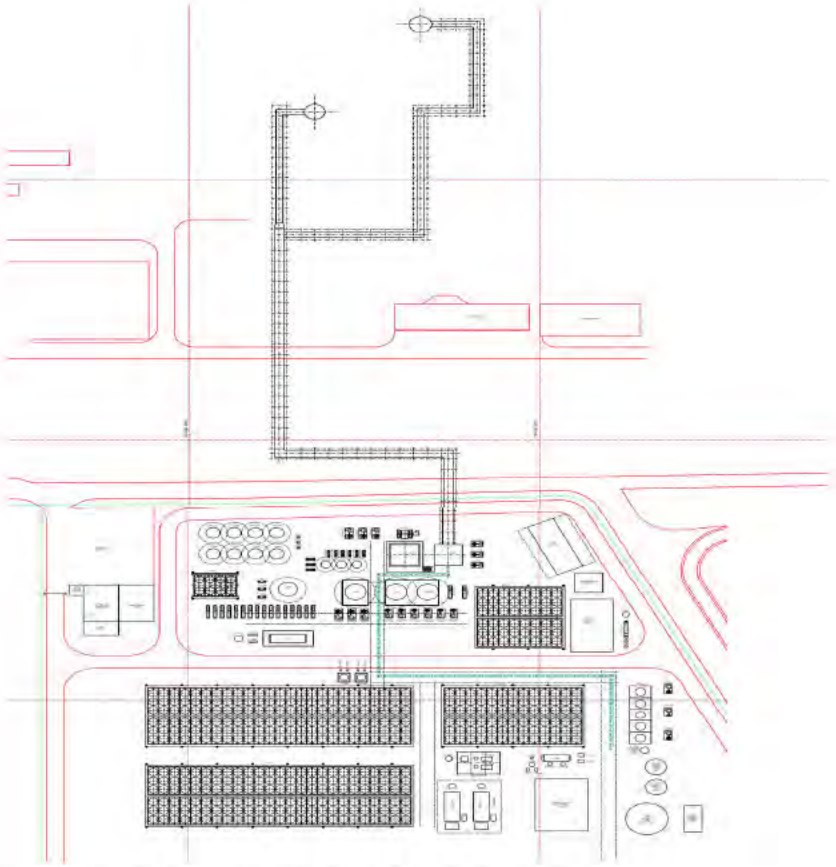


Figure 20: Plot plan for the NAS CO_2 Capture plant

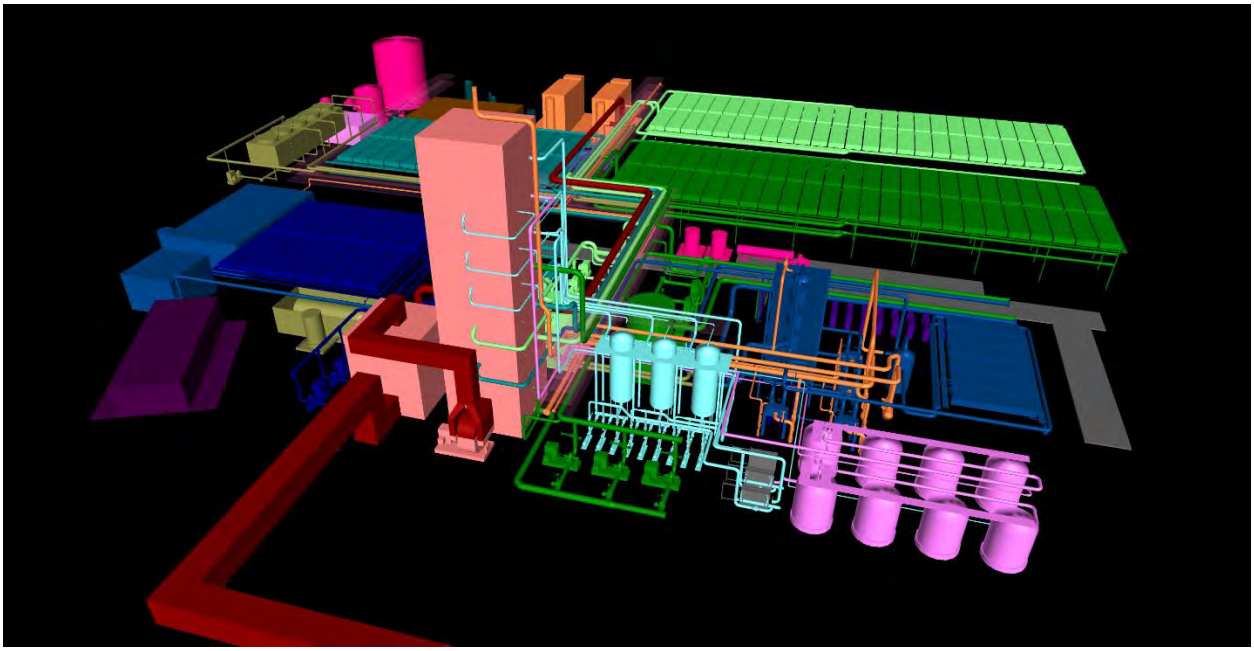


Figure 21: Snapshot of the 3D model showing layout of major equipment, flue gas duct routing, and the air coolers selected due to site water limitations

Figure 22: 3D model view with integrated scan of the existing cement plant, showing the flue gas duct routing over the rail spurs and Wald Road.

5.2.3 Mechanical Equipment Summary

The mechanical equipment summary provides an overview of the major equipment required to support the CO_2 capture process, based on process and utility service requirements established during the FEED phase. Equipment covered in this section includes vessels, heat exchangers, blowers, compressors, air coolers, pumps, and key utility packages. Equipment sizing and specifications were developed using process simulation outputs, heat and material balances, and vendor data where available.

Key process equipment such as the Direct Contact Cooler (DCC), Absorber Column, and Regenerator Column were sized based on the combined flow from the two kilns and the natural gas boiler flue gas, targeting 95% CO_2 capture efficiency. Provision was made for up to a 50% turndown ratio to allow operation with one kiln offline.

The redundancy philosophy for rotating equipment varied by type. An N+1 inline configuration was applied to all critical pumps—including lean amine circulation, solvent transfer, and cooling water pumps—to ensure uninterrupted operation during maintenance or equipment downtime. For example, three pumps each sized at 50% capacity were specified to allow full-capacity operation with one pump offline. In contrast, large equipment such as the gas blower and CO_2 compressors were designed without N+1 redundancy but incorporated appropriate design margins and availability considerations.

The hybrid cooling strategy utilized mechanical draft air coolers for primary cooling duty, supplemented by a water cooled exchanger utilizing a cooling tower where additional cooling water is required.

Steam-integrated CO_2 compressors were selected over electrically driven units to optimize energy integration and reduce electrical demand.

The natural gas-fired boiler supplies low-pressure steam for solvent regeneration and other auxiliary loads.

Final equipment specifications and vendor selection will be completed during the detailed engineering phase.

5.2.4 Equipment Layout and Access

The overall layout of the CO_2 capture facility was developed to optimize equipment placement for efficient process flow and operational accessibility. A preliminary 2D plot plan, provided in **Appendix C.1**, illustrates the spatial arrangement of major process equipment, pipe racks, and tie-in locations. This layout guided the routing of piping and utility systems while considering sufficient space for maintenance and equipment operation.

Complementing the plot plan, a 30% level AVEVA E3D 3D model was created to support spatial coordination and provide a visual representation of equipment placement and interconnecting piping. Snapshots from the 3D model, shown in Section 5.2.2. Figure 21 and Figure 22, highlight the positioning of major equipment and ductwork routes, including key interfaces such as the flue gas duct crossing over rail spurs and Wald Road.

The current level of detail provided by the plot plan and 3D model was sufficient to support the development of AACE Class 3 level cost estimates. While detailed equipment access provisions and maintenance clearances will be developed during detailed engineering, the current layout ensures adequate space for operator access, equipment installation, and future maintenance activities.

5.2.5 Capital Spares for Estimation

A Capital Spares list has been developed by KBR and is included in **Appendix C.2**. This list includes critical spare equipment, parts, components, or assemblies that are considered essential for ensuring the continuity of plant operations. These items have been included as a line item within the mechanical scope of the estimate.

Capital spares do not include commissioning spares or 2-year operational/maintenance spares. Instead, the list focuses solely on equipment and components that meet one or more of the following criteria:

- Complete warehouse spares (e.g., pumps, motors, valves) identified through reliability modeling, value engineering, or risk analysis, but not required to be installed
- Equipment expected to fail in a manner making repairs economically unattractive (i.e., repair costs exceed 50% of replacement cost)
- Proprietary equipment with limited or sole-source suppliers, or long lead times mandated by licensors or design complexity (e.g., compressor rotors)
- Customized or specially fabricated items requiring extended procurement or fabrication lead time
- Critical items for which no installed spares are provided.

This list was compiled using vendor input, prior project experience, and equipment-specific risk analysis. The final definition and procurement of capital spares will be refined during detailed engineering in consultation with vendors and the client.

5.3 Piping Engineering

The Piping Engineering discipline encompasses the detailed design, material selection, stress analysis, and constructability considerations for all process and utility piping within the carbon capture facility. This section summarizes the key piping deliverables developed during the FEED phase, providing an overview of the piping system layout, specifications, and engineering analyses. Supporting documentation and detailed design packages are provided in the associated appendices for reference.

The piping engineering scope for the carbon capture facility was developed to define the layout, material selection, flexibility, and constructability of process and utility piping systems for both ISBL and OSBL areas. Design development during the FEED phase adhered to applicable codes and standards (e.g., ASME B31.3), ensuring safe, operable, and maintainable systems that support long-term reliability.

A preliminary plot plan layout was developed to define the spatial arrangement of major process equipment, pipe racks, and tie-in locations. This guided the routing of piping systems and ensure adequate accessibility for operations and maintenance. The plot plan is provided in **Appendix C.1**.

The plot plan layout underlying the piping routing logic is shown in **Section 5.2.2,** Figure 20. For spatial context and visualization of duct routing, refer to Figures 12 and 13 in that same section. These views illustrate the flue gas duct paths to the Direct Contact Cooler (DCC) and over external interfaces, including the rail spurs and Wald Road.

A 30% 3D model of the facility was developed using AVEVA E3D. This model included major ISBL and OSBL equipment, primary piping routes, pipe racks, and structural elements. It supported early-stage spatial coordination, clash detection, and layout validation, and served as a visual reference for generating preliminary isometric drawings and conducting the stress analysis. The model will be further developed during detailed engineering phase to incorporate small-bore piping, secondary supports, and final equipment arrangements.

Piping material selection was based on service type, pressure/temperature conditions, corrosion allowances, and process fluid characteristics. An Index of Piping Material Classes and the corresponding Piping Materials Specifications Binder were prepared to define the design basis for each class and support consistent material selection across the facility.

To support procurement and detailed design, a consolidated Piping Line List was developed, identifying all process and utility lines included in the FEED scope. A Piping Specialty Items List was also compiled to document non-standard components such as strainers, hose stations, and expansion joints, which are critical for performance, safety, and maintainability.

A Preliminary Stress Analysis was performed for selected critical lines to evaluate thermal expansion, nozzle loads, and support requirements. The analysis was based on early routing and design conditions and informed initial layout and support strategies. Additionally, a Piping Tie-In List was developed to define the interface points between new systems and existing plant infrastructure. This list includes tie-in descriptions, service, size, and associated shutdown or coordination requirements., and is included in **Appendix D.1**.

KBR utilized the 3D model to extract piping quantities and generate isometric line counts for the FEED estimate, rather than developing formal isometric drawings at this stage. This model-based approach provided a comprehensive representation of the piping scope, suitable for quantity take-off and early material estimating, in line with the FEED design maturity.

5.4 Civil and Structural Engineering

5.4.1 Geotechnical Analysis

A geotechnical study was conducted to characterize the subsurface conditions at the proposed site for the CO_2 capture facility. The investigation included borehole drilling, soil sampling, laboratory testing, and groundwater level monitoring. The results provided essential data on soil bearing capacity, settlement potential, and foundation design parameters. This information was used to support the design of foundations for major process equipment, buildings, and pipe racks, as well as to inform site grading, drainage, and construction planning.

The geotechnical assessment and topographical survey were performed by Braun Intertec Corporation, an external engineering firm selected by Cemex**.** A 2D plot plan was provided by KBR. The proposed site for the CO_2 capture plant is located approximately 1600 feet west of the intersection of Wald Road and North Solms Road in New Braunfels, Texas. The site is bounded to the north by Wald Road and railroad tracks, to the east by an undeveloped area, to the south by North Solms Road followed by a ponded area, and to the west by the intersection of North Solms Road and Wald Road. The site is traversed by two natural gas pipelines along the south side of the site. The site appears to slope slightly from the southeast to the northwest. An aerial view of the site is shown in Figure 13.

Subsurface conditions were evaluated by drilling three (3) soil borings to a depth of 35 ft. Soil samples were collected at 2½-foot vertical intervals to a depth of about 10 feet, and at 5-foot intervals beyond this depth. Subsurface investigations revealed fat clay (CH) and lean clay (CL) soils extending to the termination depth of 35 feet across the site. Laboratory analysis indicates the clays are moderate to highly expansive, with potential for shrink-swell behavior due to changes in moisture content. As a result, removal of existing expansive soils and replacement with imported, non-expansive fill is recommended, particularly within proposed building pad areas. While native soils are not suitable as select fill, they exhibit good compaction characteristics and may be reused in non-structural areas, such as open spaces or, conditionally, pavement zones depending on their expansion potential.

Two soluble sulfate tests were conducted per Tex-145-E. The results indicate low sulfate concentrations, permitting the use of standard mix designs and construction methods without special sulfate mitigation.

Free water was not observed during or immediately after drilling. However, water conditions at the time of construction may vary due to rainfall, irrigation, drainage, and seasonal changes. Contractors should assess site-specific moisture and water conditions immediately prior to excavation and plan for appropriate water control measures as needed.

The Topographical Survey, conducted as part of the geotechnical investigations, is provided separately in **Appendix E.1**.

Photograph obtained from Google Earth™.

Figure 23: Plot area location for the Capture Plant

5.4.2 Stormwater Runoff Plan

The stormwater runoff plan has been developed based on site-specific conditions, including subsurface characteristics outlined in the geotechnical report. Due to the presence of expansive clay soils with limited infiltration capacity, the plan emphasizes surface drainage and controlled conveyance rather than infiltration systems. The runoff plan drawing illustrates the proposed drainage layout, including grading, swales, and stormwater collection points designed to manage runoff in compliance with applicable regulations. The stormwater runoff plan drawing is provided in **Appendix E.2**.

5.4.3 Spill Containment

The spill containment strategy summarizes the known effluent and effluent sources that will be connected to the drainage system during normal operations, maintenance operation and off-design (upset, start-up and shutdown) conditions. It also identifies the basis for tank bunds or dikes, including the equipment contained within them and their sizing criteria.

A number of effluent streams arise, and the function of drainage system is to handle these waste streams to satisfy the following objectives:

- Meet statutory and regulatory discharge requirement.
- Maintain segregation of hazardous and non-hazardous areas.
- Drain minor spills and limit the potential and extent of pool fires.
- Effectively remove fire water and storm water from plant areas.
- Prevent escalation of fire by minimizing drainage system interconnection.
- Contain and recycle, where practical, process drainage to minimize liquid effluent discharges.
- Safety- To protect personnel, plant, and equipment by preventing spillage release to environment.
- Environment- To minimize and/or to prevent direct discharge of environmentally hazardous streams to environment by directing these streams to appropriate treatment units.

5.4.3.1 Drainage System

A combination of closed and open drainage systems are considered to manage different effluent types.

1. Closed drains are used for hazardous materials like solvents and contact sewers, ensuring safe routing to treatment or disposal systems. Solvent systems feature a closed discharge to a Solvent Sump for isolation during maintenance, with recirculation back into the process system. Contact sewers handle process effluents like wash water, caustics, and acids, directing them to a Waste Water Treatment Plant (WWTP) for recycling or external discharge.
2. Open drains are utilized for non-hazardous effluents, such as stormwater from clean areas, allowing for straightforward inspection and maintenance.

5.4.3.2 Tank Secondary Containment

Additionally, secondary containment—including bunds or dikes around storage tanks and equipment—is provided to contain potential spills and prevent environmental release.

Four dikes are considered for this facility, one main dike for the ISBL equipment in amine solvent service and three minor dikes in the OSBL for the various chemical storage areas – Solvent trains, Caustic Storage area and Acid Storage areas.

Sizing for the tank dikes is based on the following requirements. These guidelines apply to both main and minor dikes.

- Containment is based on the sum of the following items:
    - Maximum tank volume in the dike
    - 25 year/24 hour rainfall (8.8 inches)
    - 6 inch freeboard
- Maximum wall height is set at 4 feet.

Material quantities and specifications are detailed separately in the **CSA Material Takeoffs (Appendix E.3)**.

5.5 Electrical Engineering

5.5.1 Electrical Engineering Studies Summary

The Electrical Engineering discipline for the project focused on developing system designs, and specifying equipment to meet the overall facility requirements. To support FEED cost estimation, the project team leveraged the 30% complete 3D model, to determine with some level of accuracy, the cable lengths and cable tray routings. This approach eliminated the need for fully developed traditional routing drawings at this stage, while still providing sufficient detail for material take-offs and layout validation.

A Hazardous Area Classification study was also performed as part of the electrical scope. Based on process safety considerations and material properties, only the Electrolyzer area was classified as hazardous, designated as Class I, Division 2. All other areas are deemed non-hazardous. This classification directly influences the selection of electrical equipment and installation methods within the designated zone. The Hazardous Area Classification drawing is provided in **Appendix F.1**.

The Electrical Load List, which outlines all connected and operating loads, is included in **Appendix F.2**. The Cable and Cable Tray Routing Drawings, extracted from the facility layout form the basis for cable length and tray quantity estimates used in the FEED cost model.

5.6 Instrumentation & Controls (I&C) Engineering

The primary objective of the I&C discipline is to establish a comprehensive control strategy for the CO_2 capture system at the Balcones Cement Plant. This framework is designed to ensure safe, efficient, and compliant operations throughout the entire process.

5.6.1 Control Narrative Framework

The control narrative outlines the principles and functionalities of the control systems implemented for the CO_2 capture process. Key elements include:

- **Distributed Control System (DCS):** The DCS is central to monitoring and managing various components, including the Direct Contact Cooler (DCC), absorption columns, and CO_2 compression systems.
- **Automated Dampers:** Flue gas flow to the CO_2 capture system is managed by automated dampers operated through the plant's basic process control system (BPCS). Real-time communication between the BPCS and the CO_2 capture control system allows coordinated operation between the existing kiln/plant controls and the new capture system.
- **Critical Measurements:** Key process parameters such as flue gas supply inlet pressure (PI-01004, PI-01037), DCC inlet temperature (TI-01005), and SO2 levels (AI-01008) are continuously monitored to ensure operational integrity.

5.6.2 Detailed Instrumentation Overview

1. Flue Gas Pre-Treatment: Incorporates automated dampers and a suite of instruments for monitoring temperature, pressure, and flow rates, ensuring accurate process control.
2. Direct Contact Cooler (DCC): Monitors inlet pressure, temperature, and flue gas composition, with built-in safety interlocks that can shut down dampers under high-pressure conditions.

3. Absorption Units: Absorption columns feature differential pressure measurements (PDI-01040) and level indicators (LI-01046) to maintain efficient solvent flow and CO_2 absorption. Safety alarms trigger automatic shutdowns as needed.
4. CO_2 Compression and Polishing: The CO_2 compressor package (K-0211) interfaces with the DCS, monitoring both outlet pressure and temperature while providing immediate alarm alerts for abnormal conditions.
5. Additional Support Systems: Utility systems facilitate service feeds (water and air) with regulated controls, while Safety Instrumented Systems (SIS) ensure emergency shutdowns are executed based on predefined criteria to uphold safety.

The control narrative specifies hardwired signals for critical commands and feedback between the CO_2 capture system and Cemex's existing BPCS, enhancing the system's reliability. Future phases of engineering will refine the control strategies to incorporate improvements based on operational experiences, including the implementation of advanced control algorithms and predictive maintenance tools.

5.7 Fire Protection Engineering

5.7.1 Fire Protection Summary

The Fire assessment has been updated since the completion of the FEED study, due to the updated information regarding the solvent.

No water-spray or water-based fire protection system is expected to be required as primary means of firefighting for this facility however, fire hydrants have been proposed from a risk-based approach (based on the early understanding of this project) and are therefore included as an option for those cases where their installation if preferred.

5.7.2 Fire Hazard Assessment

An internal coarse fire hazard assessment was conducted with the objective of identifying the potential fire scenarios likely to occur in this facility. This is a desktop exercise performed by a process safety engineer using a qualitative approach. There is no risk ranking and safeguards identified for each of the hazards

Table 12 presents the coarse fire hazard assessment.

Table 12:Fire Hazard Assessment

No	Hazard	Cause	Consequence	Remarks
1	Fuel gas / natural gas used as fuel for the steam generation package	Leakage / loss of containment	Potential fire/explosion if ignited	Risk for this event is very low given the low leak frequency (estimated to be less than $1x10^{-3}$ per year)
2	Electrically powered equipment in facilities	Electrical fault	Fire	Localized fire Source: Central Control Room (CCR), pumps, skids (energized equipment)
3	Rotating equipment in operation (e.g., pump)	Pump overheat due to poor maintenance	Fire	Localized fire
4	Combustible materials used for building/ equipment construction (e.g., CCR)	Catch fire when exposed to heat source	Fire	Localized fire

Overall, all scenarios presented in Table 12 will likely lead to localized incidents only. There will be no pool fire scenario considering no potential release of flammable liquid is expected. The possibility of fire escalation between equipment is also expected to be minimum given that:

1) Most of the structures and equipment are made of non-combustible material (i.e., concrete and steel).
2) Limited presence of flammable fluids (i.e., fuel gas), which are only at the steam generation package (with small capacity and limited equipment involved).

Accordingly, the usage of portable fire extinguishers as primary means of firefighting is proposed to address the localized fire scenarios mainly from Class A, B and C.

5.7.3 Firefighting System And Equipment

5.7.3.1 Portable Dry Chemical Fire Extinguisher

For a typical NAS facility, the multipurpose ABC dry chemical (ammonium phosphate) portable fire extinguishers with the capacity of 9kg are provided at the open process area and inside the central control room (CCR). The provision is based on the prescriptive requirements stated in NFPA 10, as per the following summary:

1) Considering the Class-B fire as the base case in the open process area, the travel distance to reach portable extinguishers at the open process area is taken as 50ft (15m) from hazards. This is complying with the recommended travel distance for 80-B rating, considering the "Extra" hazard present in this facility (as per Table 6.3.1.1 of NFPA 10).
2) The minimum capacity for 80-B:C rating of ABC dry chemical (ammonium phosphate) is 7.7kg (Table H.2 of NFPA 10). However, current provision capacity is 9kg, hence this is more than the minimum requirement.
3) One (1) no. also is provided inside the CCR as to extinguish potential Class A fires (paper, rubber and plastics).

5.7.3.2 Portable Carbon Dioxide (CO2) Fire Extinguisher

The provision of CO_2 portable extinguisher is based on the prescriptive requirement stated in NFPA 10. Considering the electrical fire hazard (Class C) presents in the Central Control Room (CCR), 1 no. of portable CO_2 extinguisher is provided with the capacity of 5kg. Considering the type of hazard presents in the CCR, the hazard will be classified as "Ordinary" given the size, numbers of energized equipment and occupancy. The "Ordinary" will fall under 10-B:C rating, hence the minimum capacity required is 4.5kg. The current provision capacity meets the minimum requirements.

5.7.3.3 Fire Hydrant (Optional)

The provision of fire hydrants is meant for secondary firefighting in which it will be utilized by trained plant first intervention team / fire brigades / fire departments personnel as firefighting support. The intention is mainly to prevent fire escalation beyond the facility limits that could impact nearby facilities and the public.

The fire hydrants, if installed, shall be compatible with the equipment specified for use by plant first intervention team or fire brigades / fire departments (local authority fire response groups). In this perspective, it should be designed in accordance with the code used/applied by the local authorities/fire marshal.

A redundant underground fire water loop with HDPE piping and sectional valves supports an 800,000-gallon fire water tank and dual pumps (electric and diesel), ensuring reliable fire suppression capability. Hydrants are spaced strategically throughout the site, supplemented by elevated and hydrant-mounted monitors delivering targeted spray coverage.

Sprinkler protection is planned primarily for the laboratory building, with wheeled Purple K fire extinguishers distributed across process areas. Fireproofing is deemed unnecessary at this stage due to the low risk of pool or jet fires.

Detection and alarm systems include CO_2 and H_2 gas detectors interfaced with the DCS, a comprehensive fire alarm system with building-specific panels and emergency communication capabilities, and a recommended VESDA system for early smoke detection in electrical and control buildings.

Design compliance aligns with IFC 2021, applicable NFPA standards, and relevant API guidelines.

5.8 Constructability

5.8.1 Constructability VIP Summary

KBR selected the Value Improving Practice (VIP) of Constructability as applied to major projects, promulgated by the Construction Industry Institute, to conduct a project constructability review. Pinnacle Results, LLC was hired to facilitate this review.

The Constructability VIP workshop, held on May 9–10, 2024, at the Cemex Office in New Braunfels, Texas, included an assessment, development, and implementation of value-improving items and potential design and execution decisions for the next stage of the project.

The objectives of the Constructability VIP exercises were:

- Provide logical, systematic methods for integrating construction practices into the project.
- Match design intentions with effective construction practices during the FEED study.
- Understand major construction methods suitable for the project.
- Identify various site construction layout options.
- Improve the construction schedule through efficient methodologies.
- Examine alternative logistical solutions at the proposed site.
- Identify sources of materials and equipment for construction.

The following project specific information was available to the participants prior to the workshop to familiarize themselves with the project scope:

- Technical Basis of Design
- Plot Plan
- Equipment Lists
- Process Flow Diagrams

Workshop participants were chosen based on their expertise, ability to lead innovative thinking, and relevant project roles.

Name	**Company & Position**
John Hughes (Remote)	KBR, Sr. Project Manager
David Barbee	KBR, Lead Process Engineer
John Pustay	KBR, Mechanical Department Manager
Abel Vera (day 1, Remote day 2)	KBR, Principal Project Manager
Nikki Wagner (Remote)	KBR, Sr. Mechanical Engineer
Vijay Gupta (day 1)	RTI, Research Chemical Engineer

Paul Mobley (Remote)	RTI, Research Chemical Engineer
Jak Tanthana (Remote 1st day)	RTI, Project Officer
Abigail Mshelbwala	SLB, Project Manager
Karuna Ganti	SLB, Project Engineering Manager
Shailesh Mistry	SLB, Principal Engineer
Scott Murray	SLB, Project Manager
Lucia Renau	Cemex, CCUS Project Developer
Edmo Gutierrez (day 1 part-time)	Cemex, CO_2 Technologies and Digital Projects
Kevin Happ	Cemex, Project Manager Sr
Elizabeth Torres	Cemex, CCUS Project Manager
Christian Valverde	Cemex, Balcones Sr. Project Manager
Jonthan Hill	Cemex, Balcones Project Manager
Fatma Sahin	Cemex, CCUS Innovation Advisor
Kevin Leodinh	DOE, Demonstrations Project Officer
John-timothy Anyanwu	DOE
James McCuish	Pinnacle Results LLC
Charles Jennings	Pinnacle Results LLC

The workshop focused on the following priorities:

- Construction Access
- Laydown Areas
- Construction Work Sequencing

Other considerations included General Design, Site Improvements, Underground Utilities, Civil, Fireproofing, Architectural & Equipment, Piping, Electrical, Instrumentation, Steam Tracing & Paint, Insulation, Structural Steel, and Cemex Constructability Key Activities.

5.8.2 Constructability Review Summary.

The proposed location for the CO_2 capture plant is a 15-acre greenfield plot south of the New Braunfels facility. Additional Cemex property to the south and west is available for potential laydown areas.

5.8.2.1 General

During the constructability review, several design/construction challenges were considered with their impacts to construction access, laydown areas, and construction sequencing. These design challenges were grouped into two categories: those due to site conditions or requirements, and those due to equipment size. Recommendations from the constructability are summarized below.

5.8.2.2 Design Challenges Due to Site Conditions

Cooling Water Constraints: Due to limited make-up water availability at the New Braunfels facility, cooling water studies were conducted to determine the appropriate utility configuration for process cooling. The cooling system optimization study resulted in utilizing air coolers, with 146 bays of cooling, and an estimated total plot area of approximately 4 acres of the total 15-acre facility plot plan (not including retention pond or laydown areas).

- Potential Constructability Impacts: ACCESS, LAYDOWN and SEQUENCING

High Water Table: Cemex advised during the constructability review that the proposed plot area has a high-water table of 7 feet. The project team agreed to minimize underground services to the maximum extent possible and only consider items such as equipment drains and grey water services. A high-water table could also potentially require an engineered drainage system, such as a well point system. This system may require a collection pond.

- Potential Constructability Impacts: LAYDOWN and SEQUENCING

Carbon Capture Plant Located Off-Site: Due to the limited available area at the existing Cemex plant for the carbon capture plant, the CC plant is remotely sited across Wald Road. This requires routing a large 10 ft x 10 ft cross sectional flue gas duct approximately 1,500 feet, across the road, to the DCC/absorber columns.

- Potential Constructability Impacts: LAYDOWN and SEQUENCING

MSHA vs. OSHA Regulations: The Cemex New Braunfels site falls under the jurisdiction of the Mine Safety and Health Administration (MSHA). The Project Team acknowledged there could be considerable differences between MSHA and OSHA regulations which may impact design, construction, commissioning, and eventual operations of the CC plant. MSHA or OSHA jurisdiction will need to be investigated and established to ensure design and construction safety implications are clearly understood by the detail design and construction stakeholders.

- Potential Constructability Impacts: SAFETY

5.8.2.3 Design Challenges Due to Equipment Size

Absorber Column:

The field erection strategy including laydown and sequencing would require careful planning and execution as the absorber column is closely located with other critical processing equipment. The field fabrication of the Absorber Column must be supported by a detailed construction schedule. The erection strategy must consider the long-term impact on the rest of the project.

- Potential Constructability Impacts: LAYDOWN and SEQUENCING

Packaged Boilers: Steam demand can be met with (2) 50% packaged boiler however, this size is at the upper end of the boiler supplier's packaged boiler design capacity, each 25.5 ft H x 22.3 W x 52 ft L. Each boiler weighs approximately 150 tons. The logistics study finds this size boiler is not truckable and therefore, smaller size boilers in a (3) x 33% configuration will have to be investigated. Cost impacts based upon previous studies are close between these two boiler configurations.

- Potential Constructability Impacts: ACCESS

Interchanger HX Units: HXs are required between the absorber column and regenerator. The HXs banks are in a section of the facility that facilitates construction access and laydown. Stacking of the plate and frame HXs was considered by the project team but determined to present concerns with maintenance access during the cleaning of the HX plates and subsequent draining of wastes and cleaning solvents in the structure.

- Potential Constructability Impacts: ACCESS, LAYDOWN and SEQUENCING

Stripper Column: The Stripper column due to its diameter is being evaluated for both shop fabrication and field erection execution strategy. A final decision on stripper column fabrication strategy will need to be made once logistics study is conducted.

- Potential Constructability Impacts: ACCESS, LAYDOWN and SEQUENCING

5.8.2.4 Construction Access

Logistics Study: Carbon Capture necessitates deployment of large equipment along with large pre-assembled units to drive a cost-effective solution. The logistics study will eventually be needed to determine the limitations for truckable modules and pre-assembles units (PAUs). There is no waterway access for barge shipment of units. Logistics study should be from point of origin to site (Logistics study establishes shipping envelope and also determines best method for shipment of heavy haul items).

Based upon discussions with some local fabrication shops in Texas, the equipment selected (as described above in the GENERAL section) should be truckable to the New Braunfels site. However, this needs to be validated by the logistics study.

Overhead Power Lines: Overhead high voltage 138kv power lines, bisecting the plant East-West, must be managed. Preliminary discussions with the local utility suggest raising the HV power lines and power and communication lines on Wald Road can be handled to accommodate transportation of equipment to site.

Rail Shipments: Cemex New Braunfels site has existing rail for feed and product loadout. Cemex mentioned this rail may have limitations regarding size and especially width of cargo. This aspect of rail limitations should be addressed in the logistics study to confirm load/sizing limitations, if any.

Access to Potential Laydown Area on Existing Cemex Plant: The East area of the Cemex property is a potential laydown area, however, access to the area is sometimes blocked due to loading and staging of rail cars. Develop strategic transport plans for trucks to enter site during off-peak (if possible) and consider all alternate routes.

South Plot Access: The plot plan area South of Wald Road can get saturated and can cause vehicles / trucks to get stuck. Consider all routes and have a fallback plan to remove vehicles from mud if necessary.

5.8.2.5 Laydown Areas

Constraints: The plot area as currently envisioned does not provide what may be considered the “ideal” laydown space (relative to a “factor” of total plot area). Considering the large area of the air coolers and utilizing some of the corners of adjacent facility designated space; the strategy of ‘just-in-time’ deliveries was considered one key approach to maintain maximum laydown areas during peak construction activities.

The following equipment was identified as candidates for ‘just-in-time’ delivery.

- Air coolers
- Flue Gas duct sections
- Tray and packing installation and storage

Temporary Construction Facilities: Laydown areas shall also consider temporary construction facilities, which could be up to 2.0 times the total build area, depending on the project. This is to allow for the following temporary facilities need to support construction:

- CM Office, Supervisor's offices, Safety facility, Quality office, Permit office, Warehouse (including Warehousing of temperature control sensitive equipment), Welfare tents (Break tents), Area for stockpiling re-usable and non-reusable soil

5.8.2.6 Sequencing of Construction

Lifting Plans: The development of lifting plans/procedures should be completed early. Due to the constraints mentioned above, this will be critical to orchestrate crane usage, costs, and safety.

Sequencing of Equipment: Development of proper sequencing of key equipment deliveries and installation such as Absorber Column, DCC, Boilers, Air coolers. The optimum path of construction and schedule will need to reflect a staging of key erection and lift and setting plans for the critical pieces of equipment identified earlier.

Engage an EPC for final path of construction and develop appropriate Advanced Work Packages (AWP). The following can be packaged by the project EP team:

EWP – Engineering work package
PWP – Procurement work package
CWP – Construction work package
IWP – Installation work package (The IWP process is typically a function of the construction execution contractor)

Tie-in Sequencing of Cement Pyro Process: Develop the sequence for shutdown / cooldown of the cement pyro process system for tie-in of CC Plant equipment. Tie-ins must be planned during schedule outages. Ensure PHA review addresses tie-in logic and cut over in design.

Consider a complete field survey of each tie-in point, irrespective of discipline. Then provide a tie-in package for each tie-in which can include a location drawing, P&ID, data sheets, photographs and description and purpose of the tie-in.

Tie-in Sequencing of Electric Power Sources: Investigate electric power sources and eventual tie-ins. In support of commissioning activities, identify power sources and early tie-in strategy if needed. It is recommended to consider whether alternative power sources are needed.

Construction Sequencing Path: The path should set up at a minimum the following objectives:

- A construction execution schedule
- High level Construction Organization
- HSSE Strategy
- QA Strategy
- QC Strategy
- Path of construction (Plot plan, CWA)
- HHR and HHL Plans
- TCF Layout and work sequence
- HSSE
- Logistics (project freight)
- Logistics strategy (Local to plant traffic/workers)
- HHL/HHL Strategy

The complete Constructability Review Summary is provided in **Appendix G.1**.

6 Project Schedule

6.1 Schedule Overview

As part of the Front-End Engineering Design (FEED) phase, KBR developed a Level 2 EPC schedule to provide a high-level view of engineering, procurement, construction, and commissioning activities. This schedule outlines key project phases, interfaces, and milestones, and supports alignment between design and execution planning. It serves as a strategic tool for scope definition, constructability planning, and development of the AACE Class 3 cost estimate.

While not fully exhaustive, the schedule is based on available FEED deliverables, current project definition, and multi-discipline input. It offers mid-level detail suitable for constructability reviews, risk identification, and initial execution strategy. This Level 2 schedule will be further developed into a detailed Level 3 schedule post-award to support project controls, progress tracking, and execution planning.

The project is assumed to commence with contract signing and a kickoff meeting (Month 0), followed by mobilization of the project team within 10 working days with an estimated duration of 24 months.

Construction is planned to begin 8 months after detailed engineering starts and will run for 24 months, overlapping with design by approximately 16 months. A 3-month commissioning phase will follow, resulting in a total project duration of approximately 36 months. The Level 1 schedule is shown in Figure 24.

Milestone description	Category	No.of Months	Month Number
Project development			
Overall Project	WBS Summary	36	
Contract Signing and Kick off meeting	Milestone		1
Project Complete	Milestone		36
Engineering	WBS Summary	24	
HAZOP Review	Milestone		8
Complete 30% Model Review	Milestone		9
Complete early IFC Packages	Milestone		15
Complete 60% Model Review	Milestone		17
Complete 90% Model Review	Milestone		21
Issue all IFC Drawings and Documents	Milestone		23
Engineering Complete	Milestone		24
Procurement	WBS Summary	24	
Place PO for Major Equipment	Milestone		13
Last Delivery of All Bulks)	Milestone		29
Last Delivery of Mechanical Items	Milestone		29
Construction	WBS Summary	29	
Commence Site Preparation Works	Milestone		8
Underground Works complete	Milestone		19
First Concrete Pouring	Milestone		20
Primary Structural Steel Erection Complete	Milestone		30
Major Equipment Erection Complete	Milestone		32
Substation Erection	Milestone		34
Mechanically Complete	Milestone		35
Commissioning Complete and Project ready for startup	Milestone		36

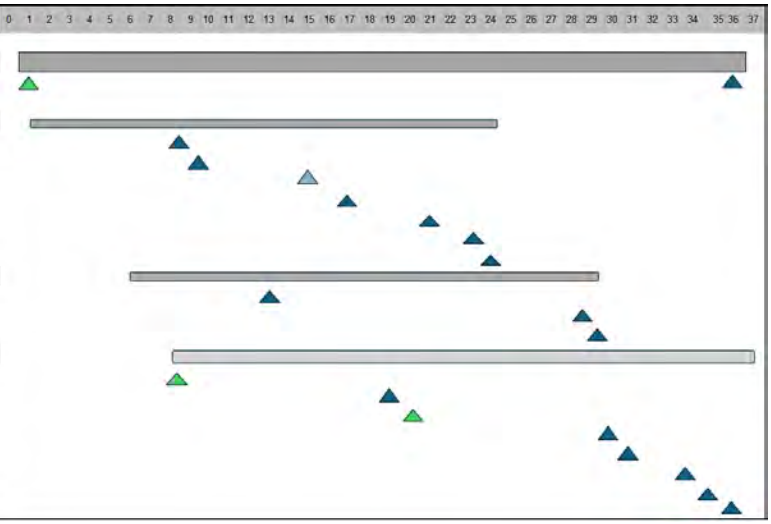


Figure 24: Level 1 Schedule for the RTI NAS CO_2 Capture Project

6.2 Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) decomposes the project scope into manageable sections to support planning, scheduling, and control. The WBS below reflects the current FEED phase understanding and is developed to Level 2. It will be further refined during the EPC phase.

Level 1	Level 2
Project Milestones	Overall Milestones
	Engineering Milestones
	Procurement Milestones
	Construction Milestones
Engineering	Project Engineering
	Process
	Mechanical
	Piping
	Civil
	Electrical
	Instrumentation
Procurement	Mechanical Equipment Ordering
	Electrical Equipment Ordering
	Instrumentation Equipment Ordering
	Piping Ordering
	Post award and Manufacturing
Construction	Early Works
	Underground works
	Above ground works
	Flue Gas Run
	Commissioning and startup

6.3 Key Milestones

A summary of key project milestones, based on the Level 2 EPC schedule, is presented below. These milestones reflect major phase transitions, critical engineering and procurement events, and key construction and commissioning targets. The timeline is expressed in approximate months from the official project start date (defined as the Contract Signing and Kickoff Meeting at Month 0). A complete list of milestones, organized by Work Breakdown Structure (WBS), is provided in **Appendix H.1** for detailed reference.

Table 13: Summary of Key Project Milestones (Months from Project Start)

Milestone	Months from Start	Notes
Contract Signing and Kickoff Meeting	0	Official project start
HAZOP Review	8	Critical safety and design review
Complete 30% Model Review	9	Early design checkpoint
Complete 60% Model Review	17	Mid-design progress milestone
Complete 90% Model Review	21	Near-final design submission

Milestone	Months from Start	Notes
Issue All IFC Drawings and Documents	23	Issuance of construction-ready documents
Engineering Complete	24	Completion of engineering phase
Place PO for Major Equipment	13	Long-lead procurement start
Commence Site Preparation Works	8	Start of construction activities
Underground Works Complete	19	Completion of early-stage construction
Primary Structural Steel Erection Complete	30	Major structural construction milestone
Mechanically Complete	35	End of major construction scope
Commissioning Complete / Project Ready for Startup	36	Completion of all commissioning activities
Project Complete	36	Formal completion and handover

Milestones are aligned with the Level 2 schedule and are subject to refinement during EPC planning.

6.4 Engineering Schedule Assumptions

The engineering schedule and associated milestones have been developed based on the following key assumptions, reflecting the current FEED deliverables and typical project execution strategy:

- The project includes structured 30%, 60%, and 90% model development stages, all of which are considered critical milestones in the schedule.
- Each model review is planned as a five-day joint review involving the client and the contractor.
- Piping, Civil, Electrical, and Instrumentation teams will actively participate in all model reviews to ensure cross-discipline coordination.
- Material Take-Offs (MTOs) will be extracted in alignment with model development stages:
    - Preliminary MTOs will be generated upon completion of the 30% model.
    - Final MTOs will be issued following the 90% model completion.
- The schedule reflects separate MTO activities and procurement cycles for Civil, Piping, Electrical, and Instrumentation disciplines.
- The HAZOP review is planned as a five-day workshop, commencing after the issuance of P&IDs for HAZOP. P&IDs will be updated post-HAZOP before progressing to detailed design.
- Critical vendor data, including general arrangement drawings, equipment dimensions, and essential technical information, is assumed to be available in time to support the 60% model development.
- Upon approval of critical vendor documents, equipment manufacturing activities are expected to commence.

These assumptions are aligned with the Level 2 EPC schedule and will be further refined during the development of the detailed Level 3 schedule in the EPC phase.

Refer to **Appendix H.1** for the detailed EPC schedule.

6.5 Procurement Schedule and Assumptions

The procurement life cycle for major equipment and packages follows a standard sequence, as illustrated in Figure 25.

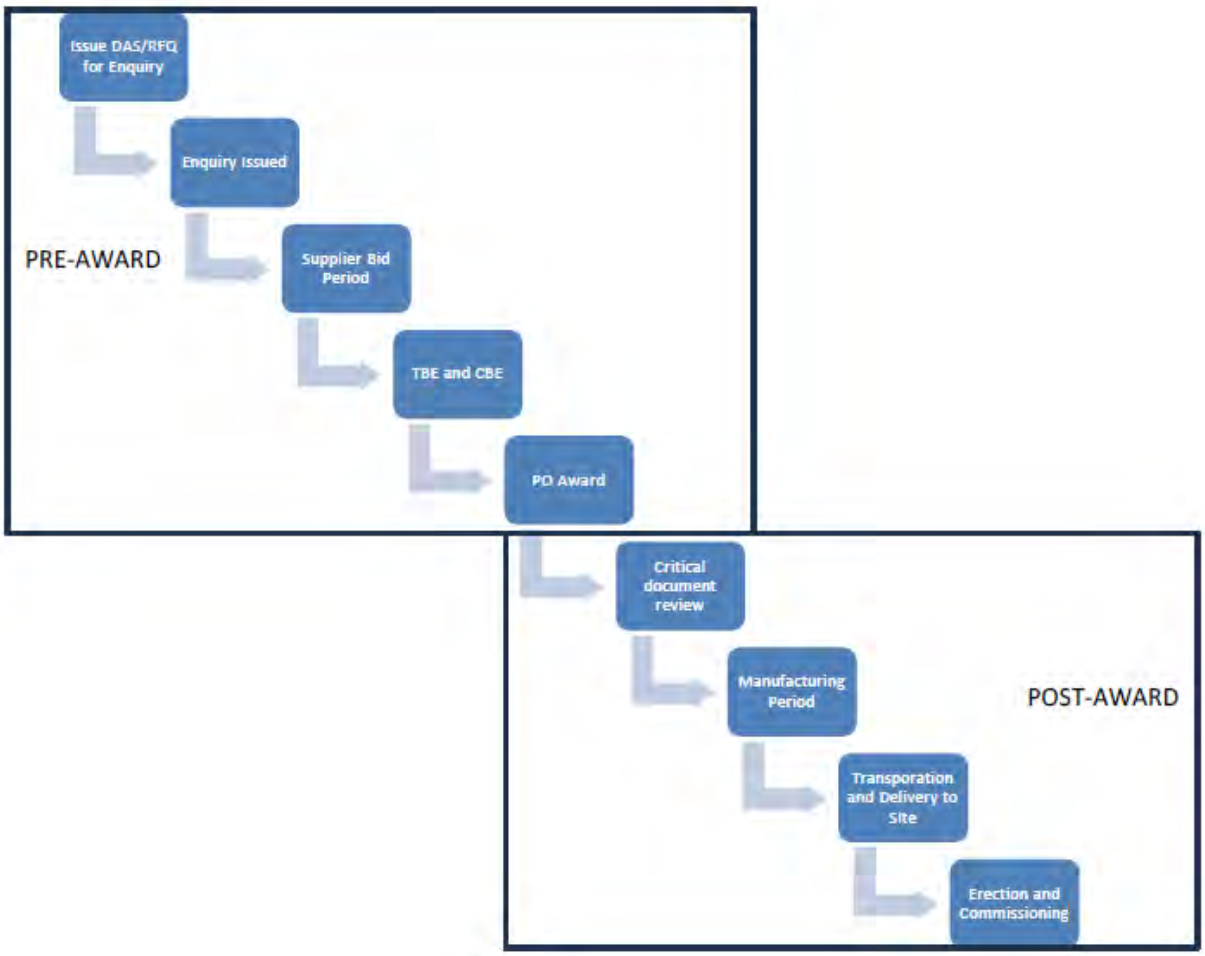


Figure 25: Procurement Lifecycle Overview

This section outlines the assumptions used to develop the procurement schedule for major equipment and packages associated with the Balcones CO_2 Capture Project. The timeline includes typical durations for requisition preparation, vendor engagement, evaluation, purchase order issuance, vendor data submission, manufacturing, and delivery to site.

6.5.1 General Procurement Timeline Assumptions

Activity	**Duration (weeks)**
Preparation of Requisition / Datasheet for Enquiry	4
Issue of Enquiry to Vendors	1
Supplier Bid Period	6
Technical and Commercial Bid Evaluation	8
Purchase Order (PO) Award	2
Critical Vendor Data Submission and Review	Up to 12
Transportation to Site	8–9

6.5.2 Equipment Manufacturing Lead Times

The manufacturing durations for key equipment and systems have been estimated based on market survey data, historical procurement records, and vendor discussions. Lead times for electrical and instrumentation components have been estimated based on historical project data. While these items generally have shorter manufacturing durations compared to mechanical equipment, some critical control and power components may have longer procurement cycles depending on vendor availability and project-specific customizations.

A detailed EPC schedule is provided in **Appendix H.1,** which includes the Level 1 schedule, the Level 2 schedule, and a Level 2 schedule with the critical path identified. It also contains discipline-wise equipment lead times for both ISBL and OSBL systems.

6.6 Construction Assumptions

This section outlines key assumptions used in developing the construction phase of the project schedule. Construction activities are broken down into distinct phases and are expected to commence approximately **8 months after contract award**, contingent on availability of sufficient IFC deliverables following the 30% model review.

Construction Work Breakdown Structure (WBS)

Construction activities are organized into the following major categories:

- Early Works
- Underground Works
- Above Ground Works
- Flue Gas Run
- Commissioning and Start-Up

Early Works

Early works include all initial site activities necessary to prepare for main construction. These are assumed to begin 8 months post-contract award and include:

- Contractor mobilization
- Site clearance (as required)
- Installation of temporary site facilities
- Site survey, expansive soil removal, filling, and compaction

Early IFC drawings are assumed to be available following the 30% model review, enabling start of these activities.

Underground Works

Following completion of underground works, above-ground activities begin and continue through mechanical completion. Underground works refer to all construction below grade, including but not limited to:

- Excavation
- Installation of underground tanks
- Firewater ring mains and collection heads
- Backfilling and compaction

Above Ground Works

Above ground works encompass the bulk of civil, structural, mechanical, piping, electrical, and instrumentation activities, summarized as follows:

Foundations and Civil Works

- Foundations for pipe racks, main equipment, and pre-engineered buildings
- Paving and road construction (executed in parallel with commissioning phase)

Structural Steel

- Primary steel: Main structural supports for major equipment
- Secondary steel: Ancillary steel structures and supports

Equipment Erection

- Direct erection of major equipment upon delivery to site
- Absorber and Direct Contact Cooler erection (~10 months duration)
- Air Coolers to be erected in batches, beginning upon first delivery

Piping Works

- Piping prefabrication
- Pipe and flange erection
- Hydrotesting

Electrical and Instrumentation (E&I) Works

- Substation erection and power cable installation
- DCS equipment erection
- Cable tray installation, cable pulling, glanding, and termination
- Instrumentation erection

Finish Works

- Insulation of instruments, equipment, and pipework
- Final painting of pipework, equipment, and pipe racks

Flue Gas Run

This is a dedicated scope section for ductwork connecting to the existing cement plant. Activities include:

- Excavation and foundation for duct supports
- Backfilling and compaction
- Erection of support racks
- Installation of associated ductwork

6.7 Commissioning and Start-Up

Commissioning is the process of verifying that all systems and components are designed, installed, tested, and operated in accordance with the owner's requirements and the design intent. It is a critical phase prior to start-up, ensuring that the facility is safe, functional, and ready to process raw materials.

Commissioning activities will commence following the completion of all mechanical, electrical, and instrumentation erection. This phase includes:

- Equipment site testing (no-load and load testing)
- Instrument loop checks
- Verification of control logic and interlocks
- System-level functional testing

A total duration of 3 months is allocated for commissioning and start-up in the project schedule.

6.8 Schedule Risks and Constraints

A formal schedule risk analysis has not yet been performed; however, key constraints have been identified based on current FEED-level information. These include timely completion of model reviews, availability of critical vendor data to support design progression, and the sequencing of engineering deliverables to enable early procurement and construction activities. These factors will be further evaluated and integrated into the detailed Level 3 EPC schedule post-award, where quantitative schedule risk analysis (QSRA) may also be performed.

6.9 Construction Execution Plan

A standalone Construction Execution Plan (CEP) has been prepared as part of the FEED deliverables and is provided in **Appendix H.2**. This document outlines the planned construction strategy, key execution milestones, construction labor plan, site logistics, temporary facilities, and quality, safety, and environmental controls.

The CEP supports the development of the Level 2 EPC schedule by defining construction sequencing, key interfaces, and execution constraints. It also includes input into schedule durations for early works, underground and above-ground construction, and commissioning readiness.

This plan will be further refined during the EPC phase and aligned with the detailed Level 3 schedule and contractor execution plans.

7 Project Cost Estimate

7.1 Introduction

The estimate covers the RTI NAS Carbon Capture Plant intended for integration with the Balcones cement plant for 95% CO_2 capture. The estimate has been prepared in alignment with AACE International's Recommended Practices (18R-97) as a Class 3 estimate, targeting a level of accuracy of +15%/-15%. This estimate was developed during FEED phase and employs the Aspen Capital Cost Estimator (ACCE V14.2). The total project cost reflects U.S. dollars with a fourth-quarter 2024 cost basis and includes escalation factors leading to a projected start date of Q1 2026. Indirect, owner-specific, and construction expenditures were carefully accounted for in this evaluation. Key exclusions and assumptions are detailed in the full Basis of Estimate (BOE) included as an appendix.

This report summarizes the estimate's purpose, methodology, cost breakdown, and assumptions, enabling stakeholders to assess the project's financial viability and risk exposure.

The estimate reflects a stick-built project execution model with a non-modular approach and assumes construction will be performed under an Engineering, Procurement, and Construction Management (EPCM) model.

7.2 Basis of Estimate (Summary)

The full Basis of Estimate document is provided in the **Appendix I.1**. Key elements of the BOE are summarized below:

7.2.1 Estimation Tools and Methodology:

Estimates were generated using the Aspen Capital Cost Estimator (ACCE V14.2) with data inputs sourced from engineering deliverables (e.g., MTOs, equipment lists, P&IDs), vendor quotes, and historical EPC data. The ACCE tool provided field labor hours and material estimates adjusted for regional cost conditions near San Antonio, Texas.

7.2.2 Currency and Units of Measure:

The estimate is presented in U.S. Dollars, calculated using Imperial units of measurement.

7.2.3 Project Work Breakdown Structure (WBS):

Costs were organized by system and discipline, as follows:

Unit 01: CO_2 Capture System
Unit 02: CO_2 Compression, Dehydration, and Polishing
Unit 03: Utility Systems which comprises of:

- Unit 11 – Raw, Potable, and Demineralized Water System
- Unit 12 – Boiler & Steam System
- Unit 14 – Solvent & Chemical Storage Utilities
- Unit 15 – Cooling Water System
- Unit 16 – Air / Nitrogen System
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack

- Unit 22 – Utility Headers
- Unit 23 – Power Generation

7.2.4 Construction Execution Basis:

The project is planned as a stick-built construction using a single mobilization strategy. Construction activities will follow a five-day workweek, comprising 40 hours of regular time and 10 hours of overtime paid at a 50% premium. Labor costs are based on local labor surveys, which were used to determine an "All-In Wage Rate" (AIWR) of $105.80 per hour. This rate includes labor wages, fringe benefits, equipment usage, temporary facilities, and contractor overhead.

7.2.5 Cost Basis and Escalation:

The cost baseline reflects Q4 2024 values. Forward escalation rates of up to 7.5% were applied to labor, materials, and equipment to reflect projected costs at midpoint construction (Q4 2027).

7.2.6 Key Assumptions and Constraints

The project assumes adequate space within the site; however, workspace constraints (e.g., working around large absorbers and regenerators) were identified and addressed with productivity adjustments. External risks, such as global pandemics or extreme weather events, were not included as they are considered force majeure events.

7.2.7 Labor Productivity Factors:

Modest inefficiency adjustments were applied to reflect the labor market, skill availability, and site-specific conditions (e.g., rigging requirements, on-site fabrication). Overall labor efficiency was determined to be 70% compared to a baseline project.

Refer to the BOE appendix for additional details regarding excluded costs, engineering deliverables, execution strategies, and owner-provided estimates.

7.3 Material Take-Offs (MTOs)

The following summarizes the material quantities used to develop the project cost estimate. These quantities were derived from discipline-level material take-offs (MTOs), preliminary design documents, and vendor data available at the time of the estimate. Key materials include structural steel, piping (aboveground and underground), electrical cable, instrumentation devices, concrete, and other civil and mechanical components. Quantities were validated through available 3D model progress, line lists, and equipment datasheets, ensuring alignment with the current level of engineering definition. These material quantities form the basis for calculating bulk material costs and associated installation labor, and they directly inform the development of the Total Installed Cost (TIC).

The following summarizes the material quantities used to develop the project cost estimate:

Table 14: Key Quantities by Account

Account	Key Qty	Key Units

Equipment	185.0	item(s)
AG Pipe	76,387.2	feet
UG Pipe	19,755.0	feet
Concrete	29,234.6	cy
Earthwork	12.0	lump sum
Other Civil	2.0	lump sum
Other Sitework	5.0	lump sum
Paving	563.7	cy
Piling	623.0	each
Roads / Railroad	9.0	lump sum
Steel	2,819.7	tons
Instrumentation	590.0	each
AG Electrical	324,811.1	feet
UG Electrical	30,061.0	feet
Equipment Insulation	31,910.3	sf
Pipe Insulation	28,238.7	feet
Paint	88,382.0	sf

7.3.1 Aboveground Piping Quantities

The aboveground piping scope comprises approximately 76,400 feet of piping and has been analyzed across multiple dimensions: bore size, installation method, fabrication location, and material type. These quantities were developed based on preliminary 3D model data, discipline-level material take-offs, and vendor inputs. The following tables and observations summarize the key drivers that informed the bulk material costs and associated installation labor in the Total Installed Cost (TIC) estimate.

Table 15: Piping by Bore Size

Category	Length (ft)	% of Total	Avg Diameter (in)
Large Bore	65,914	86.3%	18
Small Bore	10,473	13.7%	*1.5*
Total	**76,387**	**100%**	—

Large bore piping represents 86.3% of the total aboveground piping by length and contributes heavily to the total volume due to its larger average diameter (17.51 inches).

Table 16: Piping Installation Method

Method	Length (ft)	% of Total
Spool Erection	35,757	53.1%
Straight Run	31,579	46.9%
Total	**67,336**	**100%**

Spool and straight-run installations are nearly equally distributed, with spool erection accounting for 53.1% of total installation length. This reflects a construction strategy that balances preassembly and in-field installation.

Table 17: Fabrication Method

Method	Length (ft)	% of Total
Field Fabrication	41,140	52.8%
Remote Shop Fabrication	36,797	47.2%
Total	**77,937**	**100%**

Field fabrication constitutes a slightly greater share (52.8%) compared to remote shop fabrication (47.2%), indicating a mixed approach optimized for cost, schedule, and site logistics.

Table 18: Piping Materials Summary

Material	Length (ft)	% of Total	Avg Diameter (in)	Diameter × Length (in-ft)
304L SS	21,280	27.86%	16.18	344,402
A106	26,127	34.20%	20.51	535,812
A20	550	0.72%	2.18	1,198
A53	19,379	25.37%	12.59	243,931
HDPE	4,300	5.63%	6.00	25,800
PVC	4,751	6.22%	4.00	19,004
Total	**76,387**	**100%**	—	—

The material mix includes carbon steel, stainless steel, HDPE, and PVC, with material selections aligned to service conditions. The product of diameter and length provides a volume-weighted basis for estimating welding inches, insulation surface, and painting area, which are key drivers.

7.4 Capital Cost Estimates

The total estimated project costs for the Carbon Capture Plant have been calculated based on material quantities, labor hours, wage rates, vendor quotes, and indirect cost allowances. The estimate includes Total Direct Costs (TDC), indirect field costs, owner's indirect costs, escalation, and contingency.

The direct field costs encompass labor hours, average wage rates, labor costs, material costs, and their respective contributions as percentages of the Total Direct Cost (TDC). In addition to these direct costs, the estimate includes indirect field costs, owner’s indirect costs, and engineering/home office services. To arrive at the Total Installed Cost (TIC), the estimate was further adjusted for escalation and contingency. A summary of the final project costs, inclusive of these adjustments, is provided below.

The CAPEX cost estimates were developed by KBR based on detailed technical documentation, including datasheets, requisition packages, specifications, and other relevant materials, to support the procurement of vendor budgetary quotes. These quotes were evaluated against the associated design specifications to determine scope inclusions and exclusions. For any excluded items, appropriate allowances were applied to complete the estimate. Vendor quotes were obtained for all critical mechanical equipment, representing 94% of the total mechanical equipment cost. Additional quotes were also gathered for most electrical and instrumentation equipment.

Generally, the lowest technically acceptable vendor quotes were selected for inclusion. However, in cases where there was uncertainty regarding the accuracy or completeness of quotes, average pricing was used as a conservative approach. Contractor quotations were also included for various infrastructure components such as the power overhead feeder, gatehouse, warehouse, ECR building, control and change room building, maintenance building, laboratory, and compressor sheds. The combined value of vendor budgetary quotes and contractor estimates makes up approximately 66% of the total project equipment and material costs. The remaining bulk materials and equipment costs were estimated using the ACCE (Association for the Cost Engineering) methodology, with adjustments based on KBR’s historical cost data. Capital spares were also incorporated into the estimate in accordance with KBR’s projections.

The project area south of Wald Road and the length of the low duct supports area will need to be over-excavated by 9’ since the soil (expansive soils) is not suitable for structural backfill, as per the Cemex new Geotechnical Report. This excavated soil will need to be disposed of at an approved landfill off-site.

Imported non-expansive soil fill will need to be brought into the site and compacted to replace the over-excavated expansive soil. The costs for the imported fill, soil transportation, and soil disposal cost were estimated by KBR based on previous projects in the area.

The breakup of the total direct costs for major equipment systems is provided in Table 19

Table 19: Total direct costs for major equipment system

Equipment	$ Million	% Contribution to TDC
Air Cooling system	152	27.3
Absorber Column	52	9.3
CO_2 conditioning and compression	28	4.9
Piping, Racks and Ductwork	26	4.6
Boiler and Steam System	25	4.5
Feed Scrubber	22	3.9
Activated Carbon Beds	21	3.7
Centrifugal Pumps	21	3.7
Raw/Potable/Demin water	16	2.9
Solvent Heat Exchangers	11	2.0
Regenerator Column	10	1.8

Air cooling system makes up the largest share, accounting for 27.3% of the total cost. The absorber column, which is traditionally the largest cost item, now accounts for 9.3% of the total cost. CO_2 conditioning and compression accounts for ~5% of the total cost.

The CAPEX cost estimates, broken down by code of accounts from the FEED study is provided in Table 20.

Table 20: TPC summary for the cement plant with retrofit RTI CO_2 capture

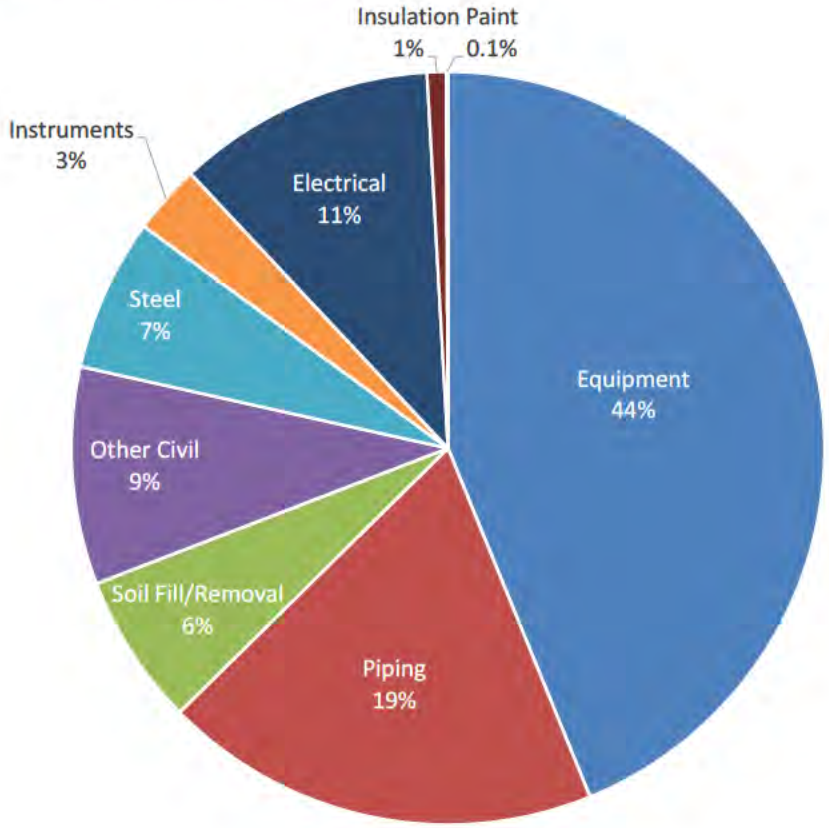
ACCT #	Description	Equipment Cost ($1000)	Material Cost ($1000)	Labor ($1000)	BEC ($1000)	CM & EPC ($1000)	TIC ($1000)	Contingency		TPC ($1000)
								Process $(1000)	Project $(1000)	
1	CO_2 Carbon Capture	$175,047	$ 60,884	$ 71,674	$307,606	$ 57,364	$364,969	$ 52,293	$ 25,157	$ 442,419
2	CO_2 Compress & Dehydration	$ 22,845	$ 1,939	$ 2,812	$ 27,596	$ 5,146	$ 32,742	$ -	$ 2,257	$ 34,999
11	Raw/Potable/Demin water	$ 3,798	$ 5,215	$ 7,244	$ 16,257	$ 3,032	$ 19,289	$ -	$ 1,330	$ 20,618
12	Boiler & Steam System	$ 18,302	$ 2,055	$ 4,516	$ 24,873	$ 4,638	$ 29,512	$ -	$ 2,034	$ 31,546
14	Solvent/Chem Storage	$ 976	$ 1,745	$ 3,150	$ 5,872	$ 1,095	$ 6,967	$ -	$ 480	$ 7,447
15	Cooling water	$ 2,664	$ 833	$ 1,824	$ 5,321	$ 992	$ 6,313	$ -	$ 435	$ 6,748
16	Air & Nitrogen	$ 2,614	$ 397	$ 954	$ 3,965	$ 739	$ 4,704	$ -	$ 324	$ 5,028
18	Waste water treatment	$ 1,682	$ 618	$ 1,569	$ 3,869	$ 721	$ 4,590	$ -	$ 316	$ 4,906
20	Stack	$ 1,378	$ 916	$ 1,270	$ 3,564	$ 665	$ 4,228	$ -	$ 291	$ 4,520
22	Utility Headers	$	$ 54,125	$ 39,021	$ 93,146	$ 17,370	$110,516	$ -	$ 7,618	$118,134
23	Power Generation	$ 979	$ 49,483	$ 15,081	$ 65,543	$ 12,223	$ 77,765	$ -	$ 5,360	$ 83,126
	Total:	$230,285	$ 178,211	$149,115	$ 557,611	$ 103,985	$661,596	$ 52,293	$ 45,603	$759,491

The Total Direct Costs (TDC) for the Carbon Capture Plant capture the core field construction expenditures across all major engineering disciplines. These costs include both labor and material components for equipment installation, piping systems, civil works, structural steel, electrical and instrumentation, insulation, and painting activities. Labor costs were developed based on detailed man-hour estimates and a composite wage rate reflective of local labor conditions. Material costs were derived from material take-offs, vendor quotes, and engineering quantities.

This section summarizes the direct costs by discipline and highlights each category's relative contribution to the total. The distribution of costs reflects the nature of a process-intensive facility, with significant weight given to mechanical and piping systems. These direct field costs form the foundation of the Total Installed Cost (TIC), to which indirects, owner's costs, escalation, and contingency are subsequently added.

Breakup of the TDC by discipline is also shown in Figure 26.

Figure 26: Breakup of the total direct costs by discipline



A summary of the TDC, Indirect Field Costs is provided in Table 21. TIC and Project Cost Summary is provided in Table 22.

Table 21: Indirect Field Cost Summary

Description	Notes	Ind Cost
CONSTRUCTION MANAGEMENT	Includes Staff & Temp Facilities	9,037,056
START-UP, COMMISSIONING	2.5% of Total Installed Costs (TIC)	18,972,500
Field Office Staff		**28,009,556**
Description	Notes	Ind Cost
SCAFFOLDING, PLATFORMS	11% of Direct Labor Costs including Equipment	15,737,509
FIRE WATCH / HOLE WATCH	1% of Direct Labor Costs	1,491,151
E U PMENT RENTAL	Small Cranes, Manlifts, etc.	In Direct Field Costs
VENDOR REPRESENTATIVES		2 302 846
FR NGE BENEFITS		In Direct Field Costs
PA ROLL TAXES & NSURANCE		In Direct Field Costs
SMALL TOOLS & CONSUMABLES		In Direct Field Costs
CRAFT SUPERVISION		In Direct Field Costs
CRAFT PER DIEM (NOTE 1)	$96/day for 50% of Crafts	6,787,697
BUSINESS EXPENSES		In Direct Field Costs
FIELD SERVICES		In Direct Field Costs
TEMP. CONST., UT LITIES		In Direct Field Costs
OVERTIME PREMIUM (NOTE 1)	40 regular + 10 overtime hours x 50% premium	In Direct Field Costs
PREVA L NG WAGE RATE (NOTE 2)		Excluded
OVERHEAD		In Direct Field Costs
PROFIT		In Direct Field Costs
Construction Indirects Total		**26,319,203**
Description	Notes	Ind Cost
CEMEX NEW POWER SUBSTATION		12,075,800
Owner's Indirects Total		**12,075,800**

Table 22: Project Cost Summary

Account	MH	Wage Rate	Labor Cost	Matl Cost	Total Cost	Percentages
(2) Equipment	145,062	120.19	17,435,052	230,284,642	247,719,694	44.4% of TDC
(3) Piping	432 036	118.12	51 030 880	59 283 342	110 314 223	19.8% of TDC
(4) Civil	449,555	87.78	39,461,054	49,711,474	89,172,528	16.0% of TDC
(5) Steel	151,411	113.18	17,137,379	19,705,834	36,843,213	6.6% of TDC
(6) Instruments	73,205	109.32	8,002,938	8,890,445	16,893,383	3.0% of TDC
(7) Electrical	113,730	105.88	12,041,383	39,592,539	51,633,922	9.3% of TDC
(8) Insulation	44,793	81.90	3,668,418	970,143	4,638,561	0.8% of TDC
(9) Paint	4,313	78.36	337,947	57,114	395,061	0.1% of TDC
Total Direct Field Costs	**1,414,104**	**105.45**	**149,115,051**	**408,495,533**	**557,610,585**	100.0% of TDC
	(TDMH)		(TDL)	(TDM)	(TDC)	
Indirect Field Costs					**54,328,759**	36.4% of TDL
	(IFMH)				(IFC)	
Owner's Indirect Costs					**12,075,800**	8.1% of TDL
					(OFC)	
Direct + Indirect Costs					**624,015,144**	82.2% of TIC
	(TFMH)				(TFC)	
Freight					13 324 866	3.3% of TDM
Heavy Lift / Haul					4,704,200	1.2% of TDM
Taxes (VAT), Import Duties, Permits						
Engineering & Home Office					50,600,000	6.7% of TIC
Total Non-Field Costs	(HOMH)				**68,629,066**	9.0% of TIC
Project Costs					**692,644,210**	124.2% of TDC
Escalation					41 522 844	5.5% of TIC
Contingency					24,741,430	3.3% of TIC
Project Costs (with Escalation & Contingency)					**758,908,484**	136.1% of TDC

7.5 Operating Cost Estimates

Operating cost projections were developed based on data generated during the FEED phase. These projections incorporate detailed estimates for consumables, waste treatment, and utility consumption,

including natural gas for steam generation and electricity for the operation of the CO_2 capture and compression systems. To account for anticipated future conditions, the costs of natural gas and electricity were escalated using internally forecasted rates provided by Cemex. Labor costs were determined by identifying the necessary operations and maintenance staffing requirements and applying prevailing wage rates corresponding to each role. This approach enabled the estimation of both fixed and variable labor costs, reflecting local labor market conditions and the technical demands of operating the facility.

Total annual variable operating costs include all consumables necessary for the operation of the facility, such as NAS solvent makeup, water and wastewater treatment chemicals, caustic soda, sulfuric acid, activated carbon, de-oxo catalyst, and triethylene glycol (TEG). Cost estimates for the NAS solvent, activated carbon, and de-oxo catalyst were developed based on vendor quotations. For other consumables—including sulfuric acid, caustic soda, and TEG—unit prices were sourced from the U.S. Department of Energy's baseline study on retrofit CO_2 capture processes at cement plants [1]. The variable operating costs also include the disposal of waste materials, including spent TEG, used adsorbents, and spent catalysts.

The total annual variable operating costs were estimated at $41.7 million. In addition, fuel and purchased power costs were estimated at $61.6 million annually. Fixed operating costs include annual operations and maintenance (O&M) labor, administrative and support staffing, as well as costs associated with maintenance materials, property taxes, and insurance. The total annual fixed operating costs were estimated at $11.4 million. Total annualized operating costs were estimated to be $108.8 million.

7.6 Cost of Capture

The cost of CO_2 capture was derived using the CAPEX estimates from the AACE Class 3 cost assessment conducted during the FEED study performed by KBR. The OPEX cost estimates were developed based on the FEED study deliverables, which included detailed lists of consumables, utility requirements, and waste management needs.

Plant availability was assumed to be 90%. The CO_2 capture plant was designed with a capture capacity of 2.4 million metric tonnes per year, based on the nominal production capacity of the cement kilns and expected variations in process flow rates. The average operating capacity of the plant is assumed to be 86%, which, when accounting for the 90% availability, results in an overall capacity factor of 74%.

Total Owner's costs encompass pre-production expenses, including six months of labor, one month of maintenance materials, and start-up and commissioning costs. Additionally, these costs cover a 60-day supply of non-fuel consumables and the expenses associated with the electrical substation required to distribute power from the grid to the capture plant, as provided by New Braunfels Utility company. The Owner's costs also include estimates for permitting, topographical, soil, and water studies, as well as legal fees and financing costs. These Total Owner's costs were added to the Total Plant Cost (TPC) to derive the Total Overnight Cost.

Overall cost of capture was estimated to be $\$101.6/t\text{-}CO_2$. This does not include the cost for transportation and sequestration.

Inclusion of the amine recovery from acid wash waste stream technology reduces the cost of capture to $\$93.0/t\text{-}CO_2$.

8 Business Case Analysis

A comprehensive pro forma financial analysis of the CO_2 capture project was conducted by Cemex to evaluate the project's economic viability and long-term financial performance. This analysis incorporates a detailed AACE Class 3 cost estimate, developed by KBR during the Front-End Engineering Design (FEED) phase. The Class 3 estimate provides a robust foundation for evaluating capital expenditures, with an expected accuracy range of +/- 15%, making it suitable for preliminary investment and funding decisions.

Operating cost projections were developed using data from the FEED phase, including detailed estimates for consumables, waste treatment, and utility consumption. This includes natural gas requirements for steam generation and electricity usage for the operation of the CO_2 capture and compression systems. To reflect future operating conditions, natural gas and electricity costs were escalated based on internal Cemex forecasted rates. Labor costs were estimated by identifying the required operational and maintenance staffing levels and applying prevailing wage rates for each role. This methodology allowed for the development of both fixed and variable labor cost projections that reflect local labor market conditions and the technical complexity of operating the facility.

CO_2 transportation costs were estimated using a recent internal quote from a comparable pipeline infrastructure project. This baseline was adjusted to reflect the specific conditions of the Balcones CO_2 capture project, including the proximity of the proposed sequestration site. For the purposes of this analysis, a conservative assumption of 20 miles of pipeline was used to estimate associated transportation costs.

CO_2 storage costs were derived from SLB's internal estimates based on analogous storage projects. These estimates include the cost of CO_2 injection and the installation and operation of measurement, monitoring, and verification (MMV) systems in accordance with regulatory and environmental compliance requirements. However, the storage cost estimate excludes financing costs, long-term liability provisions, and pore space fees, which are expected to vary based on final site selection and future regulatory frameworks.

Together, the transportation and storage cost estimates inform the broader calculation of the levelized cost of CO_2 capture and storage (CCS), supporting a comprehensive financial evaluation of the carbon management value chain for the Balcones project.

The analysis incorporates the benefit of federal 45Q tax credits, which offer a per-metric-ton incentive for captured and permanently sequestered CO_2. Under the most recent guidance provided by the Inflation Reduction Act, the value of the 45Q credit has been increased to $85 per metric ton for CO_2 stored through secure geological sequestration, which is the basis used in this analysis.

To complete the analysis, Cemex incorporated company-specific financial assumptions related to financing structure, cost of capital, and tax considerations to model project cash flows over its operational lifespan. These inputs were used to determine the levelized cost of capture, as well as key financial metrics, including the internal rate of return (IRR), net present value (NPV), and payback period.

Results from the pro forma are shown in Table 23 below. Key assumptions that are not proprietary and business confidential are listed below:

- Corporate tax rate: 21%
- Inflation assumed (from IMF's World Economic Outlook April 2025) [2]:

Concept	Units	2025	2026	2027	2028	2029	2030	2031
Inflation - USA	%	3.0%	2.5%	2.1%	2.2%	2.2%	2.2%	2.0%

Table 23: Results from the pro forma analysis for CO_2 capture at Balcones Plant using RTI's NAS technology

Total CAPEX	USD M	849
Pre-production costs	USD M	5
Inventory Capital	USD M	6
Annual OPEX – 2025 terms	**USD M**	**168**
Variable	USD M	36
Fixed O&M	USD M	11
Power and Fuel	USD M	61
Transport and Sequestration	USD M	60
Annual Emissions sequestered	K ton CO_2	1,761
Levelized cost of CCS (w T&S)	**USD**	**130**
Capture OPEX (Variable O&M + Fixed O&M)		26
Power & Fuel		38
CAPEX Capture		37
Transport & Sequestration		29
Levelized Revenue of CCS		**75**
Net Present Value		**-55**

Results from the BCA indicates a negative value for the project net present value (NPV); therefore, further incentives to make the project feasible will be needed in the future. Additional incentives could be achieved through a combination of (1) further DOE/similar grants to fund carbon capture plant construction and reduce exposure to high CAPEX, and (2) higher tax incentives to mitigate project OPEX and/or other endeavors outside of taxes. The BCA indicates that for the project to break even, given the current 12-year 45Q period, the credit value would need to be approximately $175/MT sequestered compared to the current $85/MT. Levelized revenues of 45Q credits do not reflect their full value due to intermediation costs and the fact that the project is evaluated over 25 years while the tax credit is only valid for 12 years. If the 45Q period were extended to 24 years, the required credit value would be around $120/MT for the project to break even.

The cost of cement production is projected to increase with the addition of the capture plant. At present, there is no green premium for decarbonized cement in the United States.

9 Value Engineering Opportunities

As part of the FEED phase, the project team performed a targeted value engineering (VE) review to identify potential cost-saving opportunities without compromising technical integrity or operational requirements. Two specific VE cases were identified and evaluated during this phase. The assessment focused exclusively on potential capital cost reduction, with no consideration given to schedule or lifecycle impacts. The following section outlines the VE opportunities reviewed, along with the rationale and estimated cost implications.

9.1 Co-generation of Heat and Power

During the FEED phase, one of the key value engineering opportunities evaluated was the replacement of the existing natural gas boiler—designed to supply low-pressure steam (LPS) for solvent regeneration in the CO_2 capture plant—with an integrated co-generation system. This alternative aimed to improve overall energy efficiency by generating both steam and electricity onsite.

Three configurations were assessed:

- Option A: Installation of a larger natural gas boiler producing medium-pressure steam (MPS) at 290 psig. The MPS would be expanded through a steam turbine to generate electricity, with the exhaust LPS utilized for solvent regeneration. This configuration yields approximately 36 MW of electricity, meeting 57% of the CO_2 capture and compression (CC) system's power demand.
- Option B: Installation of a boiler producing high-pressure steam (HPS) at 620 psig. Similar to Option A, the HPS would be routed through a turbine, generating approximately 52 MW of electricity, covering 82% of the CC power demand.
- Option C: Similar to Option B, this configuration also utilizes HPS but incorporates a larger BT63 turbine instead of the BT50. The higher efficiency of the BT63 turbine increases power generation to 56.5 MW, covering approximately 90% of the CC facility’s electrical load, with only 10% of power required from the grid.

To evaluate the technical and economic feasibility of each configuration, capital cost estimates were developed based on vendor quotations for both the upgraded boiler systems and the steam turbines. Operating costs, including increased natural gas consumption, were also estimated. Net power generation figures were calculated based on the steam requirements of the CO_2 capture process.

A summary of the capital and operating cost estimates for the co-generation options is provided in Table 24.

Table 24: Evaluation of Cogeneration Options

Parameter	Unit	LP Boiler	MP Boiler	HP Boiler Option 1	HP Boiler Option 2
Configuration		2 x 50%	2 x 50%	2 x 50%	2 x 50%
Steam Type		Saturated	Superheated	Superheated	Superheated
Steam Pressure	psig	125	290	620	620
Steam Temperature	°F	392	540	721	721
Price	USD (MM)	$12.54	$14.08	$15.96	$15.96
Total Boiler Required		2	2	2	2
Total Cost	USD (MM)	$25.08	$28.16	$31.92	$31.92
Power Requirement	kW	63,146	63,146	63,146	63,146
10% Over Design	kW	69,461	69,461	69,461	69,461
Power Design Requirement	MW	70	70	70	70
Turbine Quantity		N/A	2	2	1
Turbine Model		N/A	BT50	BT50	BT63
Steam Flow	lb/hr	N/A	950,000	950,000	950,000
Steam Inlet Conditions	psig / °F	N/A	290 / 537	620 / 721	620 / 721
Steam Outlet Conditions	Psig / °F	N/A	37 / 283	37 / 283	37 / 283
Generated Electricity	MW	N/A	18	26	56.5
Total Generated Energy	MW	N/A	36	52	56.5
Turbine Cost	USD (MM)	0	$3.25	$3.50	$7.00
Total Turbine Cost	USD (MM)	0	$6.50	$7.00	$7.00
Boiler-Steam Turbine Cost	USD (MM)	$25.08	$34.66	$38.92	$38.92
Installation Factor		1.60	1.60	1.60	1.60
Differential Cost	USD (MM)		$9.58	$13.84	$13.84
Installed Cost	USD (MM)		$15.36	$22.20	$22.20
Project contingency (20%)	USD (MM)		$3.07	$4.44	$4.44
TPC	**USD (MM)**		**$18.44**	**$26.64**	**$26.64**

Among the options considered, Option C appears to offer the most favorable balance between capital investment, energy efficiency, and operating cost reduction. Its ability to meet 90% of the CCS plant's power demand internally presents a significant opportunity to minimize reliance on grid electricity and improve overall project economics. However, due to its higher complexity and equipment scale, Option C will require further technical and economic validation including a more refined assessment of integration impacts, space requirements, and operational flexibility.

9.2 Increased flue gas CO_2 concentration

An air leakage assessment conducted at the plant identified the raw mill circuit as a significant source of false air ingress, particularly during raw mill operation. Air enters the system, leading to dilution of the flue gas exiting the pre-heater tower. This false air reduces the CO_2 concentration in the flue gas, which in turn negatively affects the efficiency and cost-effectiveness of downstream CO_2 capture.

Measurements taken during the assessment indicated a CO_2 concentration of approximately 12% (wet basis) when the raw mill was in operation. Based on the leakage points identified, it is estimated that eliminating

or significantly reducing false air ingress could increase the CO_2 concentration to approximately 24% (wet basis)**.** Even with a conservative assumption of 3–5% residual air leakage, the CO_2 concentration is expected to improve to 22.6–23.0%**,** representing a significant enhancement over current conditions. Given the ongoing requirement to dry raw materials, and the technical challenges associated with recovering heat from dust-laden flue gas via alternative means, continued use of pre-heater flue gas for raw material drying remains the most practical and thermally efficient approach—particularly once air leakage is minimized.

This presents a clear value engineering opportunity for the CO_2 capture project. By addressing air ingress through targeted maintenance actions, the plant can achieve a substantial increase in flue gas CO_2 concentration with minimal capital investment.

Higher CO_2 partial pressure in the flue gas will enhance capture system performance by improving solvent absorption kinetics and reducing the energy demand for solvent regeneration. In addition, the associated reduction in flue gas volumetric flow allows for downsizing key components, including absorber and DCC (Direct Contact Cooler) columns, flue gas ducts, and blower. These changes are expected to result in capital cost savings across the capture system, although the magnitude of these savings will need to be quantified through detailed design and cost estimation. Collectively, these improvements contribute to a lower overall cost per tonne of CO_2 captured, reinforcing the importance of minimizing air leakage in the raw mill circuit as part of the broader decarbonization strategy.

9.3 Amine recovery from acid wash waste

The CO_2 capture plant design proposes the use of an acid wash system for emissions control, utilizing RTI's Non-Aqueous Solvent (NAS). In its current configuration, the acid wash removes any residual amine from the treated gas by reacting the amine with the acid to form an amine-sulfate salt. This salt is typically treated as waste, and the lost amine must be replenished through the addition of makeup amine. However, this approach introduces operational inefficiencies in terms of chemical costs and waste handling.

A value engineering opportunity exists to recover the amine from the acid wash waste, leveraging the hydrophobic nature of the NAS solvent amine. Experimental work conducted by RTI has demonstrated that this amine can be successfully separated from the acid wash waste stream with a recovery rate of at least 95%. The process entails neutralizing the amine-sulfate salt to regenerate the parent amine, which then separates out as an organic phase due to its hydrophobic properties. The recovered organic amine can be recycled into the NAS solvent loop, creating a closed-loop process. By reducing the loss of amine and limiting the need for fresh chemical makeup, this recovery process offers significant cost savings.

Experimental testing has demonstrated the technical feasibility and maturity of the amine recovery from acid wash waste stream technology, thereby eliminating significant implementation risks. The technology is planned for inclusion as part of the standard design package for subsequent projects. However, it was not incorporated into the current FEED design, as its development progressed in parallel and reached completion after the FEED design freeze. The cost and performance impacts associated with its implementation have been evaluated and incorporated into the Techno-Economic Analysis (TEA) to inform future design and deployment decisions.

10 Environmental Health and Safety (EH&S)

This section of the FEED report presents prominent Environment, Health, and Safety (EH&S) considerations associated with the proposed NAS CO_2 capture technology at the Balcones site. It introduces targeted evaluations of potential emissions and waste streams, outlines the toxicological profiles of involved substances, and discusses relevant chemical hazard properties. Additionally, this section encompasses regulatory compliance aspects, an engineering assessment of hazardous materials, and comprehensive guidelines for safe handling and storage. Each of these topics is elaborated upon in the subsequent subsections to ensure a thorough understanding of the EH&S implications, facilitating safe, compliant, and environmentally responsible project execution.

10.1 Potential Ancillary Emissions and Waste Streams

The FEED study identifies the addition of a new emissions stack (A-2001) at the Balcones site as part of the CO_2 capture process. This stack, situated at the top of the acid wash section of the absorber, will serve as the primary discharge point for treated flue gas, as well as for relief, vent, and off-gas streams originating from various units across the capture plant. Emissions sources that contribute to this stack include gas reliefs from pressure safety valves (PSVs), vents from equipment such as the TEG package (A-0221) and Regenerator Column (C-0151), and the outbreathing vent from the Solvent Sump (V-1401). Although the A-2001 stack is physically separate, its emissions will ultimately merge into the absorber stack. Additional emissions will derive from direct atmospheric vents and fugitive releases across different units within the NAS CO_2 capture plant. Net change in emissions data covering minor species such as PM, THC, SO_2, CO, NO , and HCl, is summarized in Table 25. Data for CO_2 is shown as % net reduction

Table 25: Summary of the air emissions from NAS CO_2 capture plant for the design. case

Species	Net Change in Emissions (with CCS – without CCS), Design Case
	mg/Nm^3
VOC	79
HAP	12
CO_2	net 92.7% reduction
TEG	0.0
CO	37
PM2.5*	reduced to nil
NOx	21
SO_2*	reduced to nil
HCl	reduced to nil

The total liquid effluent to be discharged from NAS CO_2 capture plant to wastewater treatment plant (WWTP) at Balcones site is determined to be 88,243 lb/hr under the max condition. While the process water bleed from Feed Direct Contact Cooler V-0111 produces the largest amount of wastewater, that stream is processed to recover water and 185,484 lb/hr, or 95% is recycled to the CO_2 capture process. The remaining 9,762 lb/hr is sent to WWTP. This additional wastewater generated from the capture plant will be neutralized and processed before discharge to a pond on site.

While most information on the solid wastes generated from various equipment within the NAS CO_2 capture process are not provided by the equipment vendor, the largest solid waste to be produced by NAS CO_2 capture process is likely to be the spent adsorbent from the activated carbon beds which translates to 106.8 lb/hr of solid waste to be disposed of from the site.

10.2 Toxicological Effects of NAS Components

The NAS amine constitutes the primary focus for evaluating toxicological effects related to EH&S. The formulation comprises an amine species blended with a hydrophobic organic diluent. While comprehensive toxicity studies on NAS are currently unavailable, relevant data from past projects (DE-FE0013865, DE-FE0026466, DE-FE0031660) and existing literature have been reviewed to evaluate potential health and environmental impacts. Extensive ecological and toxicological studies are essential to establish exposure limits, acceptable contamination levels in waterways, and biological toxicity for large-scale commercial deployment.

The amine is commercially available and categorized as a combustible and corrosive liquid that can cause skin and eye irritation. As indicated by its Hazardous Material Identification System ratings, it poses low toxicity risks and is not classified under significant hazardous chemical lists (e.g., TSCA, SARA). Despite its relatively benign nature, it is critical to mitigate the risks associated with its release into the environment, whether through emissions or wastewater. Current releases are estimated at about 30 ppm; however, ongoing development of emission control technologies (ECT) aims to reduce this figure to less than 1 ppm.

The organic diluent, akin to the amine, is commercially produced, carrying no persistent or bioaccumulative risks. It is deemed harmful to aquatic life, with a Derived No Effect Level (DNEL) defined for workers. The diluent exhibits low volatility and a high biodegradability rate (99%), reflecting minimal environmental impacts. In cases where wastewater is released, it may contain trace amounts of the diluent, necessitating diligent handling as hazardous waste.

The assessment indicates that NAS solvent components possess low toxicity. Nevertheless, proactive monitoring and control measures will be imperative to minimize any environmental and health risks associated with their use in extensive applications. Further investigations and adherence to local regulations are vital for the safe implementation of NAS technology.

10.3 Physical Properties of NAS

NAS is a formulation of a hydrophobic amine in an organic diluent. NAS is a liquid characterized by relatively high density and low volatility, thus rendering it suitable for industrial applications. NAS has no measurable flash point. The NAS technology also employs an acid wash process for emissions control, effectively minimizing potential environmental and safety risks.

Corrosion coupon evaluations performed during the Technology Centre Mongstad (TCM) engineering demonstration confirmed the low-corrosivity nature of the NAS solvent [3]. This finding indicates a reduced potential for material degradation and supports consideration of lower-grade carbon steel for certain process equipment, subject to detailed design verification. Complementary testing at the National Carbon Capture Center's Slipstream Testing Unit (NCCC-SSTU) in 2018 further corroborated these results, showing metal ion concentrations substantially lower than those observed during previous MEA baseline studies. These results suggest that the NAS solvent poses minimal corrosion risk under expected operating conditions, contributing positively to overall plant safety and maintainability.

Analysis of various metal concentrations, including barium (Ba), selenium (Se), arsenic (As), cadmium (Cd), lead (Pb), and silver (Ag), in NAS solvent samples confirm compliance with U.S. Environmental Protection Agency's Resource Conservation and Recovery Act (RCRA) limits, highlighting safe handling and minimal environmental impact.

The favorable physical properties and low corrosivity profile of the NAS solvent substantiate its application in industrial settings, potentially supporting the use of lower-grade materials while ensuring adherence to regulatory requirements for environmental safety.

10.4 Compliance and Regulatory Implications

The NAS technology for acid gas removal shares similarities with established natural gas processing techniques that utilize amine solutions to effectively remove H_2S and CO_2. Numerous successful installations have been implemented across the U.S. and Canada, demonstrating safe operations in accordance with applicable regulations.

The NAS process is specifically designed to capture pollutants that would otherwise be emitted in stack emissions from power plants, producing negligible environmental impact. Compliance with the Clean Air Act and National Standards for Performance (NSPS) concerning the removal of specified amounts of SOx, NOx, and particulates remains intact, as these emissions are managed upstream of the NAS system. The implementation of emission control technologies (ECT) is anticipated to further reduce amine and degradation product emissions while minimizing solvent losses over time. Nonetheless, contaminants in the CO_2 product, including amines, must be addressed through condensation and dehydration processes to meet CO_2 pipeline standards, thereby mitigating risks related to bacterial growth within the pipeline and reservoir.

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), NAS components do not appear on the hazardous substance list. Some glycol ethers, however, are generically listed without specific Reportable Quantities. The components used in NAS's diluent are noted in the EPA's Toxic Substances Control Act (TSCA) inventory.

None of the NAS chemicals are classified as Hazardous Air Pollutants (HAP) under the Clean Air Act; however, glycol ethers may be subject to broader regulations. The NAS chemical components do not fall under air toxics regulated by the NSPS program or accidental release prevention measures specified in Section 112(r) of the Clean Air Act.

In terms of reporting obligations under the Superfund Amendments and Reauthorization Act (SARA) Title III, Sections 311-312 require facilities handling hazardous chemicals to maintain a Tiered chemical inventory if quantities exceed specified thresholds. While none of the NAS components are present on the Section 313 chemical list, Diethylene Glycol Dibutyl Ether (CAS 112-73-2) falls within the N230 category code for certain glycol ethers, potentially triggering additional reporting requirements.

The NAS technology offers a low environmental impact profile and complies with various regulatory requirements, positioning it favorably for industrial applications. Adherence to existing laws and regulations ensures safe operations while addressing any potential environmental concerns related to chemical emissions.

10.5 Engineering Analysis of Identified Hazardous Materials

To minimize emissions of NAS amine in streams intended for environmental discharge, the implementation of Emission Control Technologies (ECT), such as acid wash systems, is essential. Testing conducted at the Technology Centre Mongstad (TCM) has yielded promising results, demonstrating that overall amine emissions from the CO_2 capture plant can be maintained below 1 ppm.

Environmental releases resulting from leaks, piping failures, spills, and drips are efficiently managed through the integration of appropriate containment infrastructure. All collected drips will either be recycled or disposed of in compliance with regulatory standards. Additionally, vessels and storage containers will be designed to adhere to applicable codes and utilize compatible materials to effectively mitigate corrosion and prevent leakage.

To ensure safe handling during solvent offloading from drums or containers, engineering controls will be implemented to prevent mismatched connections to transfer pumps and the use of incompatible elastomers or hoses. Importantly, no direct access to the plant sewer from the process skid will be allowed. Personnel will utilize appropriate personal protective equipment (PPE) to avoid contact with the solvent during routine and maintenance procedures.

10.6 Precautions for Safe Handling and Storage Conditions

- To ensure the safe handling of NAS, the following precautions must be observed:
- Avoid contact with skin, eyes, and clothing; avoid inhalation of mists/vapors.
- Implement local exhaust ventilation during use.
- Wear chemical-resistant gloves and protective clothing.
- Ensure eye wash fountains and safety showers are readily accessible.

A solvent-side slipstream reclaim process is implemented to manage potential nitrosamine formation during CO_2 capture. An activated carbon bed process will be utilized for nitrosamine removal during pilot-scale operations.

The NAS solvent is not highly volatile, and vaporization from stored solvents is expected to be minimal with proper storage practices, resulting in negligible exposure levels. The primary risk of exposure may occur during the offloading of the solvent from shipping containers and during certain maintenance tasks, such as the replacement of cartridges or filters. Job Safety Analyses (JSAs) will be conducted for these procedures, and appropriate personal protective equipment (PPE), including hazard suits, gloves, face shields, and breathing apparatus, will be worn, as necessary.

Waste generated from NAS, both solid and liquid, will be disposed of at approved hazardous waste disposal facilities, with no onsite waste disposal or treatment permitted.

10.6.1 Personal Protective Equipment (PPE)

- Eye/Face Protection: Use chemical goggles or a face shield as required.
- Skin Protection: Wear protective clothing that is chemically resistant, selecting specific items (face shield, boots, apron, full-body suit) based on task requirements.
- Hand Protection: Employ chemical-resistant gloves (e.g., nitrile, chloroprene, PVC), ensuring selection considers other chemicals handled, physical requirements, and glove material characteristics.

- Respiratory Protection: Use respiratory protection if ventilation is inadequate. In emergencies or high exposure situations, a NIOSH-certified full facepiece SCBA or supplied-air respirator is advised.
- Ingestion Precautions: Avoid ingestion to prevent gastric disturbances. Eating, drinking, and tobacco use should not occur in the work area, and handwashing prior to these activities is essential.

10.6.2 Engineering Controls

Ventilation: Local exhaust ventilation or similar engineering controls must be utilized to maintain airborne levels of NAS below exposure limits. General ventilation is typically sufficient for most operations.

10.6.3 Nitrosamine Exposure Management

Potential exposure to nitrosamines can occur through incidental ingestion, dermal exposure, and inhalation; inhalation is considered the most plausible route. The use of PPE significantly minimizes both dermal exposure and incidental ingestion. To prevent the incidental inhalation, engineering control such as (i) Negative-Pressure Zones to maintain negative pressure in solvent-handling rooms, pilot units, or high-hazard areas to prevent vapors drifting into hallways or adjacent labs, (ii) Enhanced General Ventilation to increase air volumetric displacement per hour (ACH ≥ 8–12) in spaces where nitrosamines are expected to be present or accumulate.

Monitoring of air emissions in industrial settings has revealed varying concentrations of nitrosamines; extensive studies have indicated that no nitrosamines were detected during baseline air quality monitoring in operations similar to NAS. Notably, emissions from CO_2 capture pilot testing exhibited average nitrosamine derivatives of the NAS amine at 25 ppb in treated flue gas.

The precautions and protective measures outlined above are essential for the safe handling of NAS during industrial applications. With effective engineering controls and the appropriate use of personal protective measures, exposure risks can be minimized, ensuring compliance with relevant environmental health and safety standards.

For further detailed information, please refer to the full report in the **Appendix J**.

11 Lifecycle Analysis

11.1 Goal and Scope

The study presents an LCA for the proposed carbon capture system (CCS) at the Balcones Cement Plant in New Braunfels, Texas. The proposed product system is based on system/subsystem models and prototypes demonstrated in a relevant environment, with the project currently at TRL 6. It would capture and geologically sequester 95% of CO_2 directly emitted from the plant as well as additional CO_2 produced by the CCS system. This LCA incorporates CO_2 saline aquifer transport and storage, combustion emissions at the facility, process operations and chemical inputs to the facility, and construction impacts for required materials and equipment.

The goal is to compare and understand the differences between the NETL Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 environmental impacts, with a particular focus on global warming impacts, from the Cemex Balcones cement plant with and without RTI's proposed CCS system for the U.S. DOE Carbon Utilization Program and as a public record per the funding opportunity announcement requirement. The scope includes the proposed product system of the Cemex Balcones Cement Plant with carbon capture and storage, with the functional unit being a metric tonne (MT) of Type IL and Type I/II cement produced. The system boundary is cradle-to-gate, stopping at the gate of a MT of cement produced. Data representativeness assumes the CCS facility has a lifetime of 25 years, with global warming potential assessed on a 100-year basis. Electric power requirements will be modeled from the Texas Reliability Entity (TRE). No credit or allocation will be applied for co-products, and recycling and recycled content will follow the cut-off rule. See Figure 27 and Figure 28 for a simplified system boundary with reference flows between key processes or life cycle stages.

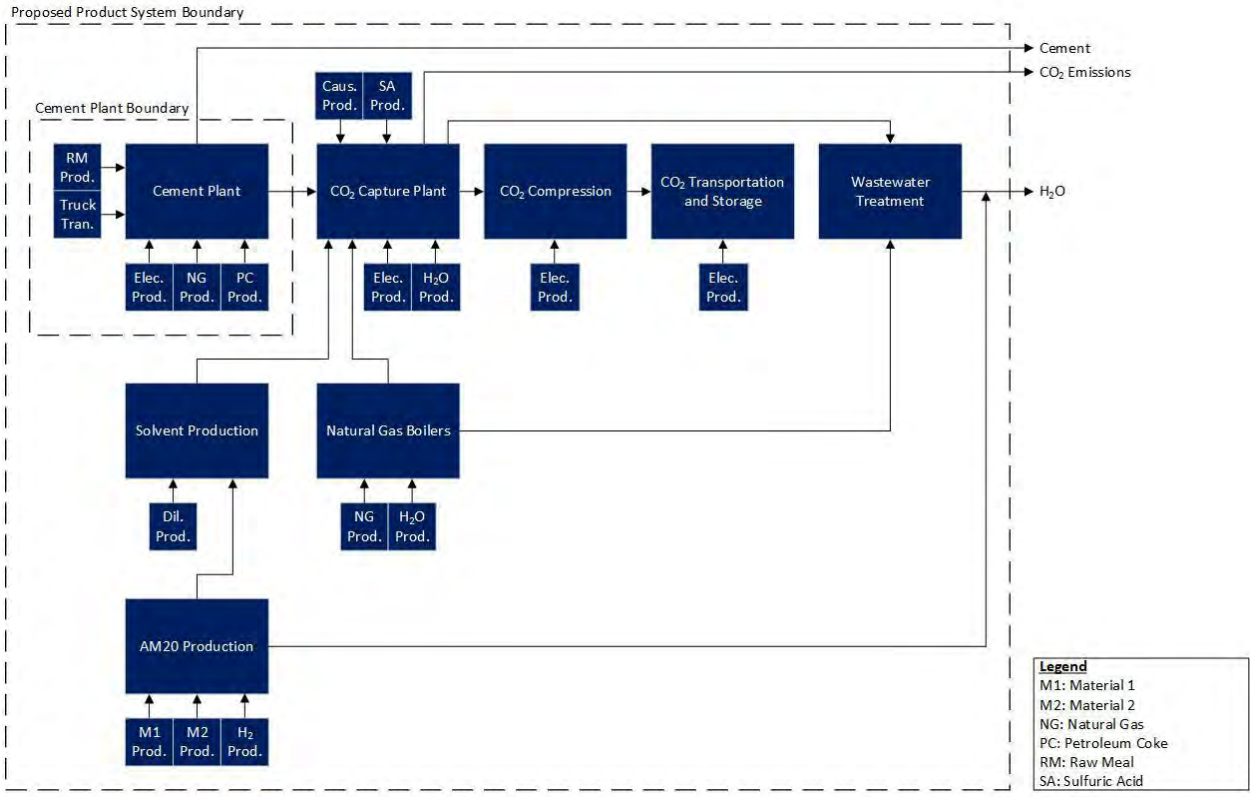


Figure 27: Process flow diagram for the proposed product system

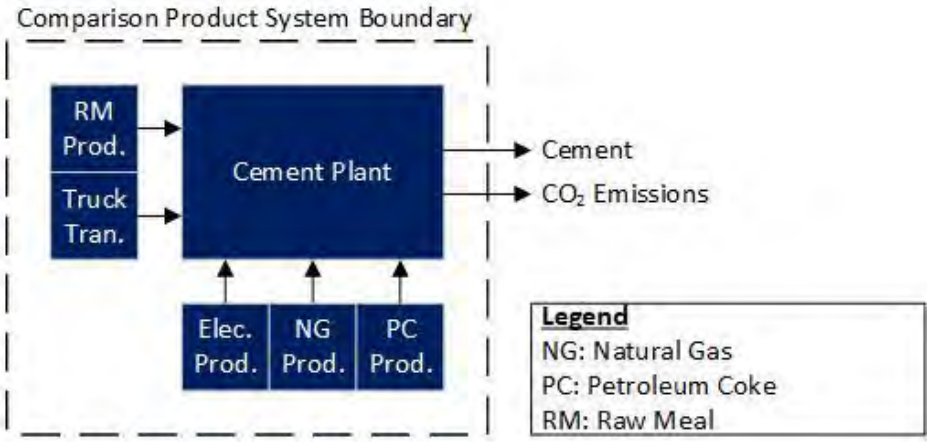


Figure 28: Process flow diagram for the comparison product system

11.2 Lifecycle Inventory Analysis

This project was modeled using OpenLCA software and uses the EcoInvent 3.10 Cutoff System Processes and NETL databases as LCIs. Further, this study uses the TRACI 2.1 impact assessment method combined with the latest global warming potential (GWP) factors included in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) report.

11.3 Lifecycle Interpretation

The life cycle results for the AR5, 100-year GWP are presented in Figure 29 and Figure 30 for both Types IL and I/II cement products. These results show the proposed product system (i.e., with CCS) with the comparison product system (i.e., without CCS) for each type of cement. The comparison product system is shown in the first column and is divided into direct and indirect CO_2 emissions. The direct CO_2 emissions are shown in orange and the indirect CO_2 emissions are shown in blue. CO_2 emissions that were added with CCS to the proposed product system are shown in gray and CO_2 emissions that are captured with CCS are shown in green. The proposed product system is shown in the last column and is divided into direct and indirect CO_2 emissions. The direct CO_2 emissions are shown in orange and the indirect CO_2 emissions are shown in light blue. The proposed product system shows a 66.1% decrease in GHG emissions for the Type IL cement and a 66.5% decrease in GHG emissions for the Type I/II cement.

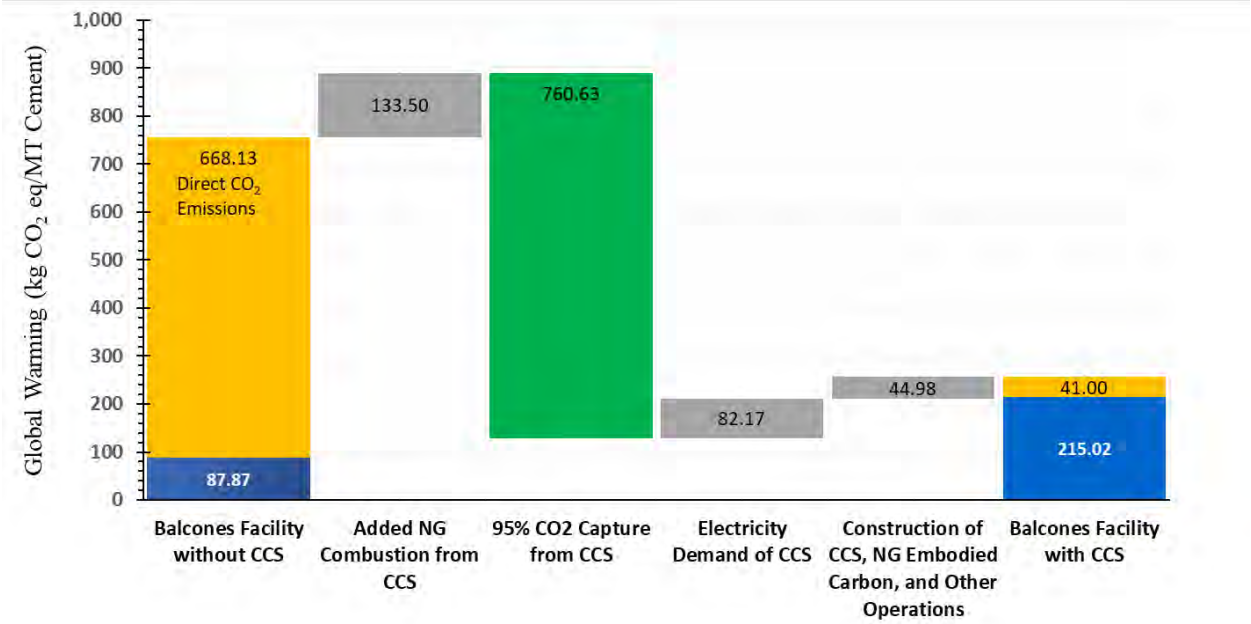


Figure 29:GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type IL cement

An estimated 668.13 kg CO_2/MT-cement produced and 725.58 kg CO_2/MT-cement produced are emitted as direct CO_2 emissions for Type IL and Type I/II cements, respectively, without the FEED CCS system. Per Cemex's environmental product declaration, the overall CO_2 emissions from production of cement at its Balcones plant is 756 kg CO_2eq/MT of Type IL cement and 816 kg CO_2eq/MT of Type I/II cement when including supporting processes. Employing the FEED carbon capture process is estimated to save 499.98 kg CO_2e/MT Type IL cement produced and 542.92 kg CO_2e/MT Type I/II cement produced, limiting direct CO_2 emissions to 41.00 kg CO_2e/MT cement and 44.59 kg CO_2/MT cement at the cement plant for Type IL and Type I/II cements, respectively. This represents a 66.1% (Type IL) and 66.5% (Type I/II) reduction in overall GHG emissions for Portland cement production.

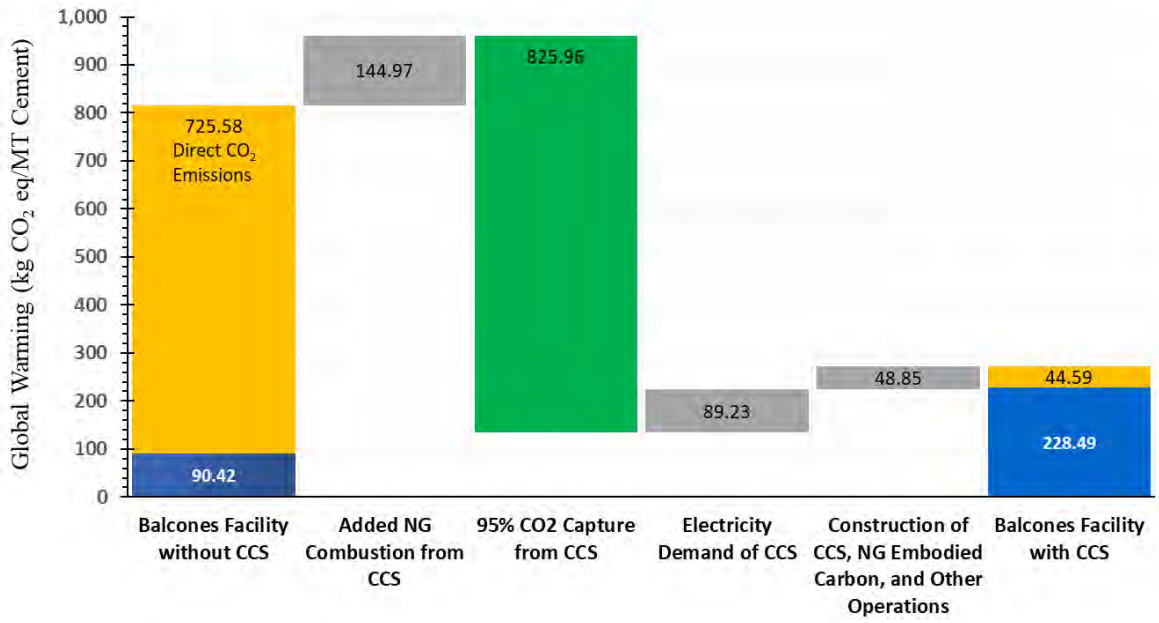


Figure 30: GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type I/II cement

As the electrical grid and transportation systems are decarbonized in the future, further CO_2eq emissions could be realized as the embodied carbon within the processes used in this model would decrease.

Given the large reductions of approximately two thirds in the Balcones cement plant's carbon footprint for both Types IL and I/II cement from the proposed CCS system, the PIs recommend further project evaluation of the Proposed Product System.

Further details on the LCA can be found in the Full LCA report in **Appendix K**.

12 Technoeconomic Analysis

A detailed technoeconomic analysis (TEA) has been carried out for CO_2 capture at Cemex's Balcones plant with using RTI-NAS technology. The TEA uses data from the AACE Class 3 level FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants.

12.1.1 Design Basis

The plant is located in New Braunfels, TX, with ambient conditions and site characteristics as shown in Table 12-1.

Table 12-1: Ambient conditions and site characteristics for the reference plant

Parameter	Description
Location	New Braunfels, TX.
Elevation (ft)	645 ft (196.6 meters)
Barometric Pressure, psia (bar)	14.696 (1.01325 bar)
Design Ambient Temperature, Dry bulb, °F (°C)	80 (26.7)
Design Ambient Temperature, Wet bulb, °F (°C)	77 (25.0)
Topography	Level
Transportation	Rail
Water	on-site well water available at average rate of 191 GPM
Access	Land locked, having access by rail and highway
CO_2 storage	Compressed to 2215 psia (152.7 bara) , transported 20 miles (32 kilometers) and sequestered in a saline formation.

12.1.2 Capital Cost Estimates

Relevant information like the technical datasheets, requisition package, specifications, etc., was used to obtain vendor budgetary quotes. The budgetary quotes were checked against the associated design specifications to see what is included and excluded. Any items excluded from the quote were estimated with allowances. Equipment quotes were obtained on all critical mechanical equipment, which make up 94% of the total mechanical equipment costs in the estimate. In addition, quotes were obtained on most electrical equipment and instruments. In general, the lowest technically viable quotes were considered for the estimate, but averages were used in a few cases due to uncertainty in the accuracy of the quote and items included by the vendor. Contractor quotes were also included for Power Overhead Feeder, Gatehouse, Warehouse, Engineering & Control Room Building, Control Room & Change Room Building, Maintenance Building, Lab, and Compressor Sheds. The combined value of the vendor budgetary quotes and contractor estimates make up 66% of the total project equipment & material costs. The remaining bulk materials and equipment were estimated by ACCE indexed based on experience.

A Cost Risk Analysis was performed by KBR for the project through a Monte Carlo simulation The analysis included conversations with the engineering disciplines and other KBR departments involved in the development of the estimate to assign proper expected variability ranges to quantities and costs. After discussions with Cemex, the P70 value of the results, corresponding to 6.9%, was included as the project contingency cost in the estimate summary. A process contingency of 17% was used for CO_2 capture CAPEX costs.

Owner's cost was then added to TPC to produce the total overnight cost (TOC) for the system. Owner's costs as defined in the DOE Baseline Study [1]

12.1.3 Operation and Maintenance Costs

Operating labor cost was determined based on the number of operators required to work in the plant. Other assumptions used are the same as the DOE-NETL 2023/3856 Baseline report [1].

The cost of consumables, including fuel, was determined based on the individual rates of consumption, the unit cost of each specific consumable commodity, and the plant annual operating hours. Waste quantities and disposal costs were evaluated similarly to the consumables.

The unit costs for major consumables and waste disposal was selected from the DOE/NETL -2023/3856 Baseline Report, Analysis of Carbon Capture Retrofits for Cement Plants [1] or vendor quotes. Natural gas fuel is purchased at $4.61/MMBtu, and power is purchased at a price of $67.3/MWh and are consistent with the values used in the DOE/NETL 2023/3856 Baseline Report.

12.1.4 Cost of Capture

The primary metric used to evaluate overall financial performance is the cost of capture (COC) for the retrofit CO_2 capture plant. All costs were expressed in the "first-year-of-construction" year dollars, and the resulting COC was also expressed in "first-year-of-construction" year dollars.

The same financial modeling methodology was used for this study as per the 2023/3856 Baseline Report [1] and guidelines in the QGESS *Cost Estimation Methodology for NETL Assessments of Power Plant Performance* [2] document. This is a simplified method that is a function of the plant TPC, capital charge factor (CCF), fixed and variable operating costs, CF, as shown in the equation below:

$$COC\left(\frac{\$}{tonne\ CO_2}\right) = \frac{TOC * CCF + FOM + VOM + PF + PP}{tonnes\ CO_2\ captured\ per\ year}$$

Where:

TOC	Total Overnight Cost of equipment added for CO_2 capture
CCF	Capital Charge Factor
FOM	Annual fixed O&M costs
VOM	Annual variable O&M costs
PF	Purchased Fuel
PP	Purchased Power

The CCF used in evaluating the COC was 8.84%, and developed by NETL's Energy Markets Analysis Team in December 2022 based on market data respective to the cement sector, as outlined in the DOE-NETL 2023/3856 Baseline report [1].

Three different cases are evaluated. Case A is the base case with the capture plant as currently designed with hybrid cooling and heat-integrated CO_2 compressors. Case B is a hypothetical case where the constraint for the limited water supply was removed and the plant and CO_2 compressors are water cooled and the plant is sited in proximity to the cement plant. Case C is a comparative case that evaluates the impact of co-generation of steam and electricity. A comparative "Cemex" case is also presented which uses the Cemex financial parameters (except for capital charge factor), Cemex's estimate for the owner's cost, labor estimates based on local wages, and utility prices.

The cost of capture, excluding T&S, using Cemex parameters was estimated to be \$101.6/t-CO_2. Using DOE parameters and assumptions results in the cost of capture of \$112.9/t-CO_2. Relaxing the constraint of limited water availability reduces the cost of capture to \$98.3/t-CO_2. Also, using a cogeneration plant for steam and electricity reduces the cost of capture for the base case from \$112.9/t-CO_2 to \$103.9/t-CO_2. Results from the TEA are summarized in Table 2.

.

Table 2: Summary of the TEA results

Case	Cemex - confidential	Case A: Base Case	Case B: Water-cooled	Case C: Co-gen
Financial Parameters	**Cemex - confidential**	**DOE**	**DOE**	**DOE**
Cooling	Hybrid (Air + water) Heat-integrated	Hybrid (Air + water) Heat-integrated	Cooling Tower water-cooled	Hybrid (Air + water) Heat-integrated
CO_2 compressors	Extended	Extended	compressors	Extended
Ductwork	Extended	Extended	Conventional	Extended
Electricity	grid	grid	grid	Co-gen
CAPEX, MM				
Total Plant Cost (TPC)	$759	$759	$621	$783
Total Overnight Cost (TOC)		$926	$759	$953
Total As Spent Capital (TASC)		$1,035	$848	$1,066
OPEX, MM/yr (100% Capacity Factor Basis)				
Fixed Operating Cost (OCfix)		$22.5	$18.7	$23.2
Var. Operating Cost, less Fuel (OCvar)		$58.4	$56.9	$57.4
Fuel + Purchased Power (OCfuel)		$70.7	$62.6	$57.2
Total OPEX	$143.8	$151.7	$138.2	$137.8
Plant Output				
CO_2 Capture Product, tonne/hr	274.0	274.0	274.0	274.0
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000	2,400,000	2,400,000
CO_2 Avoided, tonne/hr	218.4	218.4	218.4	200.5
Total CO_2 Avoided	1,913,600	1,913,600	1,913,600	1,756,200
Common Factors Used for COC Calculation				
Capital Charge Factor (CCF)		0.0884	0.0884	0.0884
Capacity Factor (CF)	0.74	0.74	0.74	0.80
Costs of CO_2 Captured (/tonne)	**101.6**	**112.9**	**98.3**	**103.9**
Costs of CO_2 Avoided (/tonne)		**141.6**	**123.3**	**141.9**
Cost of CO_2 Capture Breakdown				
CAPEX	**37.2**	**46.3**	**38.0**	**44.0**
Fixed O&M		**12.8**	**10.6**	**12.1**
Variable O&M	**64.3**	**24.4**	**23.7**	**23.9**
Fuel & Purchased Power		**29.5**	**26.1**	**23.8**
Total	**101.6**	**112.9**	**98.3**	**103.9**
T&S	**33.9**	**10.0**	**10.0**	**10.0**
Cost of Capture w T&S	**135.5**	**122.9**	**108.3**	**113.9**
Actual CO_2 Captured annually	1,766,300	1,766,300	1,766,300	1,914,302
CO_2 Capture Product, tonne/hr	201.63	201.63	201.63	218.53

12.1.5 Sensitivity Analysis

A sensitivity analysis was performed to determine the effects of various parameters of RTI's CO2 capture system on the overall cost of CO2 captured. Key parameters evaluated were (a) natural gas price, (b) electricity price, (c) solvent price, (d) plant CAPEX, (e) capacity factor, and (f) capital charge factor. The CAPEX and capacity factor were varied by +/- 15%, while the remaining parameters were varied by +/- 30%, and the cost of CO2 capture was evaluated. The sensitivity analysis was done for Case A: Base case with the capture plant as currently designed with hybrid cooling and heat-integrated CO2 compressors. Results are plotted in **Error! Reference source not found.** and **Error! Reference source not found.**.

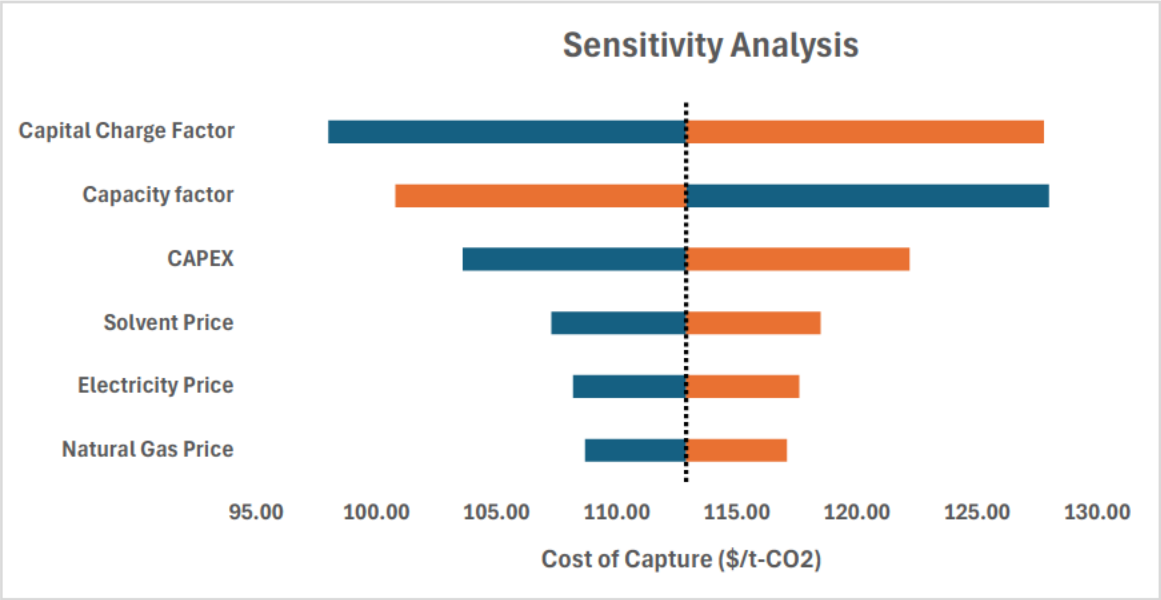


Figure 31: Tornado plot for sensitivity analysis for cost of CO_2 capture for Base Case A

For the Base Case, the sensitivity analysis indicated the highest impact from the capacity factor. A 15% reduction in capacity factor results in an increase of 13% for the cost of CO2 capture. The next sensitive parameter was the CAPEX, where a 15% increase in CAPEX increased the cost of CO2 capture by 8%. The unit price of natural gas and electricity had the lowest impact, with the cost of capture increasing by 4% with a 30% increase in the utility prices. The solvent price is also a minimal impact factor, with the cost of capture rising by 5% with a 30% increase in the unit price of NAS.

13 Technology Maturation Plan

A technology readiness assessment was performed on the NAS technology system to develop a Technology Maturation Plan (TMP) in accordance with Appendix A of DE-FOA-0002515.

The Technology Maturation Plan is provided in **Appendix M**.

14 Environmental Justice Analysis

An Environmental Justice Analysis (EJA) was performed to assess the impacts of the proposed project and technology. This analysis has been developed in accordance with Appendix N of DE-FOA-0002515.

The Environmental Justice Analysis is provided in **Appendix N**.

15 Workforce Readiness Plan

A Workforce Readiness Plan was developed describing the necessary skillset and training required to prepare the workforce needed to deploy the NAS technology. This was done in accordance with Appendix C of DE-FOA-0002515.

The Workforce Readiness Plan is provided in **Appendix O**.

16 Economic Revitalization and Jobs Creation Outcome Analysis

An economic revitalization and jobs creation outcome analysis of the proposed project and technology was completed. This analysis was developed in accordance with Appendix O of DE-FOA-0002515.

The Economic Revitalization and Jobs Creation Outcome Analysis is provided in **Appendix P**.

17 Conclusions/Recommendations

RTI International, with Cemex Inc., SLB, and KBR Inc., participated in a joint effort to perform a Front-End Engineering Design (FEED) study for carbon dioxide (CO_2) capture from cement flue gas utilizing the Non-Aqueous Solvent (NAS) CO_2 capture process developed by RTI. The FEED study evaluated the integration of RTI's CO_2 capture system at an existing cement plant, the Cemex Balcones cement plant at New Braunfels, Texas. The FEED was used to develop an Association for the Advancement of Cost Engineering (AACE) Class 3 cost estimate for a nominal 2.4 million tonnes per annum (MTPA) CO_2 capture system integrated with Cemex's Balcones cement plant in New Braunfels, TX.

Major findings from the FEED study are presented below:

- The estimated total capital expenditure (CAPEX) for the NAS CO_2 capture plant integrated with Cemex's Balcones cement plant is $849 million. This includes $558 million in direct costs, $54 million in indirect costs, $51million in engineering costs, $24 million in Owner's costs, and $104 million in contingency.
- The design rate of CO_2 capture is 2.4 MTPA (6,575 tonnes/day) at 100% capacity factor. Current CO_2 capture plant capacity factor is 74%, with a CO_2 capture rate of 1.766 MTPA (4,839 tonnes/day).
- The current design employs a hybrid air and water cooling system, with 84% of the cooling load handled by air cooling. This configuration significantly affects both capital cost and electricity consumption due to the extensive use of air coolers and the heat-integrated CO_2 compression train. The use of alternative cooling systems to compensate for limited water availability, however, has an impact on the overall cost of CO_2 capture, as detailed in the cost analysis section of this report.
- To further minimize water consumption, the design incorporates a steam-integrated CO_2 compression system, in which boiler feed water is used to generate steam instead of relying on water-cooled interstage compressors. This configuration eliminates the need for cooling tower makeup water but results in higher interstage temperatures and a corresponding 33% increase in compression power demand.
- The inclusion of air-cooled heat exchangers, which require approximately four acres of space, necessitated relocating the capture facility from its originally identified location closer to the main plant. The proposed site is a 15-acre greenfield plot south of the New Braunfels facility, situated across the road from the cement plant. Flue gas ducting will be routed over existing rail spurs and the roadway to connect the kiln flue-gas streams to the capture plant.
- The total direct costs are dominated by the air cooling system, accounting for 27.3% of the direct costs. The absorber column, which is traditionally the largest cost item, now accounts for 9.3% of the total cost. CO_2 conditioning and compression accounts for ~5% of the total cost.
- The cost of CO_2 capture could be substantially lower at sites where cooling water is readily available.
- The total annual variable operating costs were estimated at $35.8 million. In addition, fuel and purchased power costs were estimated at $61.6 million annually. Total annualized operating costs were estimated to be $109 million, resulting in a breakeven CO_2 capture cost of $101.6 per tonne of CO_2.

- The RTI NAS CO_2 capture plant requires 46 MW of electrical power and approximately 610 MMBtu/hr of natural gas for steam generation. The energy savings achieved through the NAS process's higher CO_2 regeneration pressure are partially offset by the use of a heat-integrated CO_2 compression train, implemented due to limited cooling water availability.
- The current design employs an acid wash system to control emissions by converting residual amines to amine-sulfate salts, resulting in waste generation and higher amine makeup costs. RTI International has since developed an amine recovery process that regenerates and recycles ≥95% of the parent amine. Incorporation of amine recovery is expected to reduce CO_2 capture costs (excluding transport and storage) to $93.0 per tonne.
- The FEED study did not identify any major project risks. The solvent reclamation process, which remains under development, was not included in the current design. Integration of the solvent reclamation system is planned for the detailed design phase.

The FEED study identified several opportunities for cost reduction and performance improvement that could further lower the overall cost of CO_2 capture. The following actions are recommended for the next project phase:

- **Amine Recovery:** Develop the detailed design and cost estimate for integrating the amine recovery process from the acid wash system to reduce chemical consumption and operating costs.
- **Cogeneration (CHP) Integration:** Investigate the potential for co-generation of steam and power to reduce electricity demand from the grid and improve overall energy efficiency.
- **Increased CO_2 concentration in the flue gas:** Assess options minimizing false air ingress to reduce flue gas flowrate, increase CO_2 concentration, and improve capture plant economics.
- **Solvent Reclamation:** Complete development of the solvent reclamation system and incorporate it into the plant design to support long-term operational reliability and cost efficiency.

18 References

1. DOE-NETL, Analysis of Carbon Capture Retrofits for Cement Plants. 2023.
2. IMF. World Economic Outlook (April 2025). Available from: https://www.imf.org/external/datamapper/PCPIEPCH@WEO/OEMDC/ADVEC/WEOWORLD/USA.
3. Jessop, K. E., et al. (2025). "Non-aqueous CO2 capture solvent corrosion results from Testing at Technology Centre Mongstad." International Journal of Greenhouse Gas Control **148**, 104504

19 Appendices

Appendix A Process Engineering

Appendix A.1 Design Basis Document

PROJECT DESIGN BASIS

CONFIDENTIALITY STATEMENT

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	27-MAR-24	IFI – ISSUED FOR INFORMATION	SP	JRZ	DDB	
B	30-OCT-24	IFI – ISSUED FOR INFORMATION	SP	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	27-MAR-2024	ALL	IFI – Issued for Information
B	30-OCT-2024	Cover	Updated confidentiality and export compliance statements

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1.0 GENERAL INFORMATION

1.1 INTRODUCTION

1.1.1 OVERVIEW

The Project Design Basis is intended to supply the basic information and Owner requested items which are required in the preparation of a Front End Engineering Design (FEED) package that will support the development of a +/- 15% estimate. This document contains information on project execution, economics, utility characteristics, environmental regulations and requirements, and equipment design details that require input from the Owner to ensure that the facilities as designed will meet project requirements. In some instances, actual values have not yet been determined but are required for design. These values will be shown in red to represent an early phase engineering assumption and must be updated in the next phase of engineering.

1.1.2 NAME AND LOCATION

Client:	RTI, INTERNATIONAL
Project Name:	DE-FE0032220 CARBON CAPTURE PLANT FEED STUDY FOR CEMENT MANUFACTURING
Project Location:	BALCONES PLANT, NEW BRAUNFELS, TEXAS
Logo(s):	RTI INTERNATIONAL

1.1.3 BACKGROUND

Research Triangle Institute International is developing a non-aqueous Solvent (NAS) CO_2 capture process as an advanced, next generation post combustion capture technology for CO_2 removal from power generation and industrial flue gas streams. The core of the NAS process has been the development of a family of CO_2 selective NASs that have the potential to substantially reduce thermal regeneration demand associated with solvent regeneration as compared to typically used solvents.

RTI has received funding for a carbon capture study from an FOA (Funding Opportunity Announcement) from the DOE (Department of Energy) FECM (Office of Fossil Energy and Carbon Management). The FOA is for carbon capture R&D for natural gas and industrial point sources and front-end engineering design studies for carbon capture systems at industrial facilities and natural gas plants. The OCCCM's (Office of Clean Coal and Carbon Management) mission is to drive R&D and adoption of advanced, affordable, and reliable energy systems and products from fossil resources and carbon-neutral or set-negative

emissions by "advancing technologies to cost-effectively capture carbon and securely store carbon across the economy".

As with other CO_2 capture systems, RTI's NAS CO_2 capture process utilizes an absorber tower, contacting cooled flue gas with solvent to capture CO_2. The RTI process absorber differs in design in that it includes the need for interstage coolers. Once through the absorber, flue gas is washed to remove amine and may be further treated (and/or treated in advance of the absorber) to remove other undesirable emissions (particulates, sulfur, NOx, etc.). CO_2-rich solvent from the absorber tower has the CO_2 stripped in a regenerator and the CO_2-lean solvent recirculates to the absorber. Stripped CO_2 is treated and compressed as needed for export.

RTI's approved study is the evaluation of the industrial scale application of their CO_2 capture technology to an existing concrete plant, the CEMEX Balcones Cement plant in New Braunfels, Texas. The study's basis is the installation of the RTI CO_2 capture system on the exhaust gas from the two cement kilns which have CO_2 emissions of 1.6MM metric tonnes per year. In addition, as the steam heat required for the CO_2 plant will require the installation of a natural gas boiler system, its flue gas CO_2 will also be captured. Total CO_2 capture is expected to be 95% or greater of that produced. Water availability is limited so process cooling will have to be optimized. CO_2 products will be compressed to meet end-use specifications. CO_2 product end use (sequestration, EOR, etc.) will be determined in future phases.

1.1.4 SUMMARY OF SCOPE

KBR will support RTI with a FEED study, beginning in May 2023 and to be complete by December 2024. Per the DOE FOA requirements, KBR will develop a Basic Design Package of the proposed CO_2 capture plant including integration points with the cement plant, process flow diagrams, heat and material balances, sized equipment lists, required utilities descriptions, etc. Finished deliverables include the typical list for FEED, including P&IDs, equipment layouts, 3D model, material take-off lists, etc., and a class 3 capital estimate (+/- 15%). CEMEX will provide the required site information. KBR's battery limits include the carbon capture plant's CO_2 supply piping from the three inputs (two kilns and boiler). As part of the DOE FOA application requirements, RTI has a number of other related reports to submit including technoeconomic, business case, lifecycle, and EH&S and Risk analyses.

1.1.5 DESIGN PHILOSOPHY

Design Feed Rates:	2,400,000 TPY CO_2 capture (2,100,000 TPY Net Plant for two kilns from the existing cement plant + approx. 15% CO_2 capture for the new NG boiler)

Plant Design Life Years:	25 yrs
Turndown requirements for Process Units:	The Unit will be designed for a continuous and stable operation from 40% of design feed rate.
On-stream Factor:	330 days/year (90% uptime)
Special Design Requirements:	Limited cooling water makeup available

1.2 GENERAL SITE DATA

1.2.1 SITE REFERENCE

The proposed site is at CEMEX Balcones cement plant in New Braunfels, TX.

Latitude:	North 29.709°
Longitude:	West 98.046°
Plant Area:	South of Wald Rd
Elevation Above Sea Level:	645 ft (196.6 meters)
Total Plot Area:	Approximately 15 acres
Boundary Description:	See plot below

1.2.2 ELEVATIONS

Approx. Site Elevation Above Mean Sea Level:	645 ft (197 m)
Average Frost Penetration:	None

1.2.3 OCEAN AND TIDE INFORMATION

High Tide Level:	n/a
Low Tide Level:	n/a

1.2.4 RIVER LEVELS

Name of River:	n/a
High Level:	n/a
Low Level:	n/a
100 Year Flood Level:	n/a

1.2.5 EXISTING UNDERGROUND

Nothing identified at this time.

1.3 METEOROLOGICAL DATA

1.3.1 TEMPERATURE AND HUMIDITY

Ambient Conditions:	**Units**	**Maximum (Summer)**	**Minimum (Winter)**
Average Dry Bulb Temperature:	°F		
Extreme Dry Bulb Temperature:	°F	108	21.9
Average Relative Humidity:	%		
ANSI Piping Sun Metal Temperature:	°F		
ASME Pressure Vessel MDMT:	°F	-	12
HVAC Design:	Use ASHRAE Standards:	Yes	
One Percentile Dry Bulb:	°F	98.6	31.8
Mean Coincident Wet Bulb	°F	74.2	n/a
Winterization:			
Design Freeze Temperature:	°F		TBD
Wind Speed:	mph		TBD
Permit Time to Freeze:	minutes		TBD
Cooling Towers:			
Dry Bulb Temperature:	°F	98.6	TBD

Ambient Conditions:	Units	Maximum (Summer)	Minimum (Winter)
Wet Bulb Temperature:	°F	74.2	TBD
Air Cooler Exchangers:			
Air Inlet Temperature:	°F	80	TBD
Air Compressors and Gas Turbines:			
Dry Bulb Temperature:	°F	98.6	TBD
Wet Bulb Temperature:	°F	74.2	TBD

1.3.2 BAROMETRIC PRESSURE

Design psia	Normal psia	Maximum psia	Minimum psia
14.70	14.36		
Design Maximum Rate of Change - psi/hr			

1.3.3 WIND INFORMATION

Directions of Prevailing Wind Referred to True Azimuth:				
13.5 ft/sec	for months from	January	to	December
	for months from		to	
Design Regulation or Code:	TBD			
Importance Factor:	TBD			
Exposure Category:	TBD			

1.3.4 RAINFALL INFORMATION

Design Rainfall Rate, inches/hr				
Average Annual Rainfall, inches	35 (for 20 years)			
Design Maximum Rainfall in One Hour, inches		exceeded once in		yr(s)
Design Maximum Rainfall in One Day, inches		exceeded once in		yr(s)
Rainy Season From:		to		
Additional Information:	Precipitation, in inches (1999-2019) Yearly average: 35 in. Max: 58.4 in. Min: 18.5 in.			

1.3.5 SNOWFALL INFORMATION

Normal Snow Loading, lb/ft^2		n/a	
Design Snow Loading, lb/ft^2		n/a	
Average Annual Snowfall, inches		n/a	
Snow Season From:	n/a	to	n/a
Additional Information:	New Braunfels normally does not have any snowfall throughout the year.		

1.3.6 LOCAL CORROSION/CONTAMINATION POTENTIAL

Dust:	TBD next phase
Saline Air:	TBD next phase
Sandstorm:	TBD next phase
Other (Specify):	

1.3.7 OTHER METEOROLOGICAL INFORMATION

1.4 UNITS OF MEASUREMENT

Selected Measurement System:	Imperial Units	
Type of Measurement	**Symbol**	**Full Name**
Acceleration	ft/s^2	Feet per second squared
Area	ft^2	Square feet
Concentration, Mole (Composition)	mol% mol.ppm	Mole percent Mole part per million (up to 1000 ppm)
Concentration, Mass (Composition)	wt% wt.ppm	Weight percent Weight part per million (up to 1000 ppm)
Density	lb/ft^3	Pound per cubic feet
Electric Current	A	Ampere
Electric Resistance	Ω	Ohm
Energy, Electrical	kW·h	Kilowatt hour
Energy, Mechanical	N·m	Newton meter
Energy, Thermal	kJ	Kilojoule
Flowrate, Molar	lbmole/hr	Pound moles per hour
Flowrate, Mass	lb/hr	Pounds per hour
Flowrate, Volumetric	ft^3/hr	Cubic feet per hour

Frequency	Hz	Hertz
Heat Capacity, Specific Heat	BTU/lb.F	British Thermal Unit per pounds Fahrenheit
Heat Content or Enthalpy	BTU/lb *or* BTU/ft^3	British Thermal Unit per pounds *or* British Thermal Unit per cubic feet
Heat Flow (Duty)	MW	Megawatt
Heat Transfer Coefficient	BTU/h.ft^2.F	British Thermal Unit per hour feet squared Fahrenheit
Illuminance (Light)	lx	Lux (lx = lumen/square meter)
Length, Distances	ft	Feet
Length, NPS (Nominal Pipe Size)	in	Inch (refer to ASME B36.10M for dimensions)
Mass	lb	Pounds
Power	kW *or* MW	Kilowatt *or* megawatt
Pressure	psi	Pounds per square inch
Pressure Differential	psi	Pounds per square inch
Specific Volume	ft^3/lb	Cubic feet per pound
Surface Tension	N/m	Newton per meter
Temperature	°F	Degrees Fahrenheit
Thermal Conductivity	BTU/ h.ft·F	British Thermal Unit per hour feet Fahrenheit
Time	s min hr D a	Second Minute Hour Day Annum (year)
Velocity	ft/s	Feet per second
Viscosity, Dynamic (Absolute)	cP	Centipoise
Viscosity, Kinematic	cSt	Centistoke
Voltage	V	Volt
Volume	ft^3	Cubic feet

2.0 CIVIL

2.1 SEISMIC REQUIREMENTS

Parameters determined per ASCE 7-2016

Risk Category = II

Site Class = D

S_S = 0.051

S_1 = 0.027

S_{DS} = 0.054

S_{D1} = 0.043

F_a = 1.6

F_v = 2.4

T_L = 12 seconds

Seismic Design Category = A

2.2 SOIL CHARACTERISTICS

Refer to "Preliminary Geotechnical Evaluation Report, Revised August 27, 2024" by Braun Intertec Corporation.

2.3 TYPES OF FOUNDATIONS

Tanks:	Mat foundations and piles/pile caps
Minor Buildings and Equipment:	Concrete Pads, Mat Foundations
Major Equipment and Structures:	Mat foundations and piles/pile caps

2.4 FIREPROOFING

Application Criteria (vessel skirts, structural steel, etc.):		TBD	
Materials:			
Time Rating:	hours	when tested to	

3.0 PROCESS

3.1 BATTERY LIMIT CONDITIONS

3.1.1 NORMAL CASE

	Unit		K1 K2-FG	NG-FG	NG
Phase			Vapor	Vapor	Vapor
Temperature	°F		242.9	303.1	80
Pressure	psia		14.36	14.05	14.70
Mass Enthalpy	Btu/lb		-1071	-1126	-1924
Mass Flow	lb/hr		2030967	478260	26792
Vol Flow	ft^3/min		611201	161685	10132
Mole Flow	lbmol/hr		69892	17199	1549
Molar Vap Frac.			1	1	1
Molar Liq Frac.			0	0	0
Avg MW			29	27.8	17.3
Heat Capacity	Btu/lb.F		0.26	0.27	0.51
Viscosity	lb/ft.hr		0.05	0.05	0.03
Thermal Cond	Btu/hr ft F		0.017	0.019	0.019
CO_2 Loading					
Component Mol Frac.%					
CO_2			11.50	8.69	1.00
H_2O			12.40	17.58	0
O_2			11.10	2.04	0
N_2+Ar			65.02	71.68	1.6
SO_2			1.97E-4		
CH_4					93.1
C_2H_6					3.2
C_3H_8					0.7
C_4H_{10}					0.4
Component Mass Frac.%					
CO_2			17.43	13.76	2.54
H_2O			7.67	11.39	0
O_2			12.23	2.35	0
N_2+Ar			62.71	72.23	2.59
SO_2					0
CH_4					86.1
C_2H_6					5.55
C_3H_8					1.78
C_4H_{10}					1.34

3.1.2 MAX CASE

	Unit		K1 K2-FG	NG-FG	NG
Phase			Vapor	Vapor	Vapor
Temperature	°F		263.3	303.1	80
Pressure	psia		14.36	14.50	14.7
Mass Enthalpy	Btu/lb		-1242	-1126	-1924
Mass Flow	lb/hr		2568272	710083	38028
Vol Flow	ft^3/min		788107	239876	14381
Mole Flow	lbmol/hr		87560	25516	2198
Molar Vap Frac.			1	1	1
Molar Liq Frac.			0	0	0
Avg MW			29.0	27.8	17.3
Heat Capacity	Btu/lb.F		0.26	0.27	0.51
Viscosity	lb/ft.hr		0.05	0.05	0.03
Thermal Cond	Btu/hr ft F		0.018	0.019	0.019
CO2 Loading					
Component Mol Frac.%					
CO_2			14.0	8.69	1
H_2O			13.5	17.58	0
O_2			10.6	2.04	0
N_2+Ar			61.9	71.68	1.6
SO_2			4.80E-04		
CH_4					93.1
C_2H_6					3.2
C_3H_8					0.7
C_4H_{10}					0.4
Component Mass Frac.%					
CO_2			21.1	13.76	2.54
H_2O			8.3	11.39	0
O_2			11.5	2.35	0
N_2+Ar			69.1	72.23	2.59
SO_2			0.001		
CH_4					86.10
C_2H_6					5.55
C_3H_8					1.78
C_4H_{10}					1.34

3.2 FEED COMPOSITIONS

3.2.1 NORMAL CASE

Component Mol Frac. %	Unit	K1 K2-FG	NG-FG	NG
CO_2	Mol%	11.5	8.69	1
H_2O	Mol%	12.4	17.58	0
O_2	Mol%	11.1	2.04	0
N_2+Ar	Mol%	65.0	71.68	1.6
SO_2	Mol%	2.0E-04		
CH_4	Mol%			93.1
C_2H_6	Mol%			3.2
C_3H_8	Mol%			0.7
C_4H_{10}	Mol%			0.4

3.2.2 MAX CASE

Component Mol Frac. %	Unit	K1 K2-FG	NG-FG	NG
CO_2	Mol%	14.0	8.69	1
H_2O	Mol%	13.5	17.58	0
O_2	Mol%	10.6	2.04	0
N2+Ar	Mol%	61.9	71.68	1.6
SO_2	Mol%	4.8E-04		
CH_4	Mol%			93.1
C_2H_6	Mol%			3.2
C_3H_8	Mol%			0.7
C_4H_{10}	Mol%			0.4

3.3 PRODUCT DESIGN CONDITIONS

Stream	Condition	Fluid Phase	Press. psia	Temp. °F
Product CO_2 to Pipeline	Mech Design			
	Oper Min	V	2211.82	122
	Oper Max			

3.4 PRODUCT COMPOSITIONS

Component	Unit	Value
CO_2	Vol % (min)	95
H_2O	ppmv	100
N_2	Vol % (max)	4
O_2	Vol % (max)	0.001
Ar	Vol % (max)	4
CH_4	Vol % (max)	4
H_2	Vol % (max)	4
CO	ppmv	35
SO_2	ppmv	100
NO_X	ppmv	50

3.5 OTHER CONSIDERATIONS

4.0 CHEMICALS

Material	Source or Interface	Physical State	Purity or Strength	Delivery Method	Warehouse Quantity
NAS Solvent	From Truck	L		Truck	
Sulfuric Acid	From Truck	L	~95 Wt %	Truck	
Caustic (NaOH)	From Truck	L	35 Wt %	Truck	

5.0 UTILITY SYSTEMS

5.1 FUELS

Liquids	Source or Interface	Condition	Press. Psig	Temp. °F
Diesel	Truck	Mech Design:		
		Oper Min:	TBD	TBD
		Oper Max:		

Gases	Source or Interface	Condition	Press. Psig	Temp. °F
Natural Gas	Pipeline	Mech Design:		
		Oper Min:	0	80
		Oper Max:		

5.2 WATER

5.2.1 COOLING WATER

Source or Interface:	Cooling Water Package by Vendor
Mechanical Design Pressure, psia	90
Nominal Supply Pressure, psia	80
Nominal Return Pressure, psia	45
Vacuum Design Pressure, psia	Full Vacuum
Maximum Available Exchanger ΔP, psia	14.5
Supply Temperature, °F	82
Return temperature, °F	95
Max. Allowable Exchanger Outlet Temp Rise, °F	12.6

5.2.2 OTHER WATER STREAMS

Stream	Source or Interface	Min Press @ Grade, psia	Mech. Design Press, psia	Operating Temp, °F	Design Temp, °F
Raw Water	Wastewater Treatment Package by Vendor				
CT Makeup	From Service Water				
Hose Stations	TBD	TBD	TBD	TBD	TBD
BFW	From Deaerator	164.7	181.2	248	392
Demineralized Water	Package by Vendor	71	84	108	158
Potable	Municipal Water Supply	126	139	108	158
Hydrotest	TBD	TBD	TBD	TBD	TBD

5.2.3 ANALYSES OF WATER STREAMS

	Unit	Treated Wastewater & Service Water
pH		8.5
Carbon Dioxide	mg/L	1
Conductivity	µmhos/cm	556
Total Alkalinity	mg/L	206
Total Dissolved Solids	mg/L	328
Total Suspended Solids	mg/L	7
Arsenic/ICP (Total)	mg/L	<0.010
Cadmium/ICP (Total)	mg/L	<0.005
Chromium/ICP (Total)	mg/L	<0.010
Lead/ICP (Total)	mg/L	<0.005
Iron/ICP (Total)	mg/L	0.092
Silica as SiO_2	mg/L	6.32
Manganese/ICP (Total)	mg/L	<0.010
Mercury/CVAA (Total)	mg/L	<0.002
Sodium/ICP (Total)	mg/L	12.0
Calcium/ICP (Total)	mg/L	77.9
Magnesium/ICP (Total)	mg/L	18.3
Potassium/ICP (Total)	mg/L	2.15

	Unit	Treated Wastewater & Service Water
Nitrate-N	mg/L	1.6
Sulfate	mg/L	25
Chloride	mg/L	18

5.2.4 STEAM

Steam Level	LP
Nominal Pressure from Boiler, psia	164.7
Nominal Temperature from Boiler, °F	By Boiler Vendor
Supply Pressure to Equipment, psia	39.7 (sat.)
Supply Temperature to Equipment, °F	267
Mechanical Design Pressure, psia	42.7
Mechanical Design Temperature, °F	321
Reboiler Process Min Opr. Temperature, °F	185
Reboiler Process Max Opr. Temperature, °F	248
Source or interface	NG Boiler Package

5.2.5 STEAM CONDENSATE

Condensate Level	LP
Operating Pressure, psia	25.2
Operating Temperature, °F	240
Mechanical Design Pressure, psia	39.7
Mechanical Design Temperature, °F	290

5.2.6 AIR AND INERT GAS

Fluid	Source or Interface	Nom Press, psia	Norm Temp, °F	Mech Design Press, psia	Mech Design Temp, °F	Dew Point, °F
Instrument Air	Air Compressor	113	99	152	151	< -40
Standby Instr Air	Air Compressor	113	99	152	151	< -40
Utility Air	Air Compressor	123	99	152	151	Saturated
High Pressure Nitrogen	Nitrogen Generating Skid	145	99	160	151	< 5
Low Pressure Nitrogen	Nitrogen Header Letdown	45	99	160	151	< 5

6.0 FIRE PROTECTION SYSTEMS

6.1 FIRE PROTECTION

Refer to document DE-FE0032220-KBR-00-SE-D-ZF1-001.

7.0 ENVIRONMENTAL INFORMATION

7.1 SOURCES AND POLLUTION CONTROLS

7.1.1 AIR EMISSIONS

Source / Description	Air Contaminants	Pollution Control / Disposal To
Process Vents	SO2, NOX, VOC, Particulates, CO	Controls if required
Tanks	VOC	
Material Loading	VOC	
Material Unloading	VOC	
Wastewater Systems	VOC	Atmosphere
Fugitives	VOC	
Others		

7.1.2 LIQUID EFFLUENTS

Source / Description	Collection / Conveyance System(s)*	Treatment System / Disposal To
Process Water	Collected in Process system	Discharge to waste water treatment
Solvent	Collected in solvent sump	
Non-Oily Process Water		
Contaminated Surface Runoff		
Non-Contaminated Runoff	Discharge to storm sewer/ditches	
Cooling Tower Blowdown	Collected in U/G sewer	
Boiler Blowdown	Collected in U/G sewer	
BFW Treatment Waste	Segregated collection system	Neutralized and discharged
RW Treatment Wastes		
Spent Acid(s)	Segregated collection system	Neutralized and discharged
Spent Caustics(s)	Segregated collection system	Neutralized and discharged
Spent Solvents(s)	Segregated collection system	Neutralized and discharged
Sanitary Wastes	Discharge to sanitary sewer	
Others		

* Typical Abbreviations: OWS = Oily Water Sewer; PS = Process Sewer; CS = Chemical Sewer; CWS = Clean Water Sewer; U/G = Underground; A/G = Above Ground; G = Gravity; P = Pumped; C = Concrete; S = Steel; PL = Plastic

7.1.3 SOLID WASTES

Source / Description	Hazardous or Non-hazardous Classification	Treatment / Storage / Disposal To
Process Wastes	Hazardous	
Catalysts / Packings	Non-Hazardous	Recycled to supplier when appropriate or disposal to onsite landfill or incinerator
Catalyst / Packings Support Beds	Non-Hazardous	Disposal to Onsite land fill
Resins	Non-Hazardous	Disposal to Onsite land fill
Offsite Unit Sludges / Wastes		
Utility Unit Sludges / Wastes		
Maintenance Debris		
Plant Trash	Non-Hazardous	Onsite landfill or incinerator
Others		

7.2 ENVIRONMENTAL RELEASE REQUIREMENTS / LIMITATIONS

7.2.1 AIR EMISSIONS

Release Point	Description	Requirement or Limitation	Basis	Comment

7.2.2 LIQUID EFFLUENTS

Release Point	Description	Requirement or Limitation	Basis	Comment

7.2.3 SOLID WASTES

Release Point	Description	Requirement or Limitation	Basis	Comment

7.3 NOISE CONTROL REQUIREMENTS / LIMITATIONS

Noise Control: (Sound Pressure level limits in dBA)	
Equipment, at 3 feet (Where Feasible):	85
Work Area, (Where Feasible):	90
Worker Exposure (Averaged over 8 Hours):	90
Plant Fence Line:	To Be Determined
Absolute Maximum, for Emergency and Upset Conditions:	120
Other Applicable Client Specifications and National or Local Regulations:	To Be Determined

8.0 ELECTRICAL & CONTROL SYSTEMS

8.1 ELECTRICAL DESIGN

8.1.1 POWER

Voltage Nominal	Voltage at Users	Phase	Freq (Hz)	Fault Level Max MVA	Fault Level Min MVA
13.8 kV	13.2 kV	3	60	932	693
4.16 kV	4.0 kV	3	60	346	194
480 V	460 V	3	60	77	55

Electrical Systems Definition

Required (Yes/No)	Description	Furnished By
Yes	Incoming (Utility) Power. Voltage = 138 kV	CEMEX
Yes	Substations and Transformers (Main)	CEMEX

Required (Yes/No)	Description	Furnished By
Yes	Substations and Transformers (CO_2 Plant)	KBR
No	Emergency Power Systems	NA
Yes	Uninterruptable Power Supply	KBR
Yes	Instrument Power Supply (120 V, 60 Hz)	KBR
Yes	Plant Alarm System	KBR
Yes	Plant Telephone System	KBR
Yes	Sound-powered Telephone System	KBR
Yes	Radio System	KBR
Yes	Closed-circuit Television System	KBR
No	Aircraft Warning Lights	NA
No	Cathodic Protection - Impressed Current	NA
No	Cathodic Protection - Sacrificial Anode	NA
Yes	Electric Heat Tracing System	KBR

8.1.2 AREA CLASSIFICATION

Area Classification to be in Accordance with:	P&ID, Plot Plan and NFPA
Existing Drawing References (if available):	

8.2 CONTROL SYSTEMS DESIGN

8.2.1 GENERAL PHILOSOPHY

1	Type of basic process control system:											
	DCS	X	PLC		Analog	X	Pneumatic					
2	Extent of operator interface centralization in main control room vs. local control panels						Primarily Main Control Room Local panel interface (vendor packages) TBD					
3	Location of input/output devices that convert analog signals to digital signals for data highway transmission (DCS)											
	Field	X	Main Control Room		X	Remote I/O		X				
4	Safeguarding system philosophy:											
	Sensors & input trip position:		Open		X	Closed		X				
	Actuators & trip position		Energized			De-energized		X				
	Input redundancy required					Yes, per pHA						
	Output redundancy required					Yes, per pHA						
	Processor redundancy required					Yes						
5	Hardware platform for safeguarding system:											
	Hard-wired relays		Solid-state logic			PLC						
	DCS	X	High-integrity programmable controller									
6	"Advanced Control" requirements					n/a						
7	Analyzer system requirements					Flue Gas Feed Composition Cooled Flue Gas SO2 Captured CO2 Composition O2 Polishing Reactor Feed O2 CEMS						
8	Anti-surge control for compressors					n/a						
9	"Intrinsically safe" wiring practice requirements:											
	Not req'd		U.S. standard		X	European standard						
10	"Smart" transmitter requirements:					4-20mA, 24Vdc with HART version 7 protocol whenever available.						
11	Packaged equipment instrumentation requirements:											
	Vendor's standards		X		Match balance of plant							

8.2.2 DESIGN DETAILS

1	Instrument tagging system (including instruments with packaged equipment)	Per Project Document Numbering Procedure				
2	Noise criteria for valve sizing	<85 dB				
3	Instrument wiring system:	Standard	X	Special req'ts		
4	Data highways:	Single		Redundant	X	
	Separate routing	TBD	Fireproofed		No	
5	Other	• Interface to Smart MCCs will be Ethernet/IP. • Process and safety instruments to be analog 4-20mA and 24VDC digital input/output. • PVC jacketed TC tray cables, 600V, 90°C, suitable for indoor, outdoor, and sunlight resistant will be used for instrument wiring. Typical analog and low voltage digital control (24VDC) wiring will be twisted pair AWG#16 with an overall shield 1PR#16 TWOS. TCP Modbus and Ethernet cables will be industrial CAT6A Ethernet cables. Cables shall be suitable for installation in wet and dry locations. • All Instrument, PCN Network, IT, and additional DC signals will be routed in separate raceways from AC power/control cables. • All wiring shall be run in cable tray and galvanized rigid conduit (GRC). Field instruments will be wired to local Remote I/O Cabinets. Remote I/O cabinet control network connections (fiber optic or CAT6A cable) will be run to the nearest EICR or Control Room (CCR). • 24VDC power for field instruments will be provided from Remote I/O Cabinets.				

9.0 DESIGN PHILOSOPHIES

9.1 DESIGN PRESSURE AND DESIGN TEMPERATURE (DP/DT) PHILOSOPHY

9.1.1 DESIGN PRESSURE OF EQUIPMENT

Equipment will have a design pressure that is 1.1 times greater (or a minimum of 50 psig greater) than the maximum pressure provided in the heat and material balance.

9.1.2 DESIGN TEMPERATURE OF EQUIPMENT

Design temperature is calculated at design pressure (pdes) conditions, which is the highest pressure at which mechanical strength can be guaranteed. In the absence of any other specific criteria, design temperature equals to the maximum operating temperature added with 50 °F (T design = T oper. max. + 50 °F). All equipment and piping which are to be

steamed out shall additionally be designed for steam out temperature of 267 °F calculated at corresponding saturated steam pressure of 39.7 psia(abs).

9.2 SPARING PHILOSOPHY

9.2.1 PUMPS

Unless otherwise agreed, all pumps with immediate influence on the process must have a spare. Sparing of pumps with delayed influence on the process will be agreed on a case-by-case basis.

9.2.2 COMPRESSORS

Owing to the high reliability of centrifugal compressors, a spare will typically not be specified. Full spare capacity will be specified for reciprocating compressors, i.e. typical sparing philosophy is 2 × 100. CO_2 compressors are considered 1 X 100% for this phase.

9.3 ISOLATION PHILOSOPHY

9.3.1 ISOLATION

Refer to document DE-FE0032220-KBR-00-PR-G-PHL-001.

10.0 DESIGN MARGINS

Rich bypass flowrates – Ranges from 5% to 10% of total lean solvent flowrate.

Pump flow margins – 10% design margin.

Heating and cooling duties – 10% design margin.

11.0 CODES, REGULATIONS, AND SPECIFICATIONS

11.1 SPECIFICATIONS AND STANDARDS

Refer to Appendix 1: RTI NAS FEED – List of KBR / Industry FEED Design Standards / Specifications.

APPENDIX 1: RTI NAS FEED – LIST OF KBR / INDUSTRY FEED DESIGN STANDARDS / SPECIFICATIONS

Standard Number	Category	KBR Confidential / Proprietary	Title
Mechanical Engineering			
General			
2-1TS	Technical Standards		Positive Material Identification
3-3TS	Technical Standards		Post Weld Heat Treatment
4-7TS	Technical Standards		Overlay to API RP582- General Welding Requirements
7-1-SP	Standard Practices		Equipment and Piping Corrosion Monitoring Guidelines
8-1D	Design Specifications	IP	Inspection of Materials and Equipment
9-7D	Design Specifications	IP	Dynamic Vibration Limits for Foundations and Structures Supporting Centrifugal, Rotary and Reciprocating Machines
10-3SP	Design Specifications		Guidelines for Construction of Modular Process and Utility Plants
10-4SP	Standard Practices		Guidelines for Engineering of Modular Process and Utility Plants
13-2SP	Standard Practices		Start-up Temperatures and Pressures for Pressure Containing Equipment
13-4D	Design Specifications	IP	Selection of Materials and Fabrication Requirements to Avoid Stress Corrosion in Caustic/Alkaline Services
13-5SP	Design Specifications		Positive Material Identification Guidelines
17-1TS	Technical Standards		Hydraulic Bolt Tensioning for Vessels and HXs with M36 (1 1/2 in) bolting and larger
Heat Exchangers			
MC13-1M-US-BO-M&U	Technical Specifications	IP	HX Materials
MC41-1E	Technical Specifications	IP	S&T HXs
MC41-2E-US-BO-M&U	Technical Specifications	IP	S&T HXs for General Service
MC44-2E-US-ON-M&U	Technical Specifications	IP	Plate Heat Exchangers
Pressure Vessels			
MD20-2F-US-ON-M&U	Technical Specifications	IP	Vessels Trays and Internals
MD40-1F	Technical Specifications	IP	Pressure Vessels
MD40-2F	Technical Specifications	IP	Pressure Vessels for General Service
Tanks			
MF40-1F-US-ON-M&U	Technical Specifications	IP	API 650 Storage Tanks
MF40-2F-US-ON-M&U	Technical Specifications	IP	API 620 Field Erected Storage Tanks
Rotating Machinery			
MJ21-1E	Technical Specifications	IP	Axial and Centrifugal Compressors
MJ31-1E	Technical Specifications	IP	API Type Centrifugal Pumps
MJ37-1E	Technical Specifications	IP	General Service Horizontal Pumps
Utility Equipment			
MU33-1E	Technical Specifications	IP	Packaged Demineralizer

Standard Number	Category	KBR Confidential / Proprietary	Title
MU-41-1E	Technical Specifications	IP	Packaged Boilers
MU61-1E-US-ON-M&U	Technical Specifications	IP	Cooling Tower
HVAC			
ARC01015	Standard	IP	Architectural and Building Utilities Design Criteria
Process Engineering			
GD-GL-KBR-PR-0505	Design Philosophies	IP	Design Margin Philosophy
WM-GL-ECD-SY-0517	Design Philosophies	IP	Design Pressure and Temperature Philosophy
GD-GL-KBR-PR-0519	Design Philosophies	IP	Relief, Overpressure and Flare Philosophy
WM-GL-ECD-SY-0522	Design Philosophies	IP	Valving and Blinding Philosophy
WM-GL-ECD-SY-0523	Design Philosophies	IP	Vent and Drain Philosophy
WM-GL-ECD-SY-0524	Design Philosophies	IP	Insulation and Heat Tracing Philosophy
Piping Engineering			
10-1D	Design Specifications	IP	Process Plant Arrangement
P40-1D	Design Specifications	IP	Piping for Hydrocarbon and Chemical Processing Facilities
DM-GL-KBR-PI-0721	Layout Practices	IP	Onshore Plant Layout
DM-GL-KBR-PI-0722	Layout Practices	IP	Layout of Concrete and Earthwork
DM-GL-KBR-PI-0723	Layout Practices	IP	Layout around Fired Equipment
DM-GL-KBR-PI-0724	Layout Practices	IP	Layout around Exchangers
DM-GL-KBR-PI-0725	Layout Practices	IP	Layout around Reactors and Dryers
DM-GL-KBR-PI-0726	Layout Practices	IP	Layout around Towers
DM-GL-KBR-PI-0727	Layout Practices	IP	Layout around Tanks and Drums
DM-GL-KBR-PI-0728	Layout Practices	IP	Layout around Vessels
DM-GL-KBR-PI-0732	Layout Practices	IP	Layout around Rotating Equipment
DM-GL-KBR-PI-0733	Layout Practices	IP	Layout around Buildings and Architecture
DM-GL-KBR-PI-0737	Layout Practices	IP	Layout around Pipe Racks
WM-GL-KBR-PI-0738	Layout Practices	IP	Standard Piping Details
WM-GL-KBR-PI-602	Lists	IP	Critical Line Lists
DM-GL-KBR-PI-0609		IP	Stress Calculation Controls
DM-GL-KBR-PI-0611		IP	Calculation Method & Standard Load Cases
DM-GL-KBR-PI-0621		IP	Local Pipe Stress
DM-GL-KBR-PI-0681		IP	Equipment Nozzle Loading
P1-5TS-IMPERIAL		IP	Nozzle loading specification
P24-2E	Specification	IP	Manual Valve Specifications
P26-1F	Specification		Support Standards
WM-GL-KBR-PI-0721 & WM-GL-KBR-PI-0711	Specification	IP	ONSHORE PLANT LAYOUT & ONSHORE PLOT PLANS
WM-GL-KBR-PI-0601	Procedure	IP	PIPING MECHANICAL PROJECT EXECUTION

Standard Number	Category	KBR Confidential / Proprietary	Title
Electrical Engineering			
NFPA 70	Codes		National Electrical Code
NFPA 30	Codes		Flammable and Combustible Liquids Code
NFPA 497	Codes		Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installation in Chemical Process Areas
NEMA	Standards		National Electrical Manufacturers Association (Applicable individual standards or technical documents)
IES	Standards		Illuminating Engineering Society
2009 IECC	Codes		Commercial Lighting Requirements
IEEE	Standards		Institute of Electrical and Electronics Engineers (Applicable individual standards)
UL	Standards		Underwriters Laboratories (Applicable individual standards)
ASTM	Standards		American Society for Testing Materials (Applicable individual standards)
AGI32	Software		Lighting Illumination Calculation
SKM	Software		Electrical Calculations including equipment and cable sizing, load flow, short circuit, voltage drop, motor starting, etc.
ER3-1M-NO-ON-M&U ER3-2M-US-BO-M&U ER3-3M-US-BO-M&U	Specification	IP	General Electrical Specification (Cable, JB's, Cable Trays)
MJ41-1E-US-BO-M&U	Specification	IP	SQUIRREL CAGE INDUCTION MOTORS
MJ42-1E-US-BO-M&U	Specification	IP	FORM-WOUND SQUIRREL CAGE INDUCTION MOTORS
MJ43-1E-US-BO-M&U	Specification	IP	FORM-WOUND BRUSHLESS SYNCHRONOUS MOTORS
ET3-1E-US-BO-M&U / ET1-1E-US-BO-M&U	Specification	IP	MCC / Switchgear Specifications
E40-1D-US-BO-MU	Specification	IP	ELECTRICAL SYSTEMS
EF2-1E-US-ON-MU	Specification	IP	CATHODIC PROTECTION
MJ72-1E-US-BO-MU	Specification	IP	FORM WOUND BRUSHLESS SYNCHRONOUS GENERATORS
EU1-1E-US-BO-MU	Specification	IP	LIQUID-IMMERSED POWER TRANSFORMERS
EU2-1E-US-BO-MU	Specification	IP	LIQUID-IMMERSED DISTRIBUTION TRANSFORMERS
EW1-1E-US-BO-MU	Specification	IP	STATIC PWM UNINTERRUPTIBLE POWER SUPPLIES
EW2-1E-US-BO-MU	Specification	IP	BATTERIES AND CHARGERS
EF3-1E-US-ON-U	Specification	IP	ELECTRIC HEAT TRACING
CSE Engineering	**(Control Systems Engineering)**		
PCCA001	Criteria (Design Specification)		Fixed Gas Detection Design Criteria (PIP)
PCCCV001	Criteria (Design Specification)		Control Valves Selection Criteria (PIP)

Standard Number	Category	KBR Confidential / Proprietary	Title
PCCCV002	Criteria (Design Specification)		Pressure Regulators Selection Criteria (PIP)
PCCCV003	Criteria (Design Specification)		Remotely Actuated On-Off Valves Selection Criteria (PIP)
PCCEL001	Criteria (Design Specification)		Instrumentation Electrical Design Criteria (PIP)
PCCFL001	Criteria (Design Specification)		Flow Measurement Criteria (PIP)
PCCGN002	Criteria (Design Specification)		General Instrumentation Design Criteria (PIP)
PCCIP001	Criteria (Design Specification)		Instrument Piping and Tubing Systems Criteria (PIP)
PCCLI001	Criteria (Design Specification)		Level Measurement Design Criteria (PIP)
PCCPA001	Criteria (Design Specification)		Process Analyzer System Design Criteria (PIP)
PCCPR001	Criteria (Design Specification)		Pressure Measurement Design Criteria (PIP)
PCCTE001	Criteria (Design Specification)		Temperature Measurement Design Criteria (PIP)
PCEA001	Engineering Guide		Fixed Gas Detection Guidelines (PIP)
PCECV001	Engineering Guide		Guidelines for Application of Control Valves (PIP)
PCECV002	Engineering Guide		Pressure Regulators Selection Guidelines (PIP)
PCECV003	Engineering Guide		Guidelines for Application of Remotely Actuated On-Off Valves (PIP)
PCEFL001	Engineering Guide		Flow Measurement Guidelines (PIP)
PCELI001	Engineering Guide		Level Measurement Guidelines (PIP)
PCEPA002	Engineering Guide		Process Analyzer Project Implementation Guidelines (PIP)
PCETE001	Engineering Guide		Temperature Measurement Guideline (PIP)
I35-1D-BASE-US-BO-M&U	Specification	IP	Safety Requirements Specification
I3510E BASE-US-BO-M&U	Specification	IP	BASIC PROCESS CONTROL SYSTEMS REQUIREMENTS
CSA Engineering	**(Civil, Structure, Architecture Engineering)**		
ICC - IBC 2018	Code		2018 INTERNATIONAL BUILDING CODE (IBC)
ASCE 7-16	Code		ASCE 7-16 MINIMUM DESIGN LOADS AND ASSOCIATED CRITERIA FOR BUILDINGS AND OTHER STRUCTURES
ANSI/AISC 360-16	Code		AISC - STEEL CONSTRUCTION MANUAL 15TH EDITION
ACI CODE-318-19	Code		ACI CODE-318-19: BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE AND COMMENTARY
PIP STS05120	Standard		PIP Standards - Structural and Miscellaneous Steel Fabrication Specification
PIP STS03001	Standard		PIP Standards - Plain and Reinforced Concrete Specification

Appendix B Process Engineering

Appendix B.1 Process Area Descriptions

PROCESS DESCRIPTION

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	12-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	CMA	SP	DDB	
B	13-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	CMA	SP	DDB	
C	25-APR-24	ICR – ISSUE FOR CLIENT REVIEW	IV	JRZ	DDB	
D	30-OCT-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	
E	09-DEC-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	12-OCT-2023	ALL	ICR – Issued for Client Review
B	13-OCT-2023	ALL	Incorporated Client comments, updated abbreviations
C	25-APR-2024	ALL	Updated as per latest revision of P&ID
D	30-OCT-2024	Cover	Updated confidentiality and export compliance statements
E	09-DEC-2024	3.2, 3.5, 11	Updated descriptions of Absorber Column, Regenerator Reboiler, and Stack

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1. INTRODUCTION

1.1 PROJECT OVERVIEW

RTI International, with CEMEX Inc., SLB, and KBR Inc., are participating in a joint effort to perform a Front-End Engineering Design (FEED) study for carbon dioxide (CO_2) capture from cement flue gas. The FEED study will evaluate the integration of a CO_2 capture system at the Balcones Cement Plant at New Braunfels, Texas.

The CO_2 capture plant is designed to remove at least 95% of CO_2 from the flue-gas from the Balcones cement plant kilns K1 and K2, and the associated natural gas boiler for steam generation. The captured CO_2 has a purity of > 95% CO_2, and is dried, polished to meet pipeline specifications, and compressed to 2215 psia (152.7 bara) to be made ready for sequestration. The capture plant (ISBL) consists of an integrated direct contact cooler (DCC) and SO_2 polisher, a flue gas blower, an absorption column with intercoolers, a regeneration column, associated pumps, storage and receiver vessels, and a CO_2 compression, dehydration, and polishing train.

1.2 SUMMARY OF UNITS

1.2.1 UNIT 01 – CO_2 CAPTURE

This unit contains the Direct Contact Cooler, the Absorber with integrated water wash and acid wash sections, the Lean/Rich Solvent Exchange, and the Regenerator. The Direct Contact Cooler cools the incoming flue gas while also reducing the SO_2 concentration from ~2-5 ppmv in the incoming flue gas down to <1 ppmv using an aqueous solution of sodium hydroxide (NaOH) to neutralize the SO_2. The CO_2 Absorber is a packed column containing structured packing. After absorption, the treated flue gas enters two water wash sections followed by an acid wash section, where the amine concentration is reduced to less than 1 ppm. The Regeneration Column strips the CO_2 from the solvent so the solvent can be recycled back into the Absorber. The captured CO_2 from absorption and regeneration is then sent to the compression, polishing, and dehydration unit.

1.2.2 UNIT 02 – CO_2 COMPRESSION, DEHYDRATION, AND POLISHING

The CO_2 product gas from the Regenerator is sent to the CO_2 compression unit. The CO_2 stream is compressed to 2212 psia (152.5 bara) and conditioned to meet pipeline specifications for transport.

1.2.3 UTILITY SYSTEMS

These units contain all the physical equipment (requiring plot space) used in generating and handling utility streams. These units include:

- Unit 11 – Raw, Potable, and Demineralized Water Systems
- Unit 12 – Boiler and Steam Systems
- Unit 14 – Solvent and Chemical Storage
- Unit 15 – Cooling Water System

- Unit 16 – Air/Nitrogen Systems
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack
- Unit 22 – Utility Headers

1.2.3.1 UNIT 11 – RAW WATER, POTABLE WATER AND DEMINERALIZED WATER TREATMENT

This unit takes in process water and potable water and produces and distributes demineralized water, service water, and fire water.

1.2.3.2 UNIT 12 – BOILER AND STEAM SYSTEM

The Boiler and Steam System removes dissolved oxygen from the demineralized water to produce and supply BFW to the BFW header. The unit also generates and distributes LP steam.

1.2.3.3 UNIT 14 – SOLVENT AND CHEMICAL STORAGE

This unit holds and distributes H_2SO_4, NAS, and NaOH solution for use within the facility.

1.2.3.4 UNIT 15 – COOLING WATER SYSTEM

The Cooling Water System consists of a hybrid cooling tower, chemical treatment package, and pumps to supply cooling water to users.

1.2.3.5 UNIT 16 – AIR AND NITROGEN SYSTEMS

The Air and Inert Systems handle compression, drying, and storage of the facility's supply of plant air, instrument air, and nitrogen.

1.2.3.6 UNIT 18 – WASTEWATER TREATMENT PLANT

This unit collects and treats wastewater effluent streams from throughout the facility. It also prepares process water from the DCC and process pond for use as service water.

1.2.3.7 UNIT 20 – STACK

The stack handles treated flue gas and the relief loads from the facility.

1.2.3.8 UNIT 22 – UTILITY HEADERS

This unit contains all interconnecting utility header piping that links the utility equipment with each unit that requires that utility.

2. ABBREVIATIONS

BFW – Boiler Feed Water

CEMS – Continuous Emissions Monitoring

System CO_2 – Carbon Dioxide

DCC – Direct Contact Cooler

DMW – Demineralized Water

FEED – Front-End Engineering Design

FG – Fuel Gas

H_2SO_4 – Sulfuric Acid

ISBL – Inside Battery Limit

KO – Knockout

LP – Low Pressure

N_2 – Nitrogen

NAS – Non-Aqueous Solvent

NaOH –Caustic

OSBL – Outside Battery Limit

TEG – Triethylene Glycol

SO_2 – Sulfate

WWTP – Waste Water Treatment Plant

3. UNIT 01 – CO_2 CAPTURE SYSTEM

3.1 DIRECT CONTACT COOLER

The flue gas stream from Kiln 1, Kiln 2, and the Natural Gas Boiler enters the Feed Direct Contact Cooler, or DCC (V-0111), where it is cooled and SO_2 concentration is reduced. Recirculated and cooled water from the DCC bottom enters the top of the DCC to cool the gas. The Feed Scrubber Wash Circulation Pump (P-0111 A/B/C) discharges the excess condensed water, and most of the remaining water is recirculated to the top of the bed while a small fraction of the stream splits off to be sent to the Wastewater Treatment Plant (WWTP). The DCC reduces the acid gas components in the flue gas, thus allowing the use of more cost-effective materials of construction in the blower. When the process water is recycled, water must go through the DCC Circulation Filter (F-0111), the Feed Scrubber Wash Air Cooler (E-0112), and the Feed Scrubber Wash Cooler (E-0111) before it returns to the top of the DCC. Cooled flue gas exits through the top of the DCC to the Flue Gas Blower (K-0111 A/B) and then advances to the Absorber Column (C-0121).

3.2 ABSORBER COLUMN

Cooled flue gas from the Blower enters the bottom of the Absorber and flows upward, counter-current to the CO_2 lean solvent that is fed into the top of the absorber section from the Lean Solvent Air Cooler (E-0142) to remove CO_2 from the gas stream. Gases exiting the top of the Absorber Column are vented to safe location via a stack. Provisions for a continuous emission monitoring system (CEMS) are included in the design.

The solvent is collected and sent to the Absorber Interstage Surge Tanks (T-0121, T-0122), from which the Absorber Interstage Circulation Pumps (P-0121 A/B/C, P-0122 A/B/C) send the NAS solvent stream through an air cooler to remove the heat of absorption from the CO_2. The Absorber Interstage Air Coolers (E-0121, E-0122) cool the solvent before it continues back into the column above the next stage. At the bottom of the column, the now CO_2 rich solvent is discharged by the Rich Solvent Pump (P-0124 A/B/C) to both the Lean/Rich Solvent Heat Exchanger (E-0141) and to the Regenerator Column.

3.3 ABSORBER WASH SECTION

After the packed absorber stages, the gas reaches the wash section integrated into the top of the Absorber Column. This section is where trace amounts of amines are removed. The water wash section removes the bulk of the amines, and the condensed water, along with the amines, is returned to the top of the Absorber.

One washing stage brings the gas in contact with wash water from the Activated Carbon Beds that has been scrubbed of amine. Wash water passes through this stage, then collects and enters the Absorber Overhead Wash Water Surge Drum. The water is pumped out of the drum by Absorber Overhead Wash Water Pump (P-0132 A/B/C) into the Absorber Overhead Wash Water Cooler (E-0132 In Wash Water Cooler, the wash water transfers heat

to a stream of cooling water before it enters the Activated Carbon Beds (V-0134). The beds are lined up so that once one bed is loaded with amine, the spent bed can be taken off-line while the others can continue the flow of wash water back to the Absorber.

The final stage of the column is the acid washing stage. A stream of wash water with sulfuric acid enters the top of the Absorber Column above the packing. The acid stream leaves the column after passing through the packing and enters the Absorber Overhead Acid Wash Surge Drum (V-0133) where sulfuric acid is added from Unit 14 Sulfuric Acid Storage. The treated flue gas that leaves the top of the Absorber Column is sent to the Stack.

3.4 LEAN/RICH SOLVENT EXCHANGE

CO_2 lean solvent from the Regenerator Column (C-0151) enters the Lean Solvent Surge Tank (T-0141) along with a makeup stream of NAS. CO_2 lean solvent coming into the Surge Tank first passes through the Lean/Rich Solvent Heat Exchanger (E-0141), in which heat is transferred between the CO_2 lean solvent and the CO_2 rich solvent from the Rich Solvent Pump (P-0124 A/B/C). The Surge Tank effluent discharged by the Lean Solvent Pump (P-0141 A/B/C) enters the Lean Solvent Air Cooler (E-0142). The CO_2 lean solvent then proceeds to the Absorber Column, with part of the flow passing through the Lean Solvent Particulate Filter (F-0141) and the Lean Solvent Carbon Filter (F-0142) during normal operation.

3.5 REGENERATOR

A slipstream of the CO_2 rich solvent from the Absorber Column enters the Regeneration Column (C-0151) and is distributed onto the upper packing stage along with reflux from the top of the column. The remainder of the CO_2 rich solvent passes through the Lean/Rich Heat Exchanger (E-0141) and enters the Regeneration Column at the top of the lower packing stage. A portion of the lean solvent from the bottom of the Regeneration Column is sent back to the Lean Solvent Surge Tank (T-0141) via the Lean/Rich Solvent Heat Exchanger. The remaining Regenerator Column bottoms is sent through the Regenerator Reboiler (E-0152 A/B/C/D), which uses a flow of LP steam to provide energy for regeneration. The reboilers draw feed from the chimney tray of the Regenerator Column. The vapor from the reboilers combines and is sent back to the column. The gas that reaches the top of the column first enters the Regenerator Overhead Condenser, after which it enters the Regenerator Overhead Condensate Drum (V-0151). From the Condensate Drum, pressure-controlled flow of captured CO_2 is sent to the Unit 02 CO_2 Compressor Package, and liquid reflux is recycled back to the Regenerator Column through the Regenerator Reflux Pump (P-0151 A/B). The vent line downstream of the pressure-control valve sends the captured CO_2 to the stack if there is any upset in the downstream unit (compressor package).

4. UNIT 02 – CO_2 COMPRESSION, DEHYDRATION, AND POLISHING

The CO_2 Compressor Package (K-0211) supplied by vendor compresses captured CO_2 from the Unit 01 Regenerator Column followed by polishing and TEG dehydration between the stages to meet the CO_2 product specifications. This package is comprised of a five-stage integrally geared compressor, heat exchangers, and suction/knock-out drums. The compressor is able to operate at relatively high temperatures, allowing the intercoolers to utilize a stream of BFW to recover heat from process gas and then send a return stream of LP steam to the utility header. O_2 polishing and TEG dehydration and steps occur as intermediate steps between stages 3 and 4 of the Compressor Package.

The O_2 Polishing Reactor (V-0221) is fed with CO_2 directly from stage 3 of the CO_2 Compressor Package and contains catalyst that reactors with the feed CO_2 gas and hydrogen to reduce O_2 concentration down to < 10 ppmv to meet the specifications for pipeline transport. The hydrogen supplied to the reactor is generated by electrolysis reaction, which is done in the vendor supplied Electrolyzer Package (A-0232), which utilizes demineralized water from OSBL.

The vendor-supplied TEG Dehydration Package (A-0221) is fed with CO_2 from the Polishing Reactor. A TEG makeup stream feeds into the package, and a TEG waste stream exits to the utility header. The polished, dehydrated CO_2 stream then re-enters into stage 4 of the Compressor Package to go through further cooling and compression and then is sent out through the pipeline.

5. UNIT 11 – RAW WATER SYSTEM

The Water Treatment Unit contains the following main sections:

- Raw Water System
- Demineralized Water System
- Potable Water System

5.1 RAW WATER SYSTEM

Treated wastewater from the Wastewater Treatment Package (A-1801) is sent to the Service Water Tank (T-1101) along with an additional supply raw well water from the pond via Process Water Pump (P-1801 A/B) as needed. From the tank, water is pumped by the Service Water Pump (P-1101 A/B) into the service water header, to the Unit 15 Cooling Water Package as makeup, and to the Demineralized Water Package. The Fire Water Pump (P-1102 A/B) supplies water from the Service Water Tank to the fire water header in case of an emergency. During normal operation, pressure in the fire water lines is maintained by the Fire Water Jockey Pump (P-1103 A/B), which also draws from the Service Water Tank. Both Fire Water and Jockey Pumps will be in compliance with NFPA 20. One Fire Water Pump will be diesel driven; the other Fire Water Pump will be motor driven. The tank outlet nozzle to the Service Water Pump is located at a sufficient height to ensure adequate fire water supply.

5.2 DEMINERALIZED WATER SYSTEM

The Demineralized Water Package (A-1101) removes inorganic salts from service water to reduce the likelihood of corrosion in the Deaerator (V-1201). Neutralization waste and demineralizer backwash from this package are intermittently sent to Unit 18 Waste Water Treatment. The demineralized water continues to the Demineralized Water Tank (T-1102), where it is further pumped to the Unit 12 Deaerator and the Unit 02 Electrolyzer Package by the Demineralized Water Pump (P-1104 A/B). If needed, demineralized water may also be sent to Unit 01 Direct Contact Cooler. The Demineralized Water Tank utilizes a pressure control valve to moderate nitrogen blanketing from the nitrogen header. A flow-controlled slip stream of demineralized water is intermittently recycled back to the Demineralized Water Package to be used as backwash/neutralization water.

5.3 POTABLE WATER SYSTEM

Potable water from the offsite municipality is stored in the Potable Water Tank (T-1103) and then pumped by the Potable Water Pump (P-1105 A/B) to the potable water header for distribution to all users.

6. UNIT 12 – BOILER AND STEAM SYSTEM

6.1 BOILER SYSTEM

A stream of demineralized water from the Unit 11 Demineralized Water Tank flows into the Deaerator (V-1201) after receiving a chemical injection for oxygen scavenging as a corrosion preventative from the BFW Chemical Package (A-1202). Steam condensate and a pressure-controlled stream of LP steam is introduced to the Deaerator from the LP steam header to strip the unwanted dissolved gases from the feed water. The unwanted gases are vented to the atmosphere at a safe location. The BFW is pumped out of the Deaerator by the BFW Pump (P-1201 A/B), where it is then sent to BFW users and directly to the Natural Gas Boiler Package (A-1203). The BFW Chemical Package (A-1201) is injected into this stream to control pH and scaling.

Blowdown from Unit 12 Natural Gas Boiler is sent to the Blowdown Drum (V-1202), from which flashed LP steam is sent to the LP steam header. Blowdown liquids from the bottoms are removed and sent to Unit 18 Primary Wastewater Treatment.

Steam condensate from the LP condensate header is sent to the Condensate Flash Drum (V-1203). Flashed gases are vented to atmosphere, and steam condensate collected at the bottom is sent to the Deaerator through the Condensate Pump (P-1203 A/B).

6.2 LP STEAM SYSTEM

For the production of LP steam, BFW from the Deaerator and a stream of natural gas are fed to the Natural Gas Boiler Package. The LP steam obtained from boiler enters the LP

steam header. The blowdown from the Boiler Package is sent to the Unit 12 Blowdown Drum, and flue gas is sent to the Unit 01 Feed Direct Contact Cooler.

7. UNIT 14 – SOLVENT AND CHEMICAL STORAGE UTILITIES

7.1 SOLVENT STORAGE SYSTEM

7.2 AMINE FILL IS SUPPLIED BY TRUCK DELIVERY THROUGH AN UNLOADING CONNECTION INTO THE SOLVENT STORAGE TANK (T-1401). AMINE SOLVENT IS DISCHARGED FROM THE TANK BY THE SOLVENT TRANSFER PUMP (P-1401 A/B) THROUGH THE SOLVENT SUMP FILTER (F-1401) AND THEN CARRIES ON TO THE UNIT 01 LEAN SOLVENT SURGE TANK. CAUSTIC STORAGE SYSTEM

The caustic solution is delivered by truck and discharged to the Caustic Storage Tank (T-1402) through an unloading connection. The solution is then sent to the Feed Direct Contact Cooler to neutralize SO_2 by the Caustic Transfer Pump (P-1403 A/B).

7.3 SULFURIC ACID STORAGE SYSTEM

Sulfuric acid is supplied by a truck unloading connection to the Sulfuric Acid Storage Tank (T-1403). Sulfuric acid is pumped from the tank by the Sulfuric Acid Transfer Pump (P-1404 A/B) to the acid washing stage of the Unit 01 Absorber Column.

8. UNIT 15 – COOLING WATER SYSTEM

The Cooling Water Package (A-1501) is supplied by vendor. The hybrid cooling tower operates using makeup water from the Unit 11 Service Water Tank. The cooling water supply is sent to the utility header, and cooling water blowdown is sent to Unit 18 Waste Water Treatment.

9. UNIT 16 – AIR/NITROGEN SYSTEMS

9.1 AIR COMPRESSOR SYSTEM

Air is compressed by the Primary Air Compressor Package (K-1601) and Secondary Air Compressor Package (K-1602). Both compressors are supplied by vendor and controlled by a split header pressure controller. The Air Distribution System is designed to close the plant air header control valve and start the Secondary Air Compressor after the instrument air header pressure drops below the minimum requirement. The air from the compressor packages enters the Air Receiver (V-1601), which also serves as emergency instrument air supply to safely shut down the plant in the event of a total loss of compressed air. The compressed air then feeds into the plant air header and the Instrument Air Dryer Package (A-1602) to reduce the dew point of the compressed air. The dried, compressed air then joins the instrument air header.

9.2 NITROGEN GAS SYSTEM

The inert gas used in the facility is nitrogen. The Nitrogen Generation Skid (A-1601) supplied by the vendor intermittently provides nitrogen for high pressure nitrogen users. The high pressure nitrogen at 145 psia is let down through a pressure controller valve to a low pressure nitrogen at 45 psia.

10. UNIT 18 – WASTE WATER TREATMENT PLANT

The Waste Water Treatment Package (A-1801) provided by the vendor is intended to treat water from both ISBL and OSBL areas. These streams include blowdown from the Unit 12 Blowdown Drum, neutralization waste and backwash from the Unit 11 Demineralizer, Cooling Water Blowdown from the Unit 15 Cooling Water Package, acid waste from the Acid Wash Pump (P-0133 A/B), process water from Feed Direct Contact Cooler (V-0111), blowdown from the Electrolyzer Package (A-0232), intermittent aqueous phase stream from the Unit 20 Knock Out Drum, and contact sewer drains from the facility. Treated water is recycled to the Unit 11 Service Water Tank (T-1101) or discharged to battery limit.

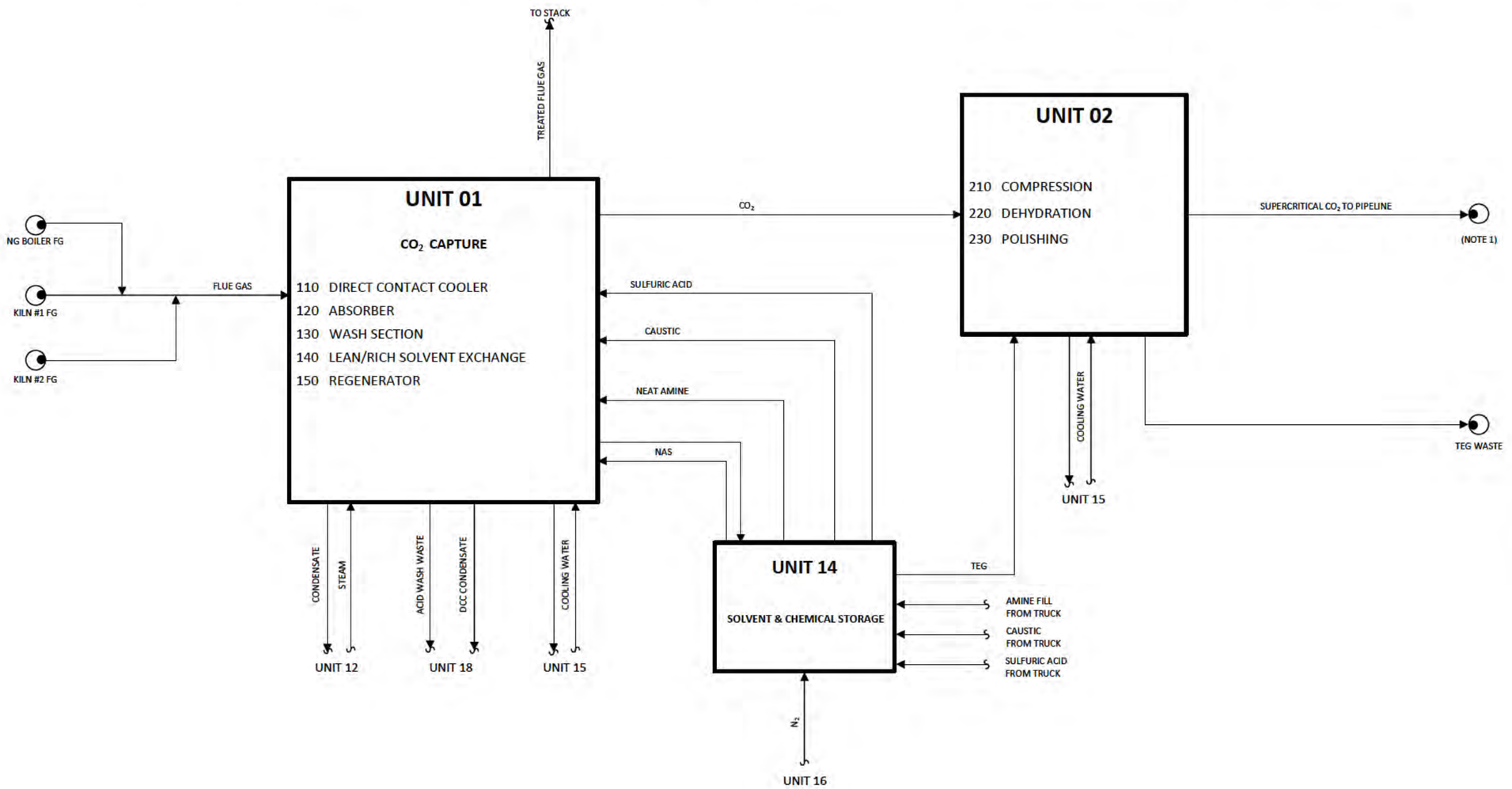
11. UNIT 20 – STACK

This unit manages the relief system and depressurizing loads from the facility. The stack is not expected to engage during normal operation. In the event of a relief or depressurization scenario, gases are routed to the stack through the main relief header.

Relief gases from the relief header enter the KO Drum (V-2001), which protects the Unit 20 stack system from liquid carryover. Gases from the top of the KO Drum are sent to the Stack (A-2001), which ties into the treated flue gas stream from the Unit 01 Absorber Column stack. Therefore, the discharge from the Absorber Column stack is the only emission point. CEMS monitors the effluent from the Absorber Column stack in Unit 01 and therefore is able to monitor the discharges from both Unit 01 and Unit 20. During plant upset in Unit 02, the captured CO_2 is also sent to stack.

The aqueous-phase liquid present in the KO Drum is intermittently discharged to Unit 18 Wastewater Treatment by the KO Drum Aqueous Phase Pump (P-2002) when the water level in the drum is deemed sufficiently high by a level control on the drum.

Appendix B.2 Block Flow Diagram



NOTES

1. CO_2 WILL BE EXPORTED TO OFF-SITE PIPELINE, DETAILS YET TO BE DETERMINED.

ABBREVIATIONS

CO_2	CARBON DIOXIDE
DMW	DEMINERALI ED WATER
FG	FLUE GAS
N_2	NITROGEN
H_2SO	SULFURIC ACID
WWTP	WASTE WATER TREATMENT PLANT
NG	NATURAL GAS
NAS	NON-A UEOUS SOLVENT
TEG	TRIETH LENE GL COL

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	SP	DDB	
ICR	C	13OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	B	06SEP2023	ISSUED FOR CLIENT APPROVAL	SD	SP	DDB	
ICR	A	25AUG2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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Engineering Services By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

BLOCK FLOW DIAGRAM
CARBON CAPTURE UNIT

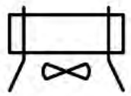
PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-00-PR-D-BFD-001	1 OF 1	D
KBR N-429	KBR		

Appendix B.3 Process Flow Diagrams

HEAT EXCHANGERS

SHELL AND TUBE

SHELL AND TUBE



AIR COOLER

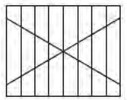
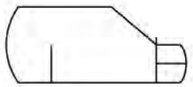
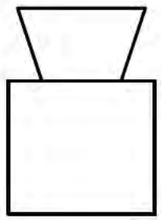


PLATE AND FRAME

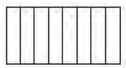


KETTEL REBOILER

SPECIALTY HEAT TRANSFER



COOLING TOWER

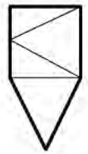


COOLING WATER EXCHANGER PACKAGE

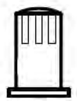
SOLIDS HANDLING

ROTARY VALVE

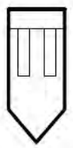
FILTER



CYCLONE



VESSEL BACKPULSE FILTER



INLINE BACKPULSE FILTER

CARTRIDGE FILTER

INLET STRAINER

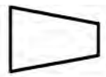
CLARIFIER

ROTATING EQUIPMENT

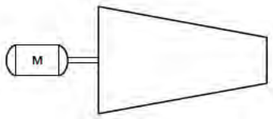
PUMP

STEAM TRAP PUMP

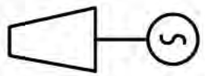
FAN



BLOWER



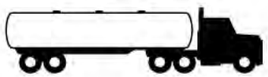
COMPRESSOR



TURBO-GENERATOR

TRANSPORTATION

BOX TRUCK

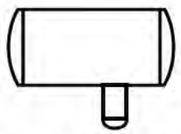


TANK TRUCK

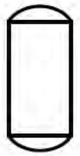
RAILCAR

VESSELS

HORIZONTAL VESSEL



HORIZONTAL VESSEL WITH WATER BOOT



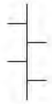
VERTICAL VESSEL

VESSEL INTERNALS

NOTE 1

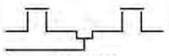
DEMISTER PAD

COALESCER



AGITATOR

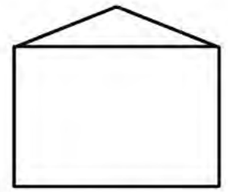
DISTRIBUTOR



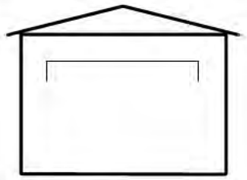
COLLECTOR

PACKING SUPPORT

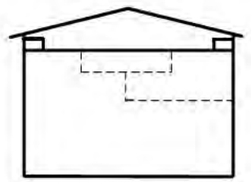
TANKS



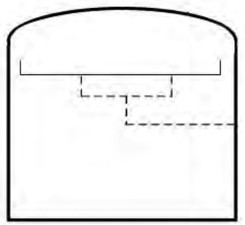
CONE ROOF TANK



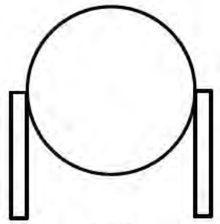
CLOSED FLOATING ROOF TANK



CLOSED FLOATING ROOF TANK WITH SKIMMER

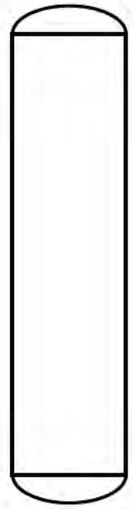


DOMED ROOF TANK WITH SKIMMER

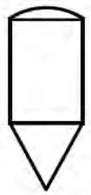


SPHERE

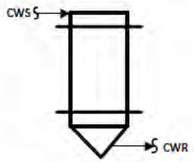
SPECIAL VESSELS



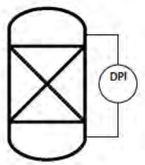
COLUMN



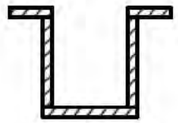
VERTICAL VESSEL WITH CONE



COOLED JACKETED VESSEL



PACKED VESSEL



BASIN

NOTES

1. DASHED LINES REPRESENT VESSEL INTERNALS.

ABBREVIATIONS

LEGEND

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	C	30OCT2024	ISSUED FOR DESIGN	SP	DDB	MHC	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SP	DDB	MHC	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SP	DDB	MHC	

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RTI INTERNATIONAL

KBR

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE

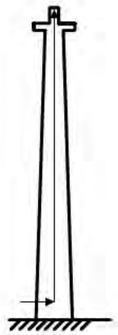
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM

GENERAL FACILITY – PROCESS DRAWING LEGEND

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT: DE-FE0032220	CLIENT: DE-FE0032220-KBR-00-PR-D-PFD-001	1 OF 2	C
KBR: N-429	KBR:		

OTHERS



STACK

EJECTOR

STATIC MIXER

SUPPLIED BY VENDOR

VENDOR PACKAGE EQUIPMENT

DRAIN SUMP

OIL/WATER/SOLIDS SEPARATOR

MISCELLANEOUS EQUIPMENT

OTHERS

ELECTRICAL HEATER

INSTRUMENTATION

MODULATING CONTROL VALVE

ACTUATED ON-OFF VALVE

CHECK VALVE

MANUAL THROTTLING VALVE

BUTTERFLY VALVE

MOTORIZED BUTTERFLY VALVE

BACK PRESSURE REGULATOR

PRESSURE REGULATOR

MANUAL VALVE

INSTRUMENT SIGNAL

DIFFERENTIAL PRESSURE INDICATOR

DIFFERENTIAL TEMPERATURE CONTROLLER

PRESSURE CONTROLLER

PRESSURE INDICATOR

LEVEL CONTROLLER

LEVEL INDICATOR

TEMPERATURE CONTROLLER

TEMPERATURE INDICATOR

FLOW CONTROLLER

FLOW INDICATOR

FEED FORWARD FLOW CONTROLLER

ANALYZER

CALCULATOR

HAND SWITCH

RISTRICTION ORIFICE

CONNECTORS

PRIMARY CONNECTOR

SECONDARY CONNECTOR

START-UP CONNECTOR

INSTRUMENT CONNECTOR

UTILITY CONNECTOR TO HEADER

OPEN SEWER

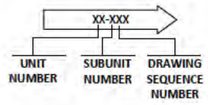
OPEN SEWER DRAIN

CONTACT DRAIN

CONTACT SEWER DRAIN

BATTERY LIMIT

OFF PAGE CONNECTOR FORMAT



NOTES

ABBREVIATIONS

LEGEND

IFD	C	30OCT2024	ISSUED FOR DESIGN	SP	DDB	MHC	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SP	DDB	MHC	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SP	DDB	MHC	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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Engineering Services By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE

Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM

GENERAL FACILITY – PROCESS DRAWING LEGEND

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-00-PR-D-PFD-002	2 OF 2	C
KBR N-429	KBR		

V-0111
FEED DIRECT
CONTACT COOLER

E-0111
FEED SCRUBBER
WASH COOLER

F-0111
FEED SCRUBBER
CIRCULATION FILTER

E-0112
FEED SCRUBBER
WASH AIR COOLER

FLUE GAS
FROM
KLIN #2

FLUE GAS
FROM
KLIN #1

FLUE GAS
FROM
NATURAL
GAS BOILER

1

M

2

K-0111 A/B

3

COOLED FLUE GAS
01-201
TO ABSORBER
COLUMN

TC

TI

13

V-0111

CWS

E-0111

CWR

TI

E-0112

FC

15

CAUSTIC

LC

F-0111
NOTE 2

12

pH

AI

14

PROCESS WATER
TO WASTE
WATER
TREATMENT

11

P-0111 A/B/C
NOTE 1

P-0111 A/B/C
FEED SCRUBBER WASH
CIRCULATION PUMP

K-0111 A/B
FLUE GAS BLOWER

NOTES

1. 3 x 50% PUMP OPERATION.
2. FINAL NUMBER OF FILTER ELEMENTS TO BE CONFIRMED BY DETAILED ENGINEERING CONTRACTOR.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT³/MIN

IFD	E	30OCT2024	ISSUED FOR DESIGN	AK	JRZ	DDB	
ICR	D	24MAY2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	C	23FEB2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	IV	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	IV	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 01 – FEED DIRECT CONTACT COOLER

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-01-PR-D-PFD-101	1 OF 1	E
KBR N-429	KBR		

T-0121
ABSORBER INTERSTAGE SURGE TANK 1

T-0122
ABSORBER INTERSTAGE SURGE TANK 2

E-0121
ABSORBER INTERSTAGE AIR COOLER 1

E-0122
ABSORBER INTERSTAGE AIR COOLER 2

C-0121
ABSORBER COLUMN

C-0121
NOTE 1

CO_2 LEAN SOLVENT
01-401
FROM LEAN SOLVENT TRIM COOLER

T-0122

LC

TI

P-0122A/B/C
NOTE 2

E-0122

T-0121

LC

TI

P-0121A/B/C
NOTE 2

E-0121

FI

COOLED FLUE GAS
01-101
FROM FLUE GAS BLOWER

3

LEVEL CONTROL
01-501
TO REGENERATOR COLUMN

LC

INT

WASH WATER
01-301
FROM ACTIVATED CARBON BED

P-0124A/B/C
NOTE 2

CO_2 RICH SOLVENT
01-401
TO LEAN/RICH SOLVENT HEAT EXCHANGER

CO_2 RICH SOLVENT
01-501
TO REGENERATOR COLUMN

P-0121A/B/C
ABSORBER INTERSTAGE CIRCULATION PUMP 1

P-0122A/B/C
ABSORBER INTERSTAGE CIRCULATION PUMP 2

P-0124A/B/C
RICH SOLVENT PUMP

NOTES

1. ABSORBER COLUMN CONTINUES ON PFD-301.
2. 3 x 50% PUMP OPERATION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT^3/MIN

IFD	D	30OCT2024	ISSUED FOR DESIGN	AK	JRZ	DDB	
ICR	C	23FEB2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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RTI NAS CARBON CAPTURE

Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM

UNIT 01 – ABSORBER COLUMN

PROJECT NUMBER	DRAWING NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-01-PR-D-PFD-201	1 OF 1	D
KBR N-429	KBR		

V-0131
ABSORBER OVERHEAD WASH WATER SURGE DRUM 1

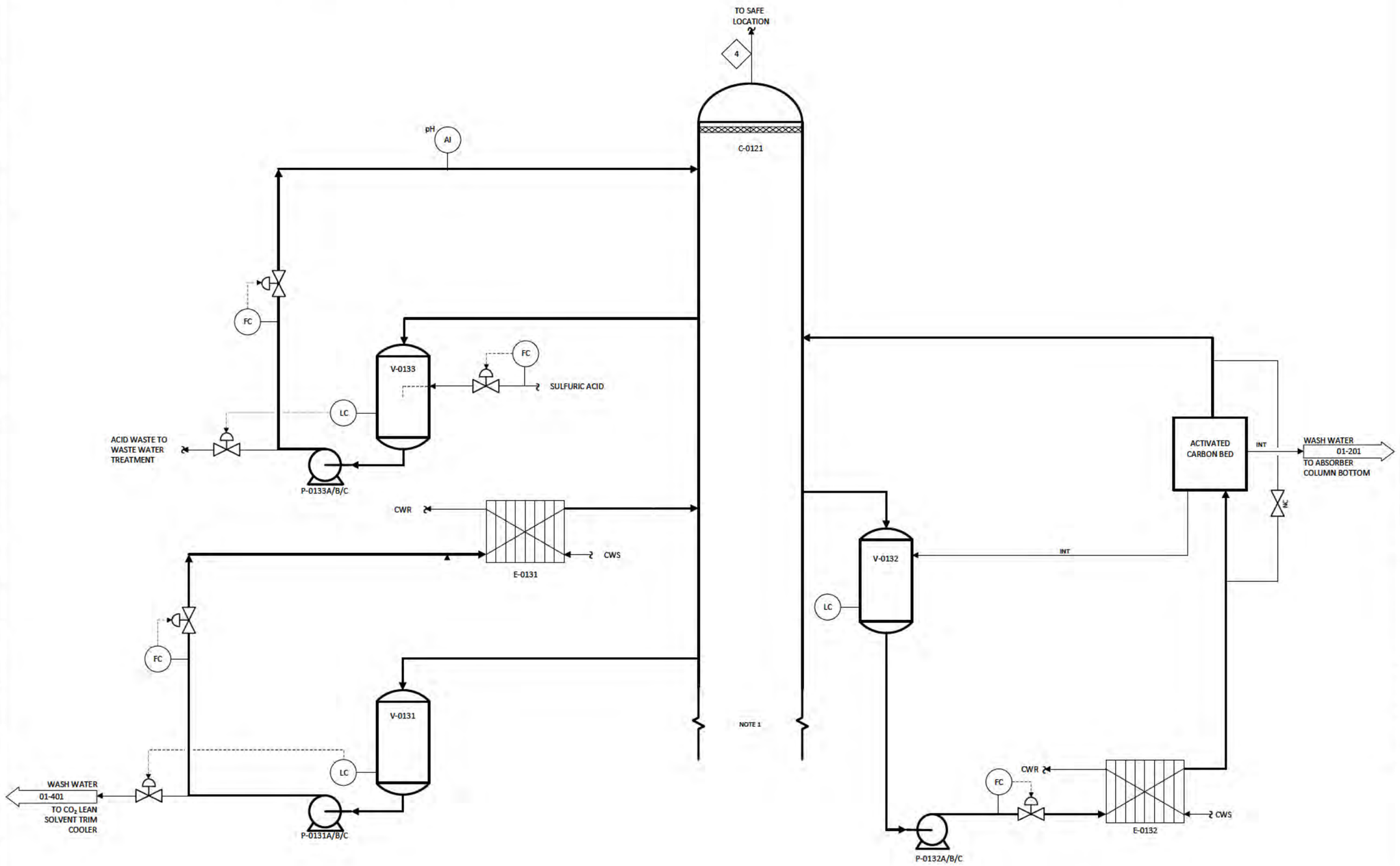
V-0133
ABSORBER OVERHEAD ACID WASH SURGE DRUM

E-0131
ABSORBER OVERHEAD WASH WATER COOLER 1

C-0121
ABSORBER COLUMN

V-0132
ABSORBER OVERHEAD WASH WATER SURGE DRUM 2

E-0132
ABSORBER OVERHEAD WASH WATERCOOLER 2



P-0133 A/B/C
ACID WASH PUMP

P-0131 A/B/C
ABSORBER OVERHEAD WASH WATER PUMP 1

P-0132 A/B/C
ABSORBER OVERHEAD WASH WATER PUMP 2

NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/HR

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	E	30OCT2024	ISSUED FOR DESIGN	AK	JRZ	DDB	
ICR	D	24MAY2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	C	23FEB2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	28SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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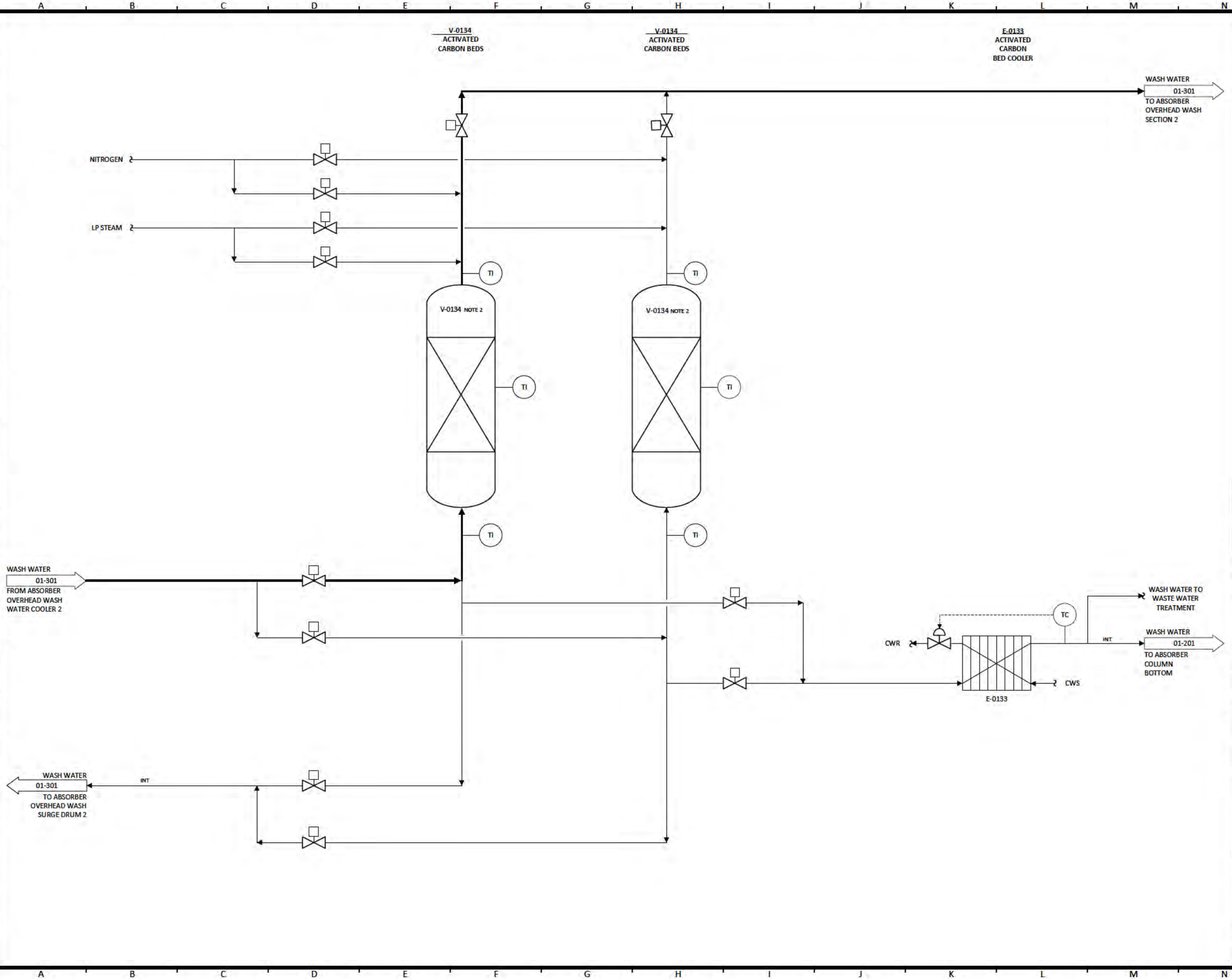
RTI INTERNATIONAL

Engineering Services By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 01 – ABSORBER WASH SECTION

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-01-PR-D-PFD-301	1 OF 1	E
KBR N-429	KBR		



NOTES

1. THIS IS A DETAILED DRAWING ON ACTIVATED CARBON BED SHOWN ON PFD-01-301.
2. TWO ACTIVATED CARBON BEDS ONE OPERATING AND ONE SPARE ARE SHOWN ON THIS PFD.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION — PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F — NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR — VOLUME FLOW, FT³/HR

IFD	D	30OCT2024	ISSUED FOR DESIGN	IV	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	DK	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	DK	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 01 – ACTIVATED CARBON BED

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN: DE-FE0032220	CLIEN: DE-FE0032220-KBR-01-PR-D-PFD-302	1 OF 1	D
KBR: N-429	KBR:		

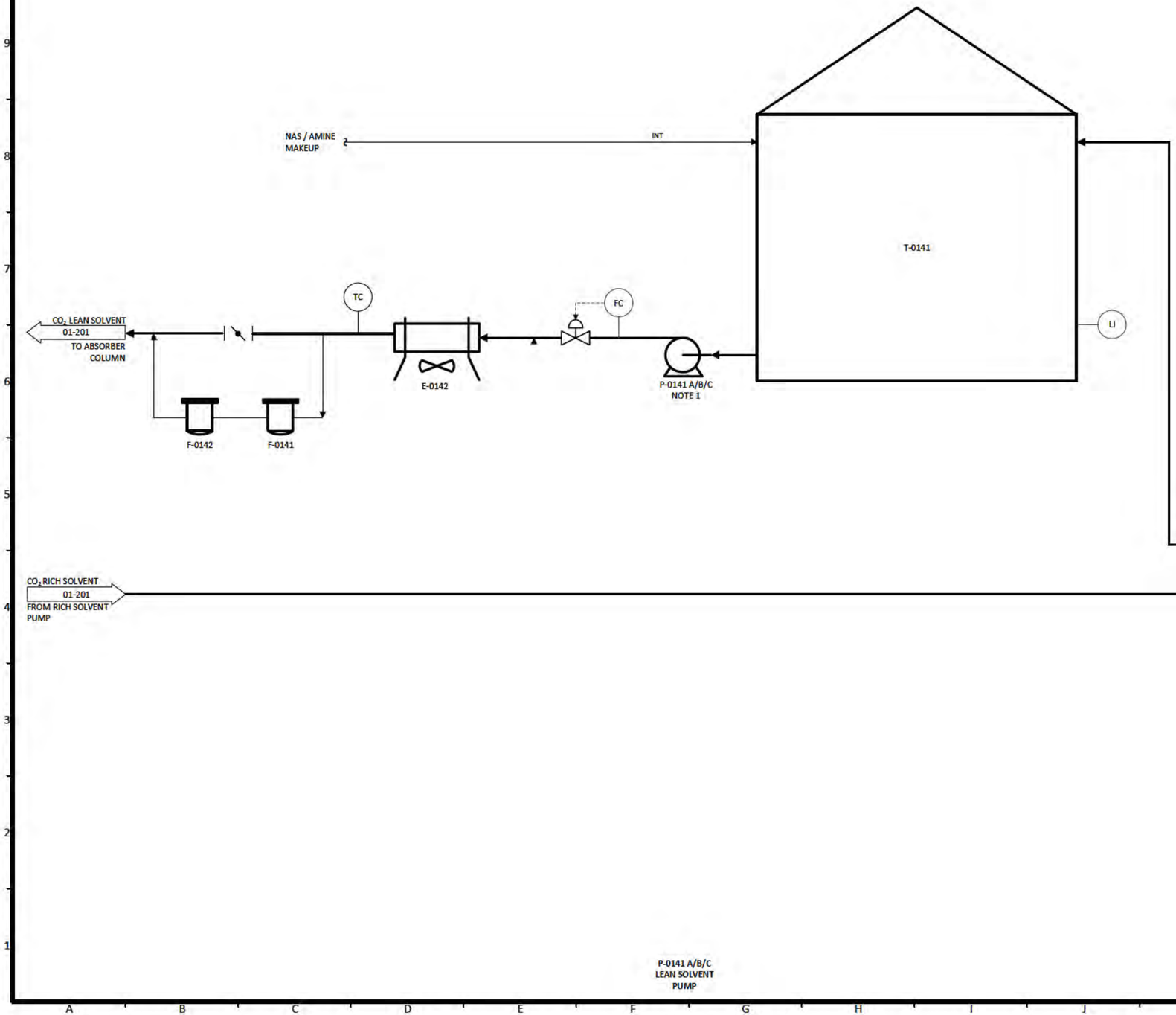
F-0142
LEAN SOLVENT
CARBON FILTER

F-0141
LEAN SOLVENT
PARTICULATE
FILTER

E-0142
LEAN SOLVENT AIR
COOLER

T-0141
LEAN SOLVENT
SURGE TANK

E-0141
LEAN/RICH SOLVENT
HEAT EXCHANGER



P-0141 A/B/C
LEAN SOLVENT
PUMP

NOTES

1. 3 x 50% PUMP OPERATION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT . MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	E	30OCT2024	ISSUED FOR DESIGN	AK	JRZ	DDB	
ICR	D	24MAY2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	C	23FEB2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 01 – LEAN/RICH SOLVENT EXCHANGER

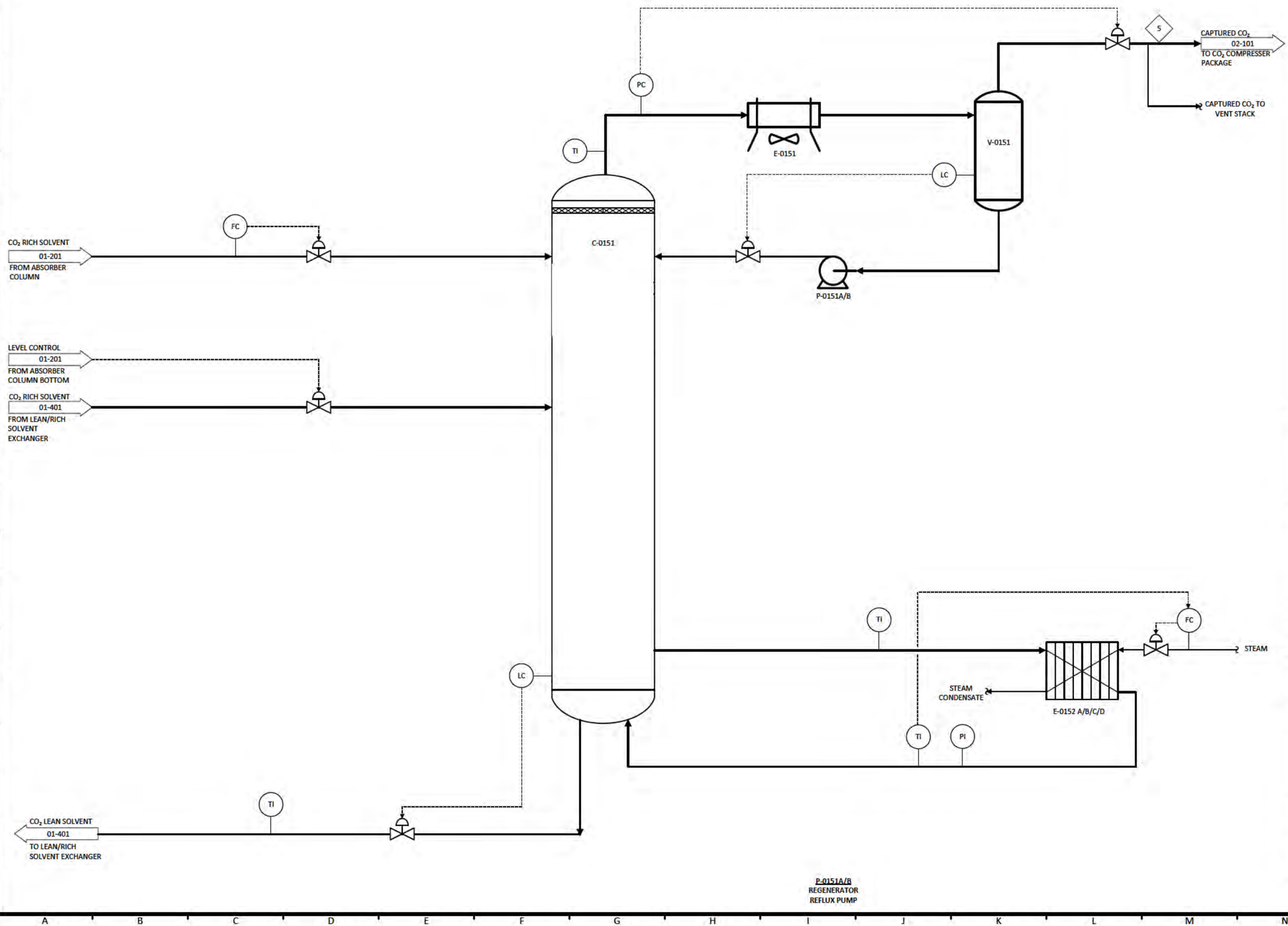
PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-01-PR-D-PFD-401	1 OF 1	E
KBR N-429	KBR		

C-0151
REGENERATOR
COLUMN

E-0151
REGENERATOR
OVERHEAD
CONDENSER

E-0152 A/B/C/D
REGENERATOR
REBOILER

V-0151
REGENERATOR
OVERHEAD
CONDENSATE DRUM



P-0151A/B
REGENERATOR
REFLUX PUMP

NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	IV	JRZ	DDB	
CR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	IV	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	IV	SP	DDB	

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RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 01 – REGENERATOR COLUMN

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT DE-FE0032220	CLIENT DE-FE0032220-KBR-01-PR-D-PFD-501	1 OF 1	D
KBR N-429	KBR		

A-0221
TEG DEHYDRATION
PACKAGE

K-0211
SUPPLIED BY VENDOR

BFW
37

CAPTURED CO_2
01-501
FROM REGENERATOR
COLUMN
5

44
COMPRESSED CO_2
TO PIPELINE

38
STEAM

41

39
CO2
02-103
TO POLISHING PACKAGE

TEG
MAKEUP
42

CW
SUPPLY

A-0221
SUPPLIED BY VENDOR

40
CO2
02-103
FROM POLISHING
PACKAGE

CW
RETURN

TEG WASTE

K-0211
CO_2 COMPRESSOR PACKAGE

NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/MIN

IFD	D	30OCT2024	ISSUED FOR DESIGN	IV	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	B	23FEB2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	IV	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 02 – CO_2 COMPRESSION AND DEHYDRATION

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-02-PR-D-PFD-101	1 OF 1	D
KBR N-429	KBR		

A-0232
ELECTROLYZER PACKAGE

OXYGEN VENT TO ATMOSPHERE

A-0232
SUPPLIED BY VENDOR
NOTE 2

PC

43

HYDROGEN
02-103
TO POLISHING UNIT

LC

OXYGEN

HYDROGEN

LI

DEMIN WATER

NOTE 1

NOTES

1. EQUIPMENT SHOWN IS FOR ONE ELECTROLYZER STACK. NUMBER OF ELECTROLYZER STACKS IS TO BE CONFIRMED.
2. ELEMENTS IN THE PACKAGE ARE A TYPICAL REPRESENTATION AND ARE TO BE UPDATED BASED ON VENDOR INFORMATION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT . MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	C	30OCT2024	ISSUED FOR DESIGN	IV	JRZ	DDB	
ICR	B	24MAY2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	A	01MAR2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	

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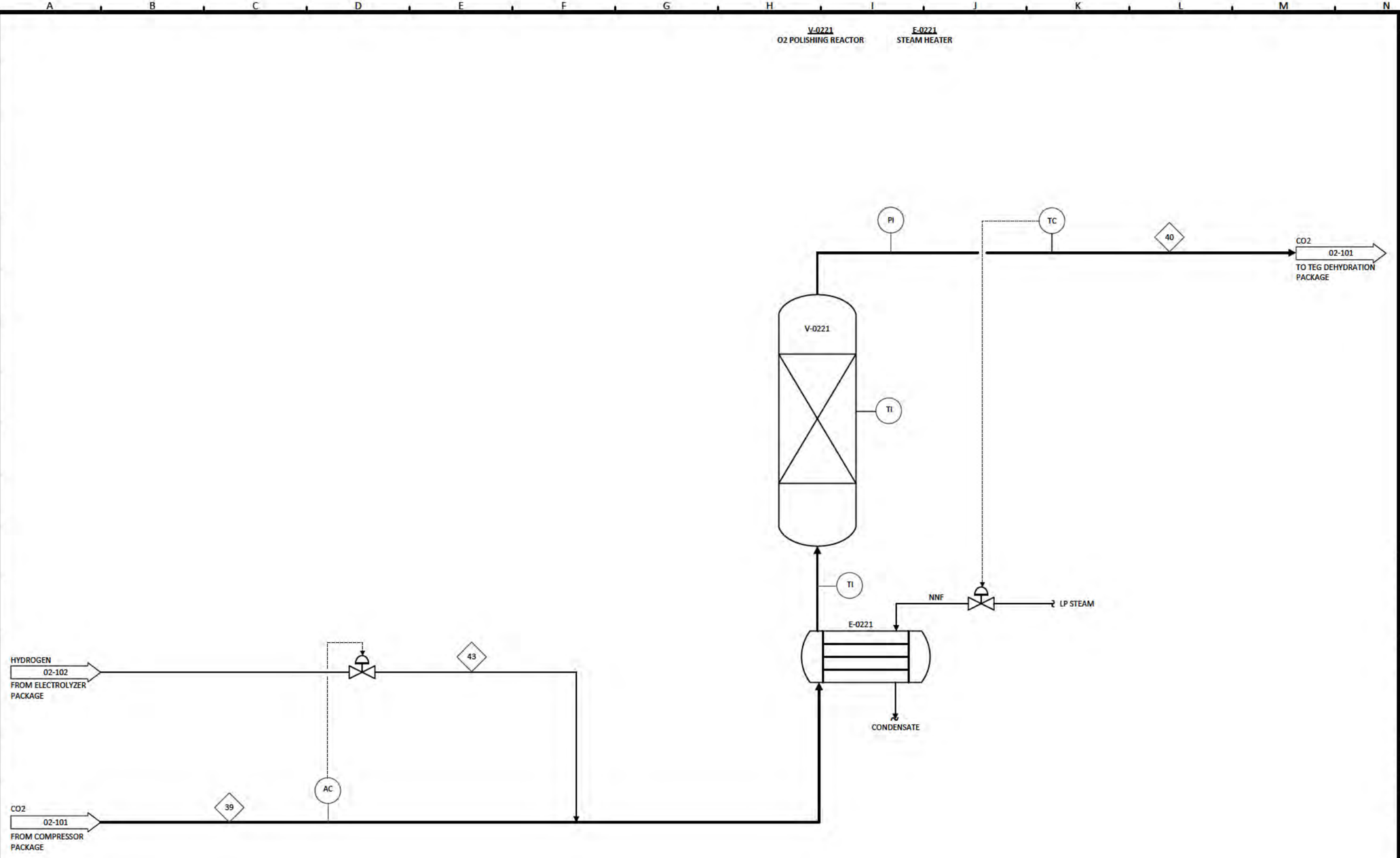
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM
UNIT 02 – ELECTROLYZER PACKAGE

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT DE-FE0032220	CLIENT DE-FE0032220-KBR-02-PR-D-PFD-102	1 OF 1	C
KBR N-429	KBR		



NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT . MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	C	30OCT2024	ISSUED FOR DESIGN	IV	JRZ	DDB	
ICR	B	24MAY2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	
ICR	A	01MAR2024	ISSUED FOR CLIENT REVIEW	IV	JRZ	DDB	

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RTI INTERNATIONAL

Engineering Services By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE

Balcones Cement Plant, New Braunfels, TX, USA

PROCESS FLOW DIAGRAM

UNIT 02 – POLISHING PACKAGE

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT DE-FE0032220	CLIENT DE-FE0032220-KBR-02-PR-D-PFD-103	1 OF 1	C
KBR N-429	KBR		

Appendix B.4 Heat and Materials Balance – ISBL

ISBL HEAT AND MATERIAL BALANCE

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	11-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
B	13-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
C	09-OCT-24	ICR – ISSUE FOR CLIENT REVIEW	AK	JRZ	DDB	
D	30-OCT-24	IFD – ISSUE FOR DESIGN	AK	JRZ	DDB	
E	22-AUG-25	IFD – ISSUE FOR DESIGN	AK	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	11-OCT-2023	ALL	ICR – Issue for Client Review
B	13-OCT-2023	ALL	Updated the template format
C	09-OCT-2024	ALL	Updated pressure from pump hydraulics
D	30-OCT-2024	Cover	Updated confidentiality and export compliance statements
E	22-AUG-2025	2	Added Streams 37-44

TABLE OF CONTENTS

1. NOTES.....4
2. ISBL HEAT AND MATERIAL BALANCE.....5

1. NOTES

1) Stream 1 to Stream 15 details provided by RTI.
2) Stream 15 (Caustic) data is for conditions at caustic pump suction.
3) The flue gas from Balcones Cement plant is generated in Cement Plant Klin-1, Cement Plant Klin-2 and associated Natural Gas Boilers used for steam generation. Flue gas from all the streams is collected and transported to the ISBL Area. The details of the streams are given below.

2. HEAT AND MATERIAL BALANCE

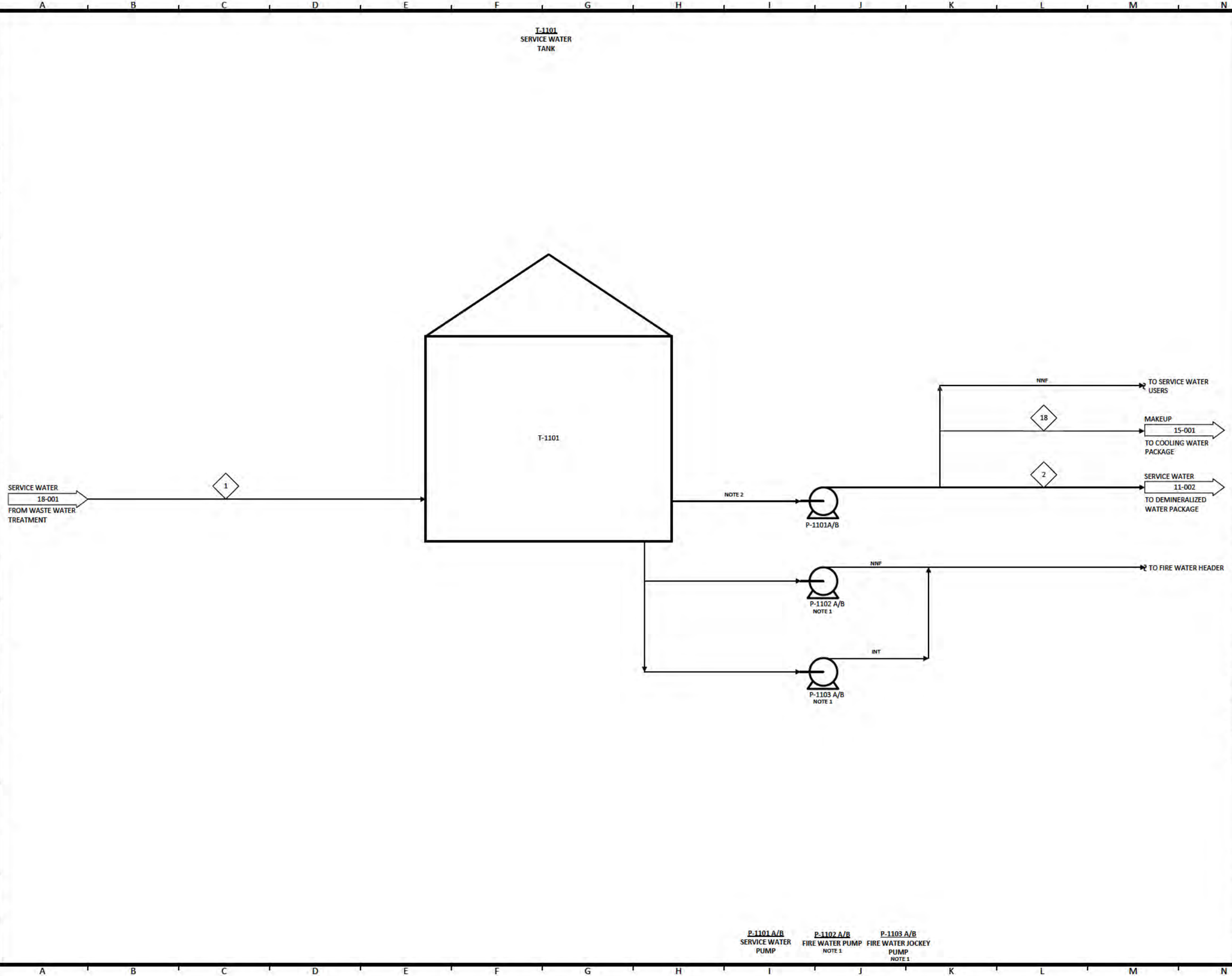
STREAM NUMBER				1		2		3		4		5	
DESCRIPTION				Flue Gas From B/L		Cooled Flue Gas From DCC		Cooled Flue Gas From Blower		Treated Flue Gas From Absorber Column		Captured CO2 From Regenerator Overhead Drum	
PFD				DE-FE032220-KBR-01-PR-D-PFD-101		DE-FE032220-KBR-01-PR-D-PFD-101		DE-FE032220-KBR-01-PR-D-PFD-101		DE-FE032220-KBR-01-PR-D-PFD-301		DE-FE032220-KBR-01-PR-D-PFD-501	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				V		V		V		V		V	
				Normal case	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	254.7	272 2	91.7	92 3	108.2	108.7	95.4	96.6	95.0	95 0
	Pressure		Psia	14.36	14.36	14.21	14.21	15.41	15.41	14 50	14.50	63 96	63.96
	Mass Enthalpy		BTU/lb	-1081	-1216	-859	-978	-855	-974	-250	-266	-3851	-3851
	Mass density		lb/ft3	0.05	0 05	0.07	0 07	0.08	0 08	0.07	0 07	0.48	0.48
	Enthalpy flow		MMBTU/hr	-2713	-3988	-2041	-3014	-2031	-3002	-494	-659	-1545	-2353
	Mass flow		lb/hr	2509601	3278355	2374761	3083109	2374761	3083109	1973536	2472216	401192	612167
	Volume flow		ft3/min	774415	1030108	551747	709297	524051	673567	481700	604967	13956	21251
	Mole flow		lbmol/hr	87092	113076	79607	102239	79607	102239	70421	88252	9183	14030
	Molar vapor fraction			1.00	1 00	1.00	1 00	1.00	1 00	1.00	1 00	1.00	1 00
	Molar liquid fraction			0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00
	Average MW			28.80	29 00	29.80	30 20	29.80	30.13	28.00	28.00	43.63	43.63
	Heat capacity		BTU/lb.F	0.26	0.26	0.24	0 24	0.24	0 24	0.25	0 25	0.21	0 21
	Viscosity		lb/ft.hr	0.05	0.05	0.04	0.04	0.04	0 04	0.04	0 04	0.04	0 04
	Thermal conductivity		BTU/h ft.F	0.018	0 018	0.014	0 014	0.014	0.014	0.015	0.015	0.010	0.010
VAPOR PHASE PROPERTIES	Mass Enthalpy		BTU/lb	-1081	-1216	-859	-978	-855	-974	-250	-266	-3851	-3851
	Mass density		lb/ft3	0.054	0 053	0.072	0 072	0.076	0 076	0.068	0.068	0.479	0.479
	Enthalpy flow		MMBTU/hr	-2713	-3988	-2041	-3014	-2031	-3002	-494	-659	-1545	-2353
	Mass flow		lb/hr	2509601	3278355	2374761	3083109	2374761	3083109	1973536	2472216	401192	610909
	Volume flow		ft3/min	774415	1030108	551747	709297	524051	673567	481700	604967	13956	21251
	Mole flow		lbmol/hr	87092	113076	79607	102239	79607	102239	70421	88252	9183	13984
	Heat capacity		BTU/lb.F	0 26	0.26	0 24	0.24	0 24	0.24	0.25	0.25	0.21	0.21
	Viscosity		lb/ft.hr	0 05	0.05	0 04	0.04	0 04	0.04	0.04	0.04	0.04	0.04
	Thermal conductivity		BTU/h ft.F	0.018	0 018	0.014	0 014	0.014	0 014	0.015	0 015	0.010	0 010
LIQUID PHASE PROPERTIES	Mass Enthalpy		BTU/lb										
	Mass density		lb/ft3										
	Enthalpy flow		MMBTU/hr										
	Mass flow		lb/hr										
	Volume flow		ft3/min										
	Mole flow		lbmol/hr										
	Heat capacity		BTU/lb.F										
	Viscosity		lb/ft.hr										
	Thermal conductivity		BTU/h ft.F										
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%	10 95	12.84	11 98	14.20	11 98	14.20	0.66	0.80	98.40	98.40
	Water	[H2O]	mole%	13.40	14.42	5.26	5.35	5.26	5.35	5.78	6.01	1 26	1.26
	Oxygen	[O2]	mole%	9.31	8.64	10.19	9.56	10.19	9.56	11 51	10.70	0.14	0.14
	Nitrogen + Argon	[N2]	mole%	66 34	64.10	72 57	70.89	72 57	70.89	82 04	82.13	0 20	0.20
	Sulfur dioxide	[SO2]	mole%	0 00037	0.00037								
	Hydrogen	[H2]	mol%										
	Sodium hydroxide	[NaOH]	mole%										
COMPONENT MASS PERCENT	Carbon Dioxide	[CO2]	wt%	16.73	19.49	17.69	20.69	17.69	20.74	1.04	1.26	99.43	99.43
	Water	[H2O]	wt%	8.38	8 96	3.18	3.19	3.18	3.20	3.72	3.87	0.52	0.52
	Oxygen	[O2]	wt%	10.34	9 53	10.94	10.13	10 94	10.15	13.15	12.23		
	Nitrogen + Argon	[N2]	wt%	64.53	61.92	68.22	65.76	68 22	65.91	82 08	82.17		
	Sulfur dioxide	[SO2]	wt%	0.0008	0 0008								
	Hydrogen	[H2]	wt%										
	Sodium hydroxide	[NaOH]	wt%										

STREAM NUMBER			11		12		13		14		15	
DESCRIPTION			Process Water From Feed Direct Contact Cooler Bottom		Process Water From Feed Scrubber Wash Circulation Pump (Recirculation)		Process Water From Feed Scrubber Wash Cooler		Process Water from Feed Scrubber to WWTP		Caustic From Caustic Transfer Pump	
PFD			DE-FE0032220-KBR-01-PR-D-PFD-101		DE-FE0032220-KBR-01-PR-D-PFD-101		DE-FE0032220-KBR-01-PR-D-PFD-101		DE-FE0032220-KBR-01-PR-D-PFD-101		DE-FE0032220-KBR-01-PR-D-PFD-101	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)			L		L		L		L		L	
			Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature	F	118.9	127.1	119.0	127.2	91.4	91.4	119 0	127.2	104 0	104.0
	Pressure	Psia	12.14	10.90	108.73	98.20	46 00	14.21	108.73	98.20	14.70	14.70
	Mass Enthalpy	BTU/lb	-6783	-6775	-6783	-6775	-6811	-6811	-6783	-6775	-6139	-6139
	Mass density	lb/ft3	60.60	60.30	60.60	60.30	61 50	61.50	60.60	60.30	85 90	85.90
	Enthalpy flow	MMBTU/hr	-60732	-67674	-59817	-66350	-60060	-66700	-915	-1323	-0.1	0
	Mass flow	lb/hr	8953320	9988722	8818480	9793476	8818480	9793476	134840	195246	29	37
	Volume flow	ft3/min	2463	2761	2426	2707	2389	2653	37	54	0 00	0
	Mole flow	lbmol/hr	496953	554422	489469	543584	489469	543584	7484	10838	3.6	4.7
	Molar vapor fraction		0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00
	Molar liquid fraction		1.00	1 00	1.00	1 00	1.00	1 00	1.00	1.00	1.00	1.00
	Average MW		18.00	18 00	18.00	18.00	18.00	18.00	18 00	18.00	22.40	22.40
	Heat capacity	BTU/lb.F	1.00	1 00	1.00	1 00	1.00	1 00	1.00	1 00	0.84	0.84
	Viscosity	lb/ft.hr	1.36	1 26	1.35	1 25	1.81	1 81	1.35	1 25	20.74	20.74
	Thermal conductivity	BTU/h ft.F	0.366	0 368	0.366	0.368	0.355	0.355	0 366	0.368	0 517	0.517
VAPOR PHASE PROPERTIES	Mass Enthalpy	BTU/lb										
	Mass density	lb/ft3										
	Enthalpy flow	MMBTU/hr										
	Mass flow	lb/hr										
	Volume flow	ft3/min										
	Mole flow	lbmol/hr										
	Heat capacity	BTU/lb.F										
	Viscosity	lb/ft.hr										
	Thermal conductivity	BTU/h ft.F										
LIQUID PHASE PROPERTIES	Mass Enthalpy	BTU/lb	-6783	-6775	-6783	-6775	-6811	-6811	-6783	-6775	-6139	-6139
	Mass density	lb/ft3	60.600	60.300	60.600	60.300	61.500	61.500	60.600	60 300	85.900	85 900
	Enthalpy flow	MMBTU/hr	-60732	-67674	-59817	-66350	-60060	-66700	-915	-1323	0	0
	Mass flow	lb/hr	8953320	9988722	8818480	9793476	8818480	9793476	134840	195246	29	37
	Volume flow	ft3/min	2463	2761	2426	2707	2389	2653	37	54	0	0
	Mole flow	lbmol/hr	496953	554422	489469	543584	489469	543584	7484	10838	3.60	4.70
	Heat capacity	BTU/lb.F	1 00	1.00	1 00	1.00	1 00	1.00	1 00	1.00	0.84	0.84
	Viscosity	lb/ft.hr	1 36	1.26	1 35	1.25	1 81	1.81	1 35	1.25	20.74	20.74
	Thermal conductivity	BTU/h ft.F	0 366	0.368	0.366	0.368	0.355	0 355	0.366	0 368	0.517	0 517
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%									
	Water	[H2O]	mole%								80.00	80 00
	Oxygen	[O2]	mole%									
	Nitrogen + Argon	[N2]	mole%									
	Sulfur dioxide	[SO2]	mole%									
	Hydrogen	[H2]	mol%									
	Sodium hydroxide	[NaOH]	mole%								20 0	20.0
COMPONENT MASS PERCENT	Carbon Dioxide	[CO2]	wt%									
	Water	[H2O]	wt%								64.32	64 32
	Oxygen	[O2]	wt%									
	Nitrogen + Argon	[N2]	wt%									
	Sulfur dioxide	[SO2]	wt%									
	Hydrogen	[H2]	wt%									
	Sodium hydroxide	[NaOH]	wt%								35.71	35.71

STREAM NUMBER				37		38		39		40		41	
DESCRIPTION				BFW to CO2 Compressor		Steam from CO2 Compressor Exchangers		CO2 from 3rd stage to Polishing Package		CO2 from Polishing Package to TEG Dehydration		Dehydrated CO2 to Compressor 4th Stage	
PFD				DE-FE0032220-KBR-02-PR-D-PFD-101		DE-FE0032220-KBR-02-PR-D-PFD-101		DE-FE0032220-KBR-02-PR-D-PFD-101		DE-FE0032220-KBR-02-PR-D-PFD-101		DE-FE0032220-KBR-02-PR-D-PFD-101	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		V		V		V		V	
				Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	248.0	248.0	267.0	267.0	122 0	122.0	124 0	124.0	122 0	122.0
	Pressure		Psia	187.90	187 90	39.70	39.70	527	527	522	522	517	517
	Mass Enthalpy		BTU/lb					-3817	-3817	-3817	-3817	-3840	-3840
	Mass density		lb/ft3	58.85	58.85	0.09	0.09	3.94	3.94	3.91	3.91	3 87	3.87
	Enthalpy flow		MMBTU/hr										
	Mass flow		lb/hr	64152	87879	62111	85084	401192	612167	400784	612245	398713	608381
	Volume flow		ft3/min	18.2	24 9	10942.7	14990.1	1695.3	2581.4	1709.7	2603 5	1717.4	2615 0
	Mole flow		lbmol/hr					9183	14030	9196.5	14049	9067.8	13835
	Molar vapor fraction					1.00	1 00	1.00	1.00	1.00	1.00	1 00	1.00
	Molar liquid fraction			1.00	1 00			0.00	0.00				
	Average MW							43.63	43.63	43 58	43.58	43 97	43.97
	Heat capacity		BTU/lb.F					0.21	0 21				
	Viscosity		lb/ft.hr					0.04	0 04				
	Thermal conductivity		BTU/h ft.F					0 010	0.010				
VAPOR PHASE PROPERTIES	Mass Enthalpy		BTU/lb										
	Mass density		lb/ft3					3 944	3.944				
	Enthalpy flow		MMBTU/hr										
	Mass flow		lb/hr					401192	610909				
	Volume flow		ft3/min					1695	2581				
	Mole flow		lbmol/hr					9183	13984				
	Heat capacity		BTU/lb.F					0.21	0 21				
	Viscosity		lb/ft.hr					0.04	0 04				
	Thermal conductivity		BTU/h ft.F					0 010	0.010				
LIQUID PHASE PROPERTIES	Mass Enthalpy		BTU/lb										
	Mass density		lb/ft3										
	Enthalpy flow		MMBTU/hr										
	Mass flow		lb/hr										
	Volume flow		ft3/min										
	Mole flow		lbmol/hr										
	Heat capacity		BTU/lb.F										
	Viscosity		lb/ft.hr										
	Thermal conductivity		BTU/h ft.F										
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%					98.40	98.40	98.264	98.264	99.787	99.787
	Water	[H2O]	mole%					1.26	1.26	1.536	1.536	0.010	0.010
	Oxygen	[O2]	mole%					0.14	0.14	0.001	0.001	0.001	0.001
	Nitrogen + Argon	[N2]	mole%					0.20	0.20	0.199	0.199	0.202	0.202
	Sulfur dioxide	[SO2]	mole%										
	Hydrogen	[H2]	mol%										
	Sodium hydroxide	[NaOH]	mole%										
COMPONENT MASS PERCENT	Carbon Dioxide	[CO2]	wt%					99.249	99.249	99.236	99.236	99.866	99.866
	Water	[H2O]	wt%					0.521	0.521	0.635	0.635	0.004	0.004
	Oxygen	[O2]	wt%					0.102	0.102	0.001	0.001	0.001	0.001
	Nitrogen + Argon	[N2]	wt%					0.128	0.128	0.128	0.128	0.129	0.129
	Sulfur dioxide	[SO2]	wt%										
	Hydrogen	[H2]	wt%										
	Sodium hydroxide	[NaOH]	wt%										

STREAM NUMBER				42		43		44	
DESCRIPTION				TEG Makeup		H2 from Electrolyzer to O2 Polishing Reactor		CO2 to Pipeline	
PFD				DE-FE0032220-KBR-02-PR-D-PFD-101		DE-FE0032220-KBR-02-PR-D-PFD-103		DE-FE0032220-KBR-02-PR-D-PFD-101	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		V		V	
				Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	108.0	108 0	122.0	122.0	122.0	122.0
	Pressure		Psia	60.00	60.00	527.00	527 00	2212	2212
	Mass Enthalpy		BTU/lb					-3924	-3924
	Mass density		lb/ft3			0.17	0.17	0.24	0.24
	Enthalpy flow		MMBTU/hr						
	Mass flow		lb/hr	12.2	16.7	51	70	398713	608381
	Volume flow		ft3/min			5.0	6.9	151.4	231.0
	Mole flow		lbmol/hr					9067.8	13835
	Molar vapor fraction					1.00	1 00	1.00	1.00
	Molar liquid fraction			1.00	1 00				
	Average MW					2.02	2 02	43 97	43.97
	Heat capacity		BTU/lb.F						
	Viscosity		lb/ft.hr						
	Thermal conductivity		BTU/h ft.F						
VAPOR PHASE PROPERTIES	Mass Enthalpy		BTU/lb						
	Mass density		lb/ft3						
	Enthalpy flow		MMBTU/hr						
	Mass flow		lb/hr						
	Volume flow		ft3/min						
	Mole flow		lbmol/hr						
	Heat capacity		BTU/lb.F						
	Viscosity		lb/ft.hr						
	Thermal conductivity		BTU/h ft.F						
LIQUID PHASE PROPERTIES	Mass Enthalpy		BTU/lb						
	Mass density		lb/ft3						
	Enthalpy flow		MMBTU/hr						
	Mass flow		lb/hr						
	Volume flow		ft3/min						
	Mole flow		lbmol/hr						
	Heat capacity		BTU/lb.F						
	Viscosity		lb/ft.hr						
	Thermal conductivity		BTU/h ft.F						
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%					99.787	99.787
	Water	[H2O]	mole%					0.010	0.010
	Oxygen	[O2]	mole%					0.001	0.001
	Nitrogen + Argon	[N2]	mole%					0.202	0.202
	Sulfur dioxide	[SO2]	mole%						
	Hydrogen	[H2]	mol%			1 000	1.000		
	Sodium hydroxide	[NaOH]	mole%						
COMPONENT MASS PERCENT	Carbon Dioxide	[CO2]	wt%					99.866	99.866
	Water	[H2O]	wt%					0.004	0.004
	Oxygen	[O2]	wt%					0.001	0.001
	Nitrogen + Argon	[N2]	wt%					0.129	0.129
	Sulfur dioxide	[SO2]	wt%						
	Hydrogen	[H2]	wt%			1 000	1.000		
	Sodium hydroxide	[NaOH]	wt%						

Appendix B.5 Utility Flow Diagrams



P-1101 A/B	P-1102 A/B	P-1103 A/B
SERVICE WATER PUMP	FIRE WATER PUMP NOTE 1	FIRE WATER JOCKEY PUMP NOTE 1

NOTES

1. FIRE WATER PUMPS WILL COMPLY WITH NFPA 20 AND BE DIESEL DRIVEN.
2. SERVICE WATER NOZZLE LOCATED AT A SUFFICIENT HEIGHT TO ALWAYS ENSURE ADEQUATE FIREWATER SUPPLY.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
CR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
CR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 11 – RAW WATER SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-11-PR-D-UFD-001	1 OF 3	D
KBR N-429	KBR		

A-1101
DEMINERALIZED WATER
PACKAGE
NOTE 1, 2

T-1102
DEMINERALIZED
WATER TANK

FC

INT

NITROGEN

PI

SERVICE WATER
11-001
FROM SERVICE WATER
TANK

2

A-1101
SUPPLIED BY VENDOR
NOTE 1

T-1102

P-1104A/B

3

DEMINERALIZED WATER
12-001
TO DEAERATOR

4

DEMINERALIZED WATER
02-102
TO ELECTROLYZER
PACKAGE

INT

NEUTRALIZATION
WASTE
18-001
TO WASTE WATER
TREATMENT

P-1104A/B
DEMINERALIZED
WATER PUMP

NOTES

1. NUMBER OF VESSELS AND VALVES TO BE DETERMINED BY VENDOR.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT^3/MIN

IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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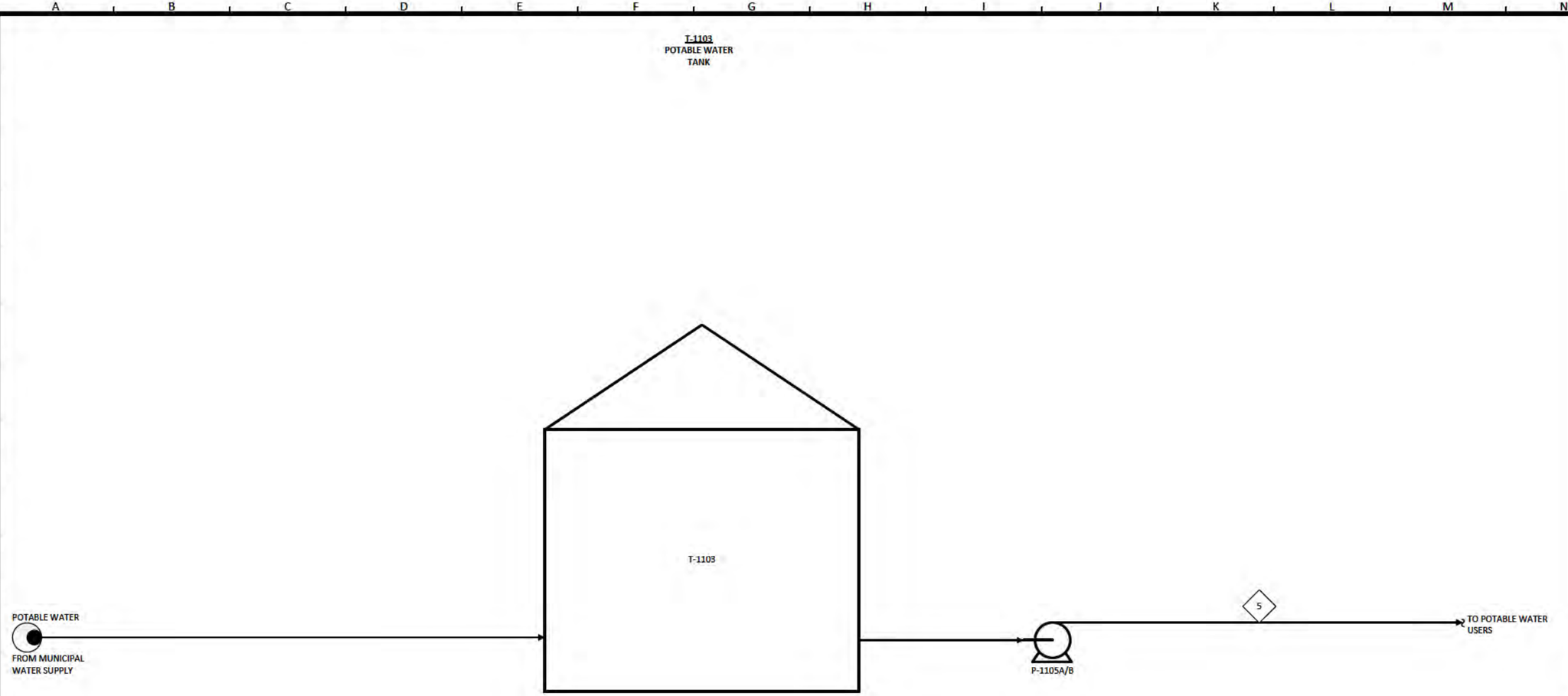
RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 11 – DEMINERALIZED WATER SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN: DE-FE0032220	CLIEN: DE-FE0032220-KBR-11-PR-D-UFD-002	2 OF 3	D
KBR: N-429	KBR:		



P-1105A/B
POTABLE WATER
PUMP

NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SP	DDB	DDB	
ICR	A	11OCT2023	ISSUED FOR CLIENT REVIEW	SP	DDB	DDB	

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RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 11 – POTABLE WATER SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-11-PR-D-UFD-003	3 OF 3	B
KBR N-429	KBR		

V-1203
CONDENSATE
FLASH DRUM

V-1202
BLOWDOWN
DRUM

A-1202
BFW CHEMICAL
PACKAGE

V-1201
DEAERATOR

A-1201
BFW CHEMICAL
PACKAGE

A-1202
SUPPLIED BY
VENDOR

NOTE 1
VENT

PC

DEMINERALIZED WATER
11-002
FROM DEMINERALIZED
WATER TANK

3

TO ATM
AT SAFE
LOCATION

10

LP STEAM

7

V-1203

V-1201

LC

LC

A-1201
SUPPLIED BY
VENDOR

STEAM
CONDENSATE

6

BFW TO
BFW HEADER

P-1203A/B

P-1201A/B

LP STEAM
TO HEADER

8

V-1202

BLOWDOWN
12-002
FROM NATURAL GAS
BOILER

9

BLOWDOWN
18-001
TO WASTE WATER
TREATMENT

P-1203A/B
CONDENSATE
PUMP

P-1201A/B
BFW PUMP

NOTES

1. VENT TO SAFE A LOCATION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	C	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	B	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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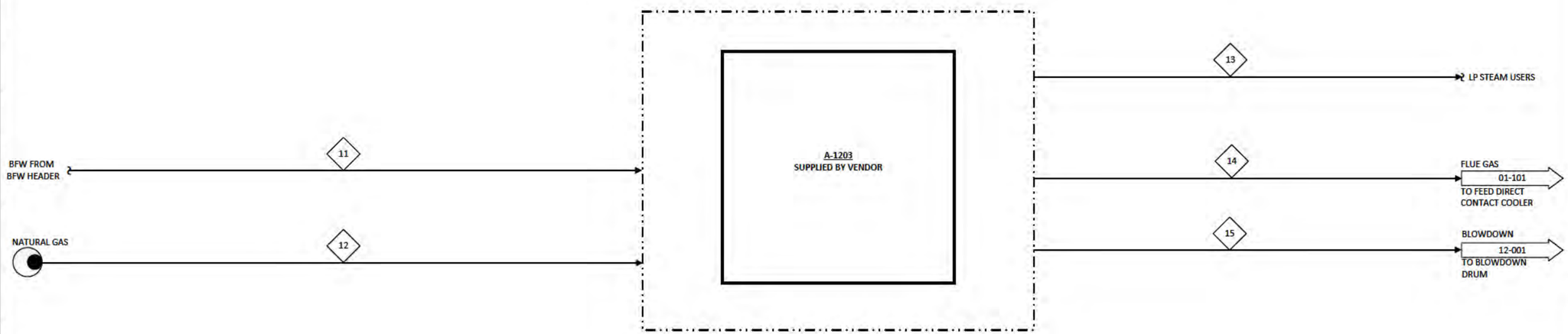
RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 12 – CONDENSATE AND BLOWDOWN SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN: DE-FE0032220	CLIEN: DE-FE0032220-KBR-12-PR-D-UFD-001	1 OF 2	C
KBR: N-429	KBR:		

A-1203
NATURAL GAS
BOILER PACKAGE



NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/MIN

IFD	C	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DOB	
ICR	B	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DOB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DOB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 12 – LP STEAM SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-12-PR-D-UFD-002	2 OF 2	C
KBR N-429	KBR		

T-1401
SOLVENT
STORAGE TANK

V-1401
SOLVENT SUMP

F-1401
SOLVENT SUMP
FILTER

NITROGEN

PI

AMINE FILL

FROM TRUCK
NOTE 2

T-1401

P-1401A/B

F-1401

NAS/AMINE
01-401
TO LEAN SOLVENT
SURGE TANK

NOTE 1
VENT

NITROGEN

FORMULATED SOLVENT

FROM TRUCK
NOTE 3

P-1402

V-1401

SOLVENT DRAIN
FROM ISBL

P-1401A/B
SOLVENT
TRANSFER PUMP

P-1402
SOLVENT SUMP
PUMP

NOTES

1. VENT TO A SAFE LOCATION.
2. AMINE TO BE SUPPLED BY TRUCK. PROVIDE TRUCK UNLOADING CONNECTION
3. FORMULATED SOLVENT TO BE SUPPLIED BY TRUCK. PROVIDE TRUCK UNLOADING CONNECTION

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT^3/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 14 – SOLVENT STORAGE SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN: DE-FE0032220	CLIEN: DE-FE0032220-KBR-14-PR-D-UFD-001	1 OF 3	D
KBR: N-429	KBR:		

T-1402
CAUSTIC
STORAGE TANK

NOTE 1
VENT

CAUSTIC
NOTE 2

NNF

T-1402
NOTE 3

LP STEAM

CONDENSATE

P-1403A/B

CAUSTIC
01-101
TO FEED DIRECT
CONTACT COOLER

NOTE 3

P-1403A/B
CAUSTIC TRANSFER PUMP

NOTES

1. VENT TO A SAFE LOCATION.
2. CAUSTIC TO BE SUPPLIED BY TRUCK. PROVIDE TRUCK UNLOADING CONNECTION.
3. TANK AND PIPING TO BE INSULATED AND HEAT TRACED TO MAINTAIN A TEMPERATURE ABOVE 57°F TO PREVENT CAUSTIC FROM FREEZING.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT . MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 14 – CAUSTIC STORAGE SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-14-PR-D-UFD-002	2 OF 3	D
KBR N-429	KBR		

T-1403
SULFURIC ACID STORAGE TANK

NOTE 1
VENT

T-1403

SULFURIC ACID
NOTE 2

NNF

P-1404A/B

17

SULFURIC ACID
01-301
TO ACID WASH

P-1404A/B
SULFURIC ACID TRANSFER PUMP

NOTES

1. VENT TO A SAFE LOCATION.
2. SULFURIC ACID TO BE SUPPLIED BY TRUCK. PROVIDE TRUCK UNLOADING CONNECTION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT^3/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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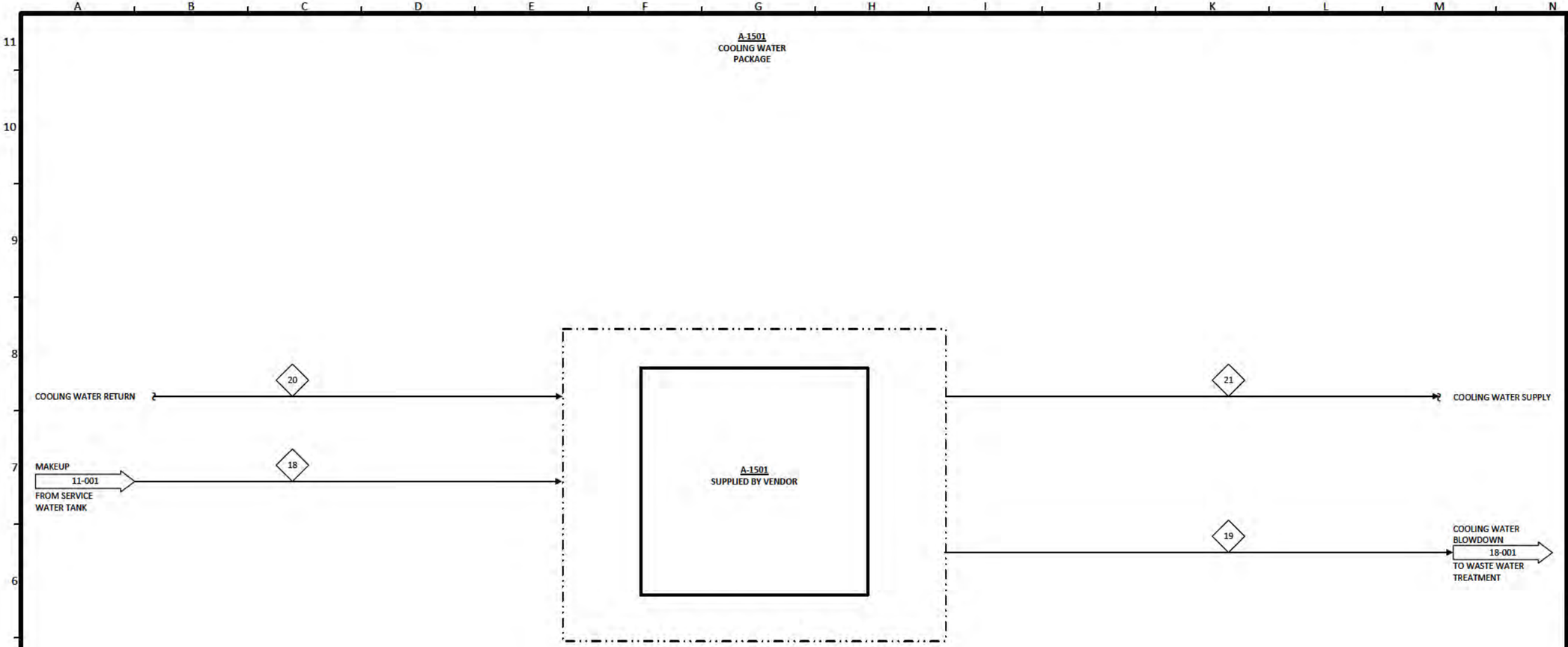
RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 14 – SULFURIC ACID STORAGE SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN: DE-FE0032220	CLIEN: DE-FE0032220-KBR-14-PR-D-UFD-003	3 OF 3	D
KBR: N-429	KBR:		



NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION

PAC AGE B VENDOR

PRESSURE, PSIA

TEMPERATURE, °F

NORMAL DUT , MMBtu/HR

MASS FLOW, LB/HR

VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	B	30OCT2024	ISSUED FOR DESIGN	SD	SP	DDB	
IOR	A	26SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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Balcones Cement Plant, New Braunfels, TX, USA

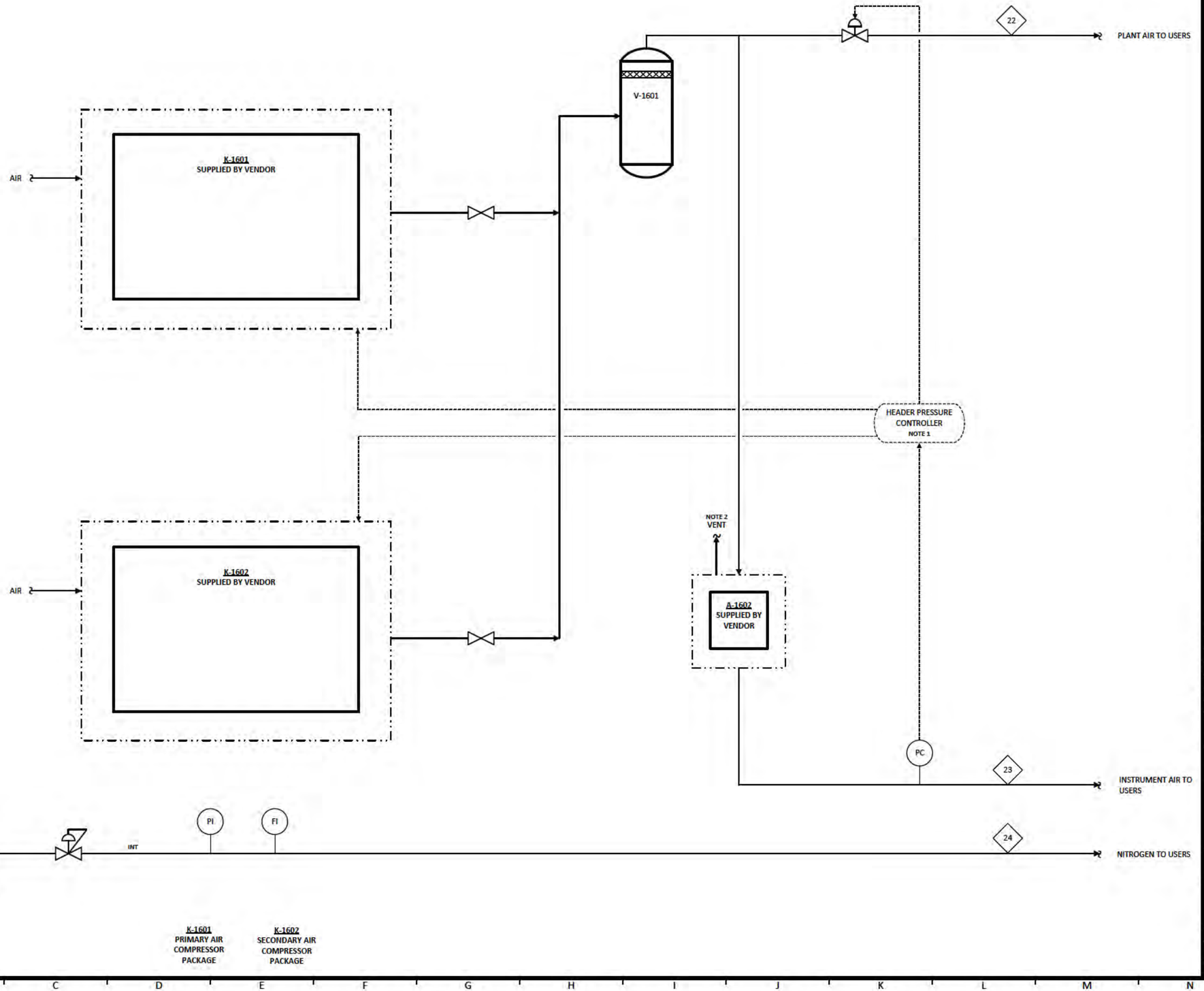
UTILITY FLOW DIAGRAM
UNIT 15 – COOLING WATER SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-15-PR-D-UFD-001	1 OF 1	B
KBR N-429	KBR		

A-1601
NITROGEN GENERATION SKID

V-1601
AIR RECEIVER

A-1602
INSTRUMENT AIR DRYER PACKAGE



K-1601
PRIMARY AIR COMPRESSOR PACKAGE

K-1602
SECONDARY AIR COMPRESSOR PACKAGE

NOTES

1. SYSTEM DESIGNED TO FIRST CLOSE PLANT AIR CONTROL VALVE AND THEN START A SECOND COMPRESSOR WHEN INSTRUMENT AIR HEADER PRESSURE DROPS BELOW MINIMUM REQUIREMENT.
2. VENT TO A SAFE LOCATION.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT . MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

IFD	B	30OCT2024	ISSUED FOR DESIGN	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 16 – AIR / NITROGEN SYSTEMS

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-16-PR-D-UFD-001	1 OF 1	B
KBR N-429	KBR		

A-1801
WASTE WATER
TREATMENT PACKAGE

NEUTRALIZATION WASTE
11-002
FROM DEMINERALIZED WATER PACKAGE
INT

BLOWDOWN
12-001
FROM BLOWDOWN DRUM
25

ACID WASTE
01-301
FROM ACID WASH
26

COOLING WATER BLOWDOWN
15-001
FROM COOLING WATER PACKAGE
27

AQUEOUS PHASE
20-001
FROM KO DRUM
NNF

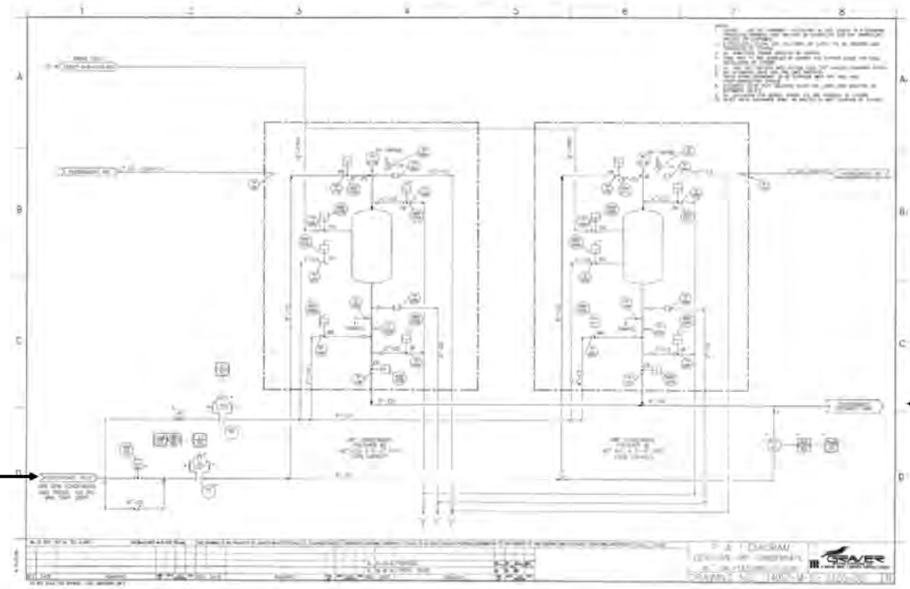
TEG WASTE
FROM TEG UNIT
28

ELECTROLYZER BLOWDOWN
20-001
FROM ELECTROLYZER
29

32

WASTE WATER DISCHARGE

A-1801
SUPPLIED BY VENDOR
GRF Condensate Filters and Sodium Softening



PROCESS WATER
01-101
FROM FEED DIRECT CONTACT COOLER
30

PROCESS WATER
TO PROCESS WATER POND
NNF

PROCESS WATER
FROM PROCESS WATER POND
31

P-1801A/B

1

SERVICE WATER
11-001
TO SERVICE WATER TANK

P-1801A/B
PROCESS WATER PUMP

NOTES

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT . MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT³/MIN

ISSUE	REV	DATE	REVIS ON DESCRIPTION	BY	CHK	APP	CLIENT
IFD	E	28OCT2025	ISSUED FOR DESIGN	SD	JRZ	DDB	
IFD	D	30OCT2024	ISSUED FOR DESIGN	SD	JRZ	DDB	
ICR	C	24MAY2024	ISSUED FOR CLIENT REVIEW	SD	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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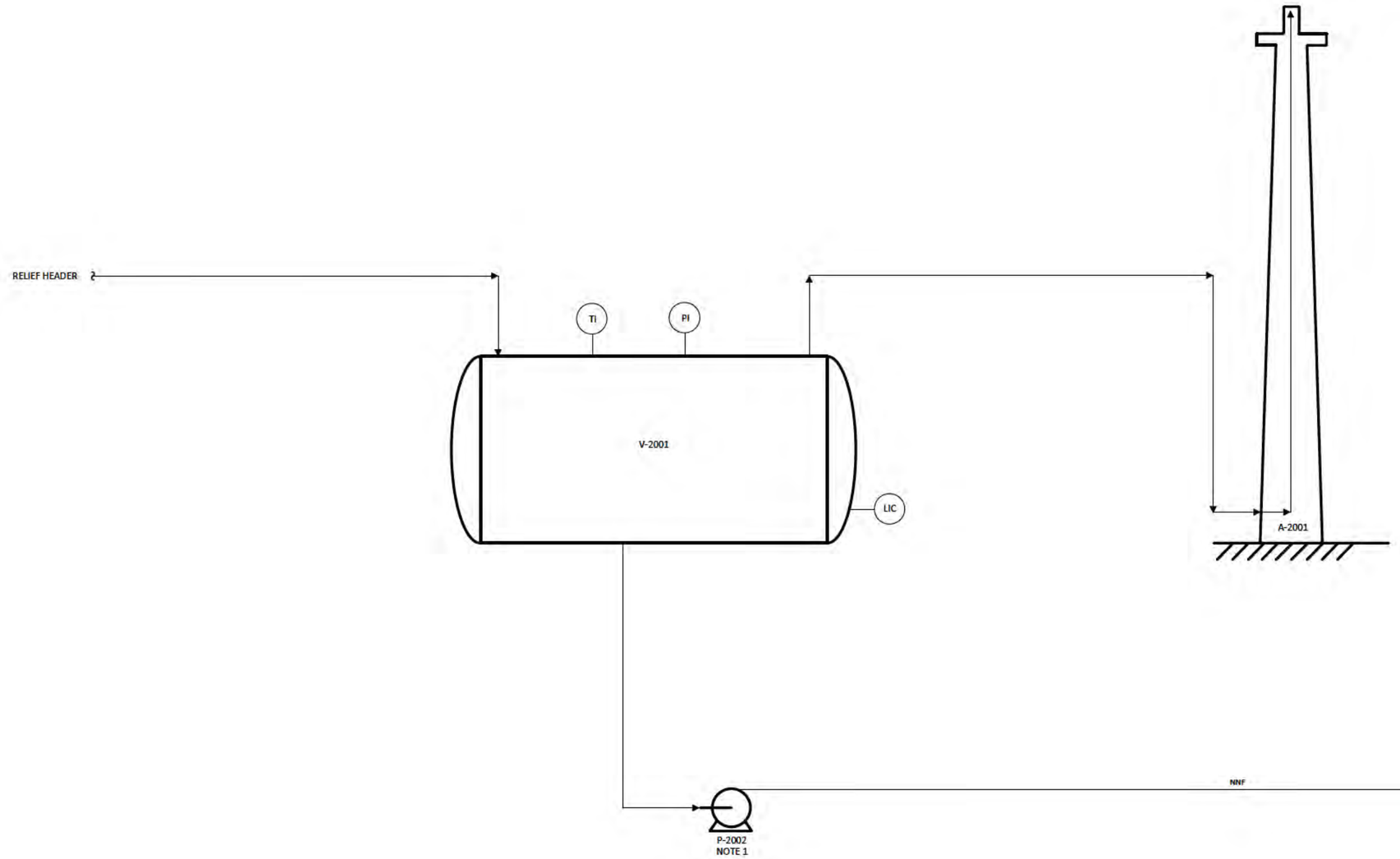
Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 18 – WASTE WATER SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CL EN DE-FE0032220-KBR-18-PR-D-UFD-001	1 OF 1	E
KBR N-429	KBR		

V-2001
KO DRUM

A-2001
STACK



P-2002
KO DRUM AQUEOUS PHASE PUMP

NOTES

1. HIGH LEVEL IN V-1203 SHOULD AUTO START THE PUMP.

ABBREVIATIONS

TBD	TO BE DETERMINED
INT	INTERMITTENT FLOW
NNF	NORMALL NO FLOW
NC	NORMALL CLOSED

LEGEND

STREAM IDENTIFICATION
PAC AGE B VENDOR
PRESSURE, PSIA
TEMPERATURE, °F
NORMAL DUT , MMBtu/HR
MASS FLOW, LB/HR
VOLUME FLOW, FT^3/MIN

	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	E	30OCT2024	ISSUED FOR DESIGN	AK	JRZ	DDB	
ICR	D	24MAY2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	C	23FEB2024	ISSUED FOR CLIENT REVIEW	AK	JRZ	DDB	
ICR	B	11OCT2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	
ICR	A	29SEP2023	ISSUED FOR CLIENT REVIEW	SD	SP	DDB	

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Balcones Cement Plant, New Braunfels, TX, USA

UTILITY FLOW DIAGRAM
UNIT 20 – STACK SYSTEM

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIEN DE-FE0032220	CLIEN DE-FE0032220-KBR-20-PR-D-UFD-001	1 OF 1	E
KBR N-429	KBR		

Appendix B.6 Heat and Materials Balance – OSBL

OSBL HEAT AND MATERIAL BALANCE

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	22-AUG-25	IFD – ISSUE FOR DESIGN	DDB	DDB	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	22-AUG-2025	ALL	IFD – Issue for Design

TABLE OF CONTENTS

1. NOTES 4
2. OSBL HEAT AND MATERIAL BALANCE 5

1. NOTES

1) Flowrates given are at steady state. Lines that are Normally No Flow (NNF) or Intermittent (INT) in operation are not defined in this document. This results in an overall mass balance that is close to, but not exactly, 100% closed.

2. OSBL HEAT AND MATERIAL BALANCE

STREAM NUMBER				1		2		3		4		5		6	
DESCRIPTION				Service Water from Water Treatment		Service Water to Demineralization		Demin Water to Deaerator		Demin Water to Electrolyzer		Potable Water from Potable Water Tank to Users		Boiler Feed Water to Header	
PFD				DE-FE032220-KBR-11-PR-D-UFD-001		DE-FE032220-KBR-11-PR-D-UFD-001		DE-FE032220-KBR-11-PR-D-UFD-002		DE-FE032220-KBR-11-PR-D-UFD-002		DE-FE032220-KBR-11-PR-D-UFD-003		DE-FE032220-KBR-12-PR-D-UFD-001	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		L		L		L		L		L	
				Normal case	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	108.0	248.0	248.0
	Pressure		Psia	15.90	15.90	15.90	15.90	29.40	29.40	29.40	29.40	74.70	74.70	187.90	187.90
	Mass density		lb/ft3	61.80	61.80	61.80	61.80	61.80	61.80	61.80	61.80	61.80	61.80	58.85	58.85
	Mass flow		lb/hr	190744	328352	82239	109607	73904	99162	1439	1971	23851	37480	633401	866138
	Volume flow		ft3/min	51.4	88.6	22.2	29.6	19.9	26.7	0.4	0.5	6.4	10.1	179.4	245.3
	Molar vapor fraction														
	Molar liquid fraction			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%												
	Water	[H2O]	mole%												
	Oxygen	[O2]	mole%												
	Nitrogen + Argon	[N2]	mole%												
	Sulfur dioxide	[SO2]	mole%												
	Methane	[C1H4]	mole%												
	Ethane	[C2H6]	mole%												
	Propane	[C3H8]	mole%												
	Butane	[C4H10]	mole%												
	Sulfuric Acid	[H2SO4]	mole%												
	Sodium Hydroxide	[NaOH]	mole%												

STREAM NUMBER				7		8		9		10		11		12	
DESCRIPTION				Steam Condensate to Deaerator		LP Steam from Flash Drum to Steam Header		Steam Condensate Blowdown to Water Treatment		LP Steam to Deaerator Stripper		Boiler Feed Water to Natural Gas Boilers		Natural Gas to Boilers	
PFD				DE-FE032220-KBR-12-PR-D-UFD-001		DE-FE032220-KBR-12-PR-D-UFD-001		DE-FE032220-KBR-12-PR-D-UFD-001		DE-FE032220-KBR-12-PR-D-UFD-001		DE-FE032220-KBR-12-PR-D-UFD-002		DE-FE032220-KBR-12-PR-D-UFD-002	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		V		L		V		L		V	
				Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	212.0	212.0	267.0	267.0	267.0	267.0	95.0	95.0	248.0	248.0	108.0	108.0
	Pressure		Psia	70.74	70.74	39.70	39.70	39.70	39.70	39.70	39.70	187.90	187.90	54.70	54.70
	Mass density		lb/ft3	59.80	59.80	0.09	0.09	58.30	58.30	0.0946	0.0946	58.85	58.85	0.0112	0.0112
	Mass flow		lb/hr	561954	770192	1896	2594	15322	20964	56811	75183	569249	778259	24780	38028
	Volume flow		ft3/min	156.6	214.7	334.0	457.0	4.4	6.0	10009.0	13245.8	161.2	220.4	36875.0	56589.3
	Molar vapor fraction					1.00	1.00			1.00	1.00			1.00	1.00
	Molar liquid fraction			1.00	1.00			1.00	1.00			1.00	1.00		
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%												
	Water	[H2O]	mole%												
	Oxygen	[O2]	mole%												
	Nitrogen + Argon	[N2]	mole%											5.00	5.00
	Sulfur dioxide	[SO2]	mole%												
	Methane	[C1H4]	mole%											90.0	90.0
	Ethane	[C2H6]	mole%											5.0	5.0
	Propane	[C3H8]	mole%												
	Butane	[C4H10]	mole%												
	Sulfuric Acid	[H2SO4]	mole%												
	Sodium Hydroxide	[NaOH]	mole%												

STREAM NUMBER				13		14		15		16		17		18	
DESCRIPTION				LP Steam to Users		Flue Gas to DCC		Blowdown		Caustic to DCC 35 wt% NaOH in Water		Sulfuric Acid to Acid Wash 95 wt% H2SO4 in Water		Makeup Water to Cooling Tower	
PFD				DE-FE032220-KBR-12-PR-D-UFD-002		DE-FE032220-KBR-12-PR-D-UFD-002		DE-FE032220-KBR-12-PR-D-UFD-002		DE-FE032220-KBR-14-PR-D-UFD-002		DE-FE032220-KBR-14-PR-D-UFD-003		DE-FE032220-KBR-15-PR-D-UFD-001	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				V		V		L		L		L		L	
				Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	267.0	267.0	303.1	303.1	267.0	267.0	108.0	108.0	108.0	108.0	108.0	108.0
	Pressure		Psia	39.70	39.70	14.05	14.05	39.70	39.70	41.00	41.00	32.55	32.55	15.90	15.90
	Mass density		lb/ft3	0.0946	0.0946	0.0056	0.0056	58.30	58.30	85.90	85.90	113.71	113.71	61.80	61.80
	Mass flow		lb/hr	554613	757496	478260	710083	14636	20763	229	314	255	349	108505	218745
	Volume flow		ft3/min	97711.9	133455.9	161685	239876	4.2	5.9	0.044	0.061	0.037	0.051	29.3	59.0
	Molar vapor fraction			1.00	1.00	1.00	1.00								
	Molar liquid fraction							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%			8.69	8.69								
	Water	[H2O]	mole%			17.58	17.58			80.40	80.40	22.30	22.30		
	Oxygen	[O2]	mole%			2.04	2.04								
	Nitrogen + Argon	[N2]	mole%			71.68	71.68								
	Sulfur dioxide	[SO2]	mole%												
	Methane	[C1H4]	mole%												
	Ethane	[C2H6]	mole%												
	Propane	[C3H8]	mole%												
	Butane	[C4H10]	mole%												
	Sulfuric Acid	[H2SO4]	mole%									77.7	77.7		
	Sodium Hydroxide	[NaOH]	mole%							19.6	19.6				

STREAM NUMBER				19		20		21		22		23		24	
DESCRIPTION				Blowdown from Cooling Tower		Cooling Water Return to Cooling Tower		Cooling Water Supply to Header		Compressed Air to Header		Instrument Air to Header		Nitrogen to Header	
PFD				DE-FE032220-KBR-15-PR-D-UFD-001		DE-FE032220-KBR-15-PR-D-UFD-001		DE-FE032220-KBR-15-PR-D-UFD-001		DE-FE032220-KBR-16-PR-D-UFD-001		DE-FE032220-KBR-16-PR-D-UFD-001		DE-FE032220-KBR-16-PR-D-UFD-001	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		L		L		V		V		V	
				Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	108.0	108.0	95.0	95.0	82.0	82.0	108.0	108.0	108.0	108.0	108.0	108.0
	Pressure		Psia	15.90	15.90	44.70	44.70	137.50	137.50	123.00	123.00	113.00	113.00	123.00	123.00
	Mass density		lb/ft3	61.80	61.80	61.50	61.50	61.80	61.80	0.585	0.585	0.537	0.537	0.527	0.527
	Mass flow		lb/hr	30203	42847	6889192	15277446	6889192	15277446	2250	2250	1170	1170	5277	5277
	Volume flow		ft3/min	8.1	11.6	1867.0	4140.2	1857.9	4120.1	64.1	64.2	36.3	36.3	166.9	166.9
	Molar vapor fraction									1.00	1.00	1.00	1.00	1.00	1.00
	Molar liquid fraction			1.00	1.00	1.00	1.00	1.00	1.00						
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%												
	Water	[H2O]	mole%												
	Oxygen	[O2]	mole%												
	Nitrogen + Argon	[N2]	mole%												
	Sulfur dioxide	[SO2]	mole%												
	Methane	[C1H4]	mole%												
	Ethane	[C2H6]	mole%												
	Propane	[C3H8]	mole%												
	Butane	[C4H10]	mole%												
	Sulfuric Acid	[H2SO4]	mole%												
	Sodium Hydroxide	[NaOH]	mole%												

STREAM NUMBER				25		26		27		28		29	
DESCRIPTION				Blowdown from Blowdown Drum		Acid Waste from Acid Wash		Cooling Water Blowdown from Cooling Tower		TEG Waste		Electrolyzer Blowdown	
PFD				DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		L		L		L		L	
				Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	267.0	267.0	97.0	97.0	108.0	108.0	108.0	108.0	108.0	108.0
	Pressure		Psia	39.70	39.70	14.70	14.70	15.90	15.90	14.70	14.70	14.70	14.70
	Mass density		lb/ft3	58.30	58.30	64.10	64.10	61.80	61.80	61.80	61.80	61.80	61.80
	Mass flow		lb/hr	15322	20964	8335	10445	30203	42847	1573	2232	950	1341
	Volume flow		ft3/min	4.4	6.0	2.2	2.7	8.1	11.6	0.4	0.6	0.3	0.4
	Molar vapor fraction												
	Molar liquid fraction			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%										
	Water	[H2O]	mole%										
	Oxygen	[O2]	mole%										
	Nitrogen + Argon	[N2]	mole%										
	Sulfur dioxide	[SO2]	mole%										
	Methane	[C1H4]	mole%										
	Ethane	[C2H6]	mole%										
	Propane	[C3H8]	mole%										
	Butane	[C4H10]	mole%										
	Sulfuric Acid	[H2SO4]	mole%										
	Sodium Hydroxide	[NaOH]	mole%										

STREAM NUMBER				30		31		32	
DESCRIPTION				Process Water from Direct Contact Cooler		Process Water from Pond		Waste Water Discharge to Municipality	
PFD				DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001		DE-FE032220-KBR-18-PR-D-UFD-001	
PHASE (V = Vapor, L = Liquid, V / L = Mixed)				L		L		L	
				Normal	Max case	Normal	Max case	Normal	Max case
TOTAL STREAM PROPERTIES	Temperature		F	119.0	127.2	108.0	108.0	108.0	108.0
	Pressure		Psia	106.70	92.06	14.70	14.70	14.70	14.70
	Mass density		lb/ft3	60.60	60.30	61.80	61.80	62.00	62.00
	Mass flow		lb/hr	134840	195246	62646	142868	60976	85359
	Volume flow		ft3/min	37.1	54.0	16.9	38.5	16.4	22.9
	Molar vapor fraction								
	Molar liquid fraction			1.00	1.00	1.00	1.00	1.00	1.00
COMPONENT MOLE PERCENT	Carbon Dioxide	[CO2]	mole%						
	Water	[H2O]	mole%						
	Oxygen	[O2]	mole%						
	Nitrogen + Argon	[N2]	mole%						
	Sulfur dioxide	[SO2]	mole%						
	Methane	[C1H4]	mole%						
	Ethane	[C2H6]	mole%						
	Propane	[C3H8]	mole%						
	Butane	[C4H10]	mole%						
	Sulfuric Acid	[H2SO4]	mole%						
	Sodium Hydroxide	[NaOH]	mole%						

Appendix B.7 Battery Limit Summary

BATTERY LIMIT SUMMARY

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A	8-NOV-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
B	5-APR-24	ICR – ISSUE FOR CLIENT REVIEW	SD	JRZ	DDB	
C	30-OCT-24	IFD – ISSUE FOR DESIGN	SD	JRZ	DDB	
D	09-DEC-24	IFD – ISSUE FOR DESIGN	SD	JRZ	DDB	
E	10-APR-25	IFD – ISSUE FOR DESIGN	SD	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	8-NOV-2023	ALL	ICR – Issued for Client Review
B	5-APR-2024	1.1, 1.2	Updated rates based on latest material balance and design basis.
C	30-OCT-2024	Cover	Updated confidentiality and export compliance statements.
D	09-DEC-2024	All	Updated stream descriptions, rates of TEG and wastewater, and product specifications
E	10-APR-2025	1	Updated water, amine, sulfuric acid, caustic values per latest design basis and vendor info

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1. BATTERY LIMIT SUMMARY

1.1 NORMAL CASE

Stream Description	**Process Inlet Flow Rate** lb/hr	**Process Outlet Flow Rate** lb/hr	**Temp.** At Battery Limit °F	**Pressure** At Battery Limit Psia	**Density** At Battery Limit lb/ft^3
Flue Gas (Kiln 1)	975,813	-	258.8	14.4	0.054
Flue Gas (Kiln 2)	1,055,154	-	228.2	14.4	0.056
Compressed CO_2 to Pipeline	-	401,192	122	2212	41.2
Potable Water (Municipal Water Supply)	23,851 (1)	-	108	126	62.4
Natural Gas	24,780	-	80	14.7	0.044
Amine Fill from Truck	404 (2)	-	108	14.7	58.7
Caustic from Truck	229 (2)	-	108	14.7	85.9
Sulfuric Acid from Truck	255 (2)	-	108	14.7	0.114
Process Water from Water Pond	198,896 (3)	-	108	14.7	62.4
Wastewater Discharge (4)		63036	108	14.7	62.4
Make-up Triethylene Glycol (TEG)	≤ 12.2 (5)	-	131	543	68.4

NOTES:

1. Assumed 100 people on site with average usage of 3.9 ft^3/person/day. Number of people to be updated at client's discretion in a later phase of engineering. Also assumed two safety shower and eye wash stations are operating simultaneously, consuming 183.6 ft^3/hr of potable water each. The rate based on only the average usage for 100 people is 1007 lb/hr.
2. Average flow.
3. Assumed Process Water Pump flow rate is 191 gpm.
4. Ambient conditions are assumed for water discharge, to be confirmed by the wastewater treatment vendor. This does not include the DCC condensate that is treated and recycled to the process.
5. Initial charge of TEG is 109,796 lb.

1.2 MAX CASE

Stream Description	**Process Inlet Flow Rate** lb/hr	**Process Outlet Flow Rate** lb/hr	**Temp.** At Battery Limit °F	**Pressure** At Battery Limit Psia	**Density** At Battery Limit lb/ft^3
Flue Gas (Kiln 1)	1,282,700	-	298.4	14.4	0.052
Flue Gas (Kiln 2)	1,285,572	-	228.2	14.4	0.057
Compressed CO_2 to Pipeline	-	610,909	122	2212	41.2
Potable Water (Municipal Water Supply)	23,851 (1)	-	108	126	62.4
Natural Gas	38,028	-	80	14.7	0.044
Amine Fill from Truck	606 (2)	-	108	14.7	58.7
Caustic from Truck	254 (2)	-	108	14.7	85.9
Sulfuric Acid from Truck	255 (2)	-	108	14.7	0.114
Process Water from Water Pond	198,896 (3)	-	108	14.7	62.4
Wastewater Discharge (4)	-	88243	108	14.7	62.4
Make-up Triethylene Glycol (TEG)	≤ 12.2 (5)	-	131	543	68.4

NOTES:

1. Assumed 100 people on site with average usage of 3.9 ft^3/person/day. Number of people to be updated at client's discretion in a later phase of engineering. Also assumed two safety shower and eye wash stations are operating simultaneously, consuming 183.6 ft^3/hr of potable water each. The rate based on only the average usage for 100 people is 1007 lb/hr.
2. Average flow.
3. Assumed Process Water Pump flow rate is 191 gpm.
4. Maximum rate of treated wastewater. This does not include the DCC condensate that is treated and recycled to the process. Ambient conditions are assumed for water discharge, to be confirmed by the wastewater treatment vendor. Refer to Effluent and Emission Summary (DE-FE0032220-KBR-00-EV-C-EV2-001) for details.
5. Initial charge of TEG is 109,796 lb.

2. PRODUCT SPECIFICATIONS

CO_2 stream composition recommended limit (Source: DOE-NETL (2019), Quality Guidelines for Energy System Studies – CO_2 Impurity Design Parameters).

Component	Unit (max, unless noted otherwise)	Value
CO_2	Vol% (min)	95
H_2O	ppmv	100
N_2	Vol%	4
O_2	Vol%	0.001
Ar	Vol%	4
CH_4	Vol%	4
H_2	Vol%	4
CO	ppmv	35
SO_2	ppmv	100
NOx	ppmv	50

Appendix B.8 ISBL Equipment List

ISBL SIZED EQUIPMENT LIST

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	11-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	SD	SP	DDB	
B	13-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
C	27-MAR-24	ICR – ISSUE FOR CLIENT REVIEW	IV	JRZ	DDB	
D	05-APR-24	ICR – ISSUE FOR CLIENT REVIEW	IV	JRZ	DDB	
E	30-OCT-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	11-OCT-2023	ALL	ICR – Issue for Client Review
B	13-OCT-2023	ALL	Incorporated Client comments
C	27-MAR-2024	ALL	Updates per PDN Hybrid Cooling System
D	05-APR-2024	Page 6	Updated exchanger duties
E	30-OCT-2024	All	IFD – Issue for Design

PRELIMINAR SI ED E UIPMENT LIST COLUMN/REACTOR SUMMAR

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	OPER TEMP. °F	DESIGN TEMP. °F	DESIGN PRESS. psia	SIZING INFO
C-0121	Absorber Column	01-201	1	109	168	20	Removed
C-0151	Regenerator Column	01-501	1	226	276	73 / FV	Removed

PRELIMINAR SI ED E UIPMENT LIST DRUMS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ORIENTATION	ELEVATION	OPER TEMP.	DESIGN TEMP.	DESIGN PRESS.	SIZING INFO
				V or H	Hung/Grade	°F	°F	psia	
V-0111	Feed Direct Contact Cooler	01-101	1	V	Grade	272	322	20	Removed
V-0131	Absorber Overhead Wash Water Surge Drum 1	01-301	1	V	Grade	101	168	66 / FV	Removed
V-0132	Absorber Overhead Wash Water Surge Drum 2	01-301	1	V	Grade	98	168	66 / FV	Removed
V-0133	Absorber Overhead Acid Wash Surge Drum	01-301	1	V	Grade	98	168	66 / FV	Removed
V-0134	Activated Carbon Beds	01-302	-	V	Grade	267	317	203 / FV	Removed
V-0151	Regenerator Overhead Condensate Drum	01-501	1	V	Hung	122	276	73 / FV	Removed
V-0221	O_2 Polishing Reactor	02-103	1	V	Grade	267	317	595	Removed

PRELIMINARY SIZED EQUIPMENT LIST COMPRESSORS

EQUIP. NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	TYPE	FLUID	SUCTION PRESSURE	DISCHARGE PRESSURE	SUCTION TEMP.	DISCHARGE TEMP.	DESIGN PRESSURE	DESIGN TEMP.	MOTOR (each)
						psia	psia	°F	°F	psia	°F	HP
-0111A/B	Flue Gas Blower	01-101	2	Blower	Flue-gas	14.2	15.4	92	109	20	159	3000 (2)
-0211	CO_2 Compressor Package	02-101	1	Centrifugal	CO_2	57.4	2216	122	494	-	-	40,000

PRELIMINAR SI ED E UIPMENT LIST EXCHANGERS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	HEAT EXCHANGER TYPE	FLUID	OPER TEMP.	DESIGN TEMP.	DESIGN PRESS.
					°F	°F	psia
E-0111	Feed Scrubber Wash Cooler	01-101	Plate and Frame	Process Water	107	322	175
E-0112	Feed Scrubber Wash Air Cooler	01-101	Air Cooler	Process Water	125	322	175
E-0121	Absorber Interstage Air Cooler 1	01-201	Air Cooler	NAS	121	168	155
E-0122	Absorber Interstage Air Cooler 2	01-201	Air Cooler	NAS	106	153	165
E-0131	Absorber Overhead Wash Water Cooler 1	01-301	Plate and Frame	Wash Water	101	151	187
E-0132	Absorber Overhead Wash Water Cooler 2	01-301	Plate and Frame	Wash Water	97	148	203
E-0133	Activated Carbon Bed Cooler	01-302	Plate and Frame	Wash Water	212	317	203
E-0141	Lean/Rich Solvent Heat Exchanger	01-401	Plate and Frame	NAS	224	274	220
E-0142	Lean Solvent Air Cooler	01-401	Air Cooler	Lean NAS	128	183	191
E-0151	Regenerator Overhead Condenser	01-501	Air Cooler	CO_2	188	276	73
E-0152 A/B/C/D	Regenerator Reboiler	01-501	Plate and Frame	NAS	267	317	90
E-0221	Steam Heater	02-103	Shell and Tube	CO_2 & H_2	267	317	595

PRELIMINAR SI ED E UIPMENT LIST PUMPS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	TYPE	FLUID	SUCTION PRESSURE	DISCHARGE PRESSURE	HEAD	OPER TEMP.
						psia	psia	ft	°F
P-0111A/B/C	Feed Scrubber Wash Circulation Pump	01-101	2	Centrifugal	Process water	13.9	108.9	227	119
P-0121A/B/C	Absorber Interstage Circulation Pump 1	01-201	2	Centrifugal	NAS	13.9	103.2	204	115
P-0122A/B/C	Absorber Interstage Circulation Pump 2	01-201	2	Centrifugal	NAS	13.8	111.5	227	98
P-0124A/B/C	Rich Solvent Pump	01-201	2	Centrifugal	NAS	14.7	118.2	232	122
P-0131A/B/C	Absorber Overhead Wash Water Pump 1	01-301	2	Centrifugal	Wash Water	14.2	126.0	302	99
P-0132A/B/C	Absorber Overhead Wash Water Pump 2	01-301	2	Centrifugal	Wash Water	14.7	136.4	286	97
P-0133A/B/C	Acid Wash Pump	01-301	2	Centrifugal	Sulfuric Acid	14.4	107.5	219	97
P-0141A/B/C	Lean Solvent Pump	01-401	2	Centrifugal	Lean NAS	13.2	140.1	301	132
P-0151A/B	Regenerator Reflux Pump	01-501	2	Centrifugal	Process Condensate	66.4	106.1	93	95

PRELIMINARY SIZED EQUIPMENT LIST FILTERS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ELEVATION	OPER TEMP.	DESIGN TEMP.	DESIGN PRESS.	MOC	SIZE
									D x L
				Hung/Grade	°F	°F	psia		ft
F-0111	Feed Scrubber Circulation Filter	01-101	See Notes	Grade	127	322	175	304LSS	2 x 5.5
F-0141	Lean Solvent Particulate Filter	01-401	1	Grade	95	183	191	CS + 1/8 CA	8 x 10
F-0142	Lean Solvent Carbon Filter	01-401	1	Grade	95	183	191	CS + 1/8 CA	8 x 10

PRELIMINAR SI ED E UIPMENT LIST TAN S

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ORIENTATON	ELEVATION	OPER TEMP.	DESIGN TEMP.	DESIGN PRESS.
				V/H	Hung/Grade	°F	F	psia
T-0121	Absorber Interstage Surge Tank 1	01-201	1	V	Grade	118	168	14.26 / 16.1
T-0122	Absorber Interstage Surge Tank 2	01-201	1	V	Grade	103	168	14.26 / 16.1
T-0141	Lean Solvent Surge Tank	01-401	1	V	Grade	133	183	14.26 / 17.2

PRELIMINAR SI ED E UIPMENT LIST OTHER E UIPMENT

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	CAPACITY
A-0221	TEG Dehydration Package	02-101	1	450,000 lb/hr
A-0232	Electrolyzer Package	02-103	1	70 b/hr H_2

Appendix B.9 OSBL Equipment List

OSBL SIZED EQUIPMENT LIST

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C	28-MAR-24	ICR – ISSUE FOR CLIENT REVIEW	IV	JRZ	DDB	
D	05-APR-24	ICR – ISSUE FOR CLIENT REVIEW	IV	JRZ	DDB	
E	30-OCT-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

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A	11-OCT-2023	ALL	ICR – Issue for Client Review
B	13-OCT-2023	ALL	Incorporated Client comments
C	28-MAR-2024	ALL	Updates per PDN Hybrid Cooling System
D	05-APR-2024	ALL	Updates to drums, pumps, and other equipment
E	30-OCT-2024	All	IFD – Issue for Design

PRELIMINAR SI ED E UIPMENT LIST COMPRESSORS

EQUIP. NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	TYPE	FLUID	SUCTION PRESSURE psia	DISCHARGE PRESSURE psia	MOTOR bHP POWER HP	MECH MOTOR HP	MOC	WEIGHT Lbs each	SIZE LxW ft
-1601	Primary Air Compressor Package	16-001	1	Rotary Screw	Air	15	124	134	150	CS	10,000 (compressor) 3,000 (dryer)	8 ft x 16 ft 10 ft x 10 ft
-1602	Secondary Air Compressor Package	16-001	1	Rotary Screw	Air	15	124	134	150	CS	10,000	8 ft x 16 ft

PRELIMINAR SI ED E UIPMENT LIST DRUMS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ID ft	TL - TL ft	ORIEN-TATION V or H	ELEVATION Hung/Grade	OPER TEMP. °F	DESIGN TEMP. °F	DESIGN PRESS. psia	SHELL MOC	WEIGHT Empty lb	WEIGHT Full lb
V-1201	Deaerator	12-001	1	12	36	H	Grade	267	321	43 / FV	Shell / Heads: CS + 1/8 CA + PWHT Internals: 304LSS	36,000	300,000
V-1202	Blowdown Drum	12-001	1	3.3	9.8	V	Grade	267	321	43 / FV	CS + 1/8 CA	4,000	12,000
V-1203	Condensate Flash Drum	12-003	1	8.3	21	V	Grade	212	321	43 / FV	CS + 1/8 CA	17,000	100,000
V-1401	Solvent Sump	14-001	1	16	50	H	Underground	68	158	66	CS + 1/8 CA	66,000	720,000
V-1601	Air Receiver	16-001	1	10	30	V	Grade	99	151	152	Shell / Heads: CS + 1/8 CA Internals: 316LSS	27,000	190,000
V-2001	O Drum	20-001	1	20	35	H	Grade	179	550	66	304LSS Clad CS	56,000	770,000

PRELIMINAR SI ED E UIPMENT LIST PUMPS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	TYPE	FLUID	SUCTION PRESSURE psia	DISCHARGE PRESSURE psia	HEAD ft	OPER TEMP. °F	DESIGN TEMP. °F	DESIGN PRESS. psia	MOC CASE	MOC IMPEL-LER	WEIGHT LBs each	SKID SIZE (each) LxW ft
P-1101A/B	Service Water Pump	11-001	2	Centrifugal	Service Water	16.3	77.3	142	108	158	92	CS	CS	2,500	4 ft x 6 ft
P-1102A	Fire Water Pump	11-001	1	Centrifugal	Fire Water	13.9	175.0	375	108	158	215	CS	CS	7,000	4 ft x 8 ft (Electric Motor)
P-1102B	Fire Water Pump	11-001	1	Centrifugal	Fire Water	13.9	175.0	375	108	158	215	CS	CS	7,600	4 ft x 12 ft (Diesel Engine)
P-1103A/B	Fire Water Jockey Pump	11-001	2	Centrifugal	Fire Water	17.0	177.9	375	108	158	218	CS	CS	500	Vertical in-line
P-1104A/B	Demineralized Water Pump	11-002	2	Centrifugal	Demineralized Water	17.0	109.6	216	108	158	133	CS	304LSS	5,000	4 ft x 6 ft
P-1105A/B	Potable Water	11-003	2	Centrifugal	Water	17.3	126.8	255	108	158	154	CS	304LSS	5,000	4 ft x 6 ft
P-1106A/B	Raw Water Pump	-	2	Centrifgual	Water	-	-	-	-	-	-	-	-	-	4 ft x 6 ft
P-1201A/B	BFW Pump	12-001	2	Centrifugal	Boiler Feed Water	43.6	187.9	353	248	298	224	CS	12Cr	25,000	6 ft x 10 ft
P-1203A/B	Condensate Pump	12-003	2	Centrifugal	Steam Condensate	21.3	70.7	119	212	262	83	CS	12Cr	5,000	6 ft x 10 ft
P-1401A/B	Solvent Transfer Pump	14-001	2	Centrifugal	NAS	15.0	41.7	66	108	158	48	CS + 1/8 CA	316LSS	2,500	4 ft x 6 ft
P-1402	Solvent Sump Pump	14-001	1	Centrifugal Submersible	NAS	13.6	66.7	122	68	118	80	CS + 1/8 CA	316LSS	2,500	4 ft x 6 ft
P-1403A/B	Caustic Transfer Pump	14-002	2	Positive Displacement	Caustic	15.6	41.0	43	104	154	48	CS	CS	2,500	4 ft x 6 ft
P-1404A/B	Sulfuric Acid Transfer Pump	14-003	2	Positive Displacement	Sulfuric Acid	17.5	32.6	35	108	158	36	CS + 1/4 CA	CS + 1/4 CA	2,500	4 ft x 6 ft
P-1501 A/B/C	Cooling Water Pump	15-001	3	Positive Displacement	Water	32.3	152.2	277	82	132	182	CS	13Cr	21,300	7 ft x 13 ft
P-1801A/B	Waste Water Pump	18-001	2	Centrifugal	Water	13.9	81.5	156	68	118	98	CS	12Cr	2,500	4 ft x 6 ft
P-2002	O Drum Aqueous Phase Pump	20-001	1	Centrifugal	Water	16.1	87.0	165	108	158	104	CS	304LSS	2,500	4 ft x 6 ft

PRELIMINAR SI ED E UIPMENT LIST FILTERS

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ELEVATION Hung/Grade	OPER TEMP. °F	DESIGN TEMP. °F	DESIGN PRESS. psia	MOC	WEIGHT Lb
F-1401	Solvent Sump Filter	14-001	1	Grade	108	158	88	CS + 1/8 CA	2,000

PRELIMINAR SI ED E UIPMENT LIST TAN S

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	ELEVATION	ORIENTATION	OPER TEMP.	DESIGN TEMP.	DESIGN PRESS.	WEIGHT	
				Hung/Grade	H/V	°F	°F	psia	Dry lb.	Wet lb.
T-1101	Service Water Tank	11-001	1	Grade	V	108	158	14.7	-	9,800,000
T-1102	Demineralized Water Tank	11-002	1	Grade	V	108	158	14.26 / 17.2	64,000	1,100,000
T-1103	Potable Water Tank	11-003	1	Grade	V	108	158	14.7	22,000	164,000
T-1401	Solvent Storage Tank	14-001	1	Grade	V	108	158	14.26 / 17.2	24,000	166,000
T-1402	Caustic Storage Tank	14-002	1	Grade	V	108	158	14.7	21,000	127,000
T-1403	Sulfuric Acid Storage Tank	14-003	1	Grade	V	108	158	14.7	21,000	127,000

PRELIMINAR SI ED E UIPMENT LIST OTHER E UIPMENT

EQUIP NUMBER	ITEM NAME	PFD / UFD NUMBER	NUMBER OF ITEMS	WEIGHT		SKID SIZE (each)	OTHER INFORMATION
				Dry lb	Wet lb	ft	
A-1101	Demineralized Water Package	11-002	1	50,000	300,000	8 ft x 40 ft	
A-1201	BFW Chemical Package (Oxygen Scavanger)	12-001	1	10,000	12,000	4 ft x 6 ft	
A-1202	BFW Chemical Package (Corrosion Inhibitor)	12-001	1	10,000	12,000	4 ft x 6 ft	
A-1203	Natural Gas Boiler Package	12-002	2	650,000	700,000	See notes	(2) 50% Packaged Boilers each rated nominally 395,000 lb/hr. (2) 100% FD Fans. 500 HP each fan. Boiler Package size: 34 ft W x 50 ft L
A-1501	Cooling Water Package	15-001	1	220,000	455,000	See notes	(9) fans 75 HP each (675 HP total) Size of 9 cells: 23 ft W x 147 ft L
A-1601	Nitrogen Generation Skid	16-001	1	90,000	100,000	18 ft x 40 ft	Skid includes: (2) Compressor skids (each 6 ft W x 19 ft L), One PSA unit skid (13 ft W x 11 ft L), total skid is 18 ft W x 40 ft L Each compressor has (1) 450 HP motor. Each compressor has 15 HP fan motors. Dryer is 2 HP. Trim Cooler is 10 HP. Control panel will have 10 amp load. Freeze protection 5 amp each compressor.
A-1602	Instrument Air Dryer Package	16-001	1	See -1601	See -1601	See -1601	Refer to Compressor Table
A-1801	Waste Water Treatment Package	18-001	1	2 (2300) 1 (1400)	2 (3000) 1 (6500)	100 ft x 30 ft	2 x 100%. GRF - 2, 60 diameter Tanks. Brine system with pump. Reclaim DCC and Cooling Tower Blowdown. Design temp. 300 F, design press. 150 psia
A-1801B	Acid Waste Treatment	18-001	1	-	-	-	Design temp. 150 F, design press. 100 psia
A-2001	Stack	20-001	1	-	-	-	By Civil, Structural, and Architectural (CSA)

Appendix B.10 Utility Summary

UTILITY SUMMARY

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A	12-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
B	13-OCT-23	ICR – ISSUE FOR CLIENT REVIEW	AK	SP	DDB	
C	28-MAR-24	ICR – ISSUE FOR CLIENT REVIEW	AK	JRZ	DDB	
D	05-APR-24	ICR – ISSUE FOR CLIENT REVIEW	AK	JRZ	DDB	
E	30-OCT-24	IFD – ISSUE FOR DESIGN	AK	JRZ	DDB	
F	09-DEC-24	IFD – ISSUE FOR DESIGN	AK	JRZ	DDB	
G	07-MAR-25	IFD – ISSUE FOR DESIGN	AK	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	12-OCT-2023	ALL	ICR – Issued for Client Review
B	13-OCT-2023	ALL	Incorporated Client comments
C	28-MAR-2024	ALL	Updates per PDN Hybrid Cooling System
D	05-APR-2024	ALL	Updates to steam and water balances and power summary
E	30-OCT-2024	Cover	Updated confidentiality and export compliance statements
F	09-DEC-2024	3	Updated K-0111 A/B power requirement
G	07-MAR-2025	3	Update CO2 Compressor power, and missing package power

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1. NOTES

1) BFW requirement is based on the steam generation rate in the Natural Gas Boiler Package, CO_2 Compression Package, and 3% blowdown from the boiler.
2) Cooling Tower recirculation rate is calculated based on the max case exchanger heat duties and temperature rise of 12.6 °F.
3) The Instrument and Plant Air requirements are high-level estimates to be refined during later phases of engineering.
4) Assumed 100 people on site with average usage of 3.9 ft^3/person/day. Number of people to be updated at client's discretion in a later phase of engineering. Also assumed two safety shower and eye wash stations are operating simultaneously, consuming 183.6 ft^3/hr of potable water each.
5) Steam requirement for the Natural Gas Boiler Package is calculated based on the total facility steam demand minus the steam produced by the CO_2 Compressor Package. Steam generator pressure is assumed to be 150 psig.
6) Nitrogen rate requirement is a high-level estimate to be refined during later phases of engineering.

2. UTILITY INTERFACE SUMMARY

Interface Summary			
			Design Case
Electric Power Requirement		**kw**	63,146
LP Steam Requirement	Note 5	**lb/hr**	845,375
Pressure		**psia**	39.7
Temperature		**°F**	267
Total Condensate		**lb/hr**	770,192
Pressure		**psia**	25
Temperature		**°F**	240
Total BFW Requirement	Note 1	**lb/hr**	866,138
Pressure		**psia**	184
Temperature		**°F**	248
Cooling Water			
Cooling Water Tower (Recirculation)	Note 2	**lb/hr**	13,888,587
Cooling Duty		**MMBTU/hr**	175
Supply Temperature		**°F**	82
Return Temperature		**°F**	95
Makeup		**lb/hr**	218,745
Instrument Air Requirement (Dry Basis)	Note 3	**scfh**	15,606
Pressure		**psia**	113
Plant Air Requirement	Note 3	**scfh**	30,000
Pressure		**psia**	123
N2 Requirement	Note 6	**scfh**	72,748
H2 Requirement		**lb/hr**	70
Natural Gas Requirement		**lb/hr**	38,028
Potable Water Requirement	Note 4	**lb/hr**	23,851
Demin Water Requirement		**lb/hr**	99,162
Service Water		**lb/hr**	317,907

3. POWER SUMMARY

Electrical Power Requirement, kW			Design Case
Packages	**Unit No**	**Description**	
K-0211	02	CO2 Compressor Package	26,954
A-0221	02	TEG Dehydration Package	661
A-0232	02	Electrolyzer Package	1,858
A-1101	11	Demineralized Water Package	-
A-1201	12	BFW Chemical Injection Package	3.7
A-1202	12	BFW Chemical Injection Package	3.7
A-1203	12	Natural Gas Boiler	746
A-1501	15	Cooling Water Package	2,408
A-1601	16	Nitrogen Generation Package	354
K-1601	16	Primary Air Compressor Package	100
K-1602	16	Secondry Air Compressor Package	100
A-1801	18	Waste Water System Package	22
Blowers			
K-0111 A/B	01	Flue Gas Blower	4,474
Pumps			
P-0111 A/B/C	01	Feed Scrubber Wash Circulation Pump	1,305
P-0121 A/B/C	01	Absorber Interstage Circulation Pump 1	2,436
P-0122 A/B/C	01	Absorber Interstage Circulation Pump 2	2,649
P-0124 A/B/C	01	Rich Solvent Pump	2,889
P-0131 A/B/C	01	Absorber Overhead Wash Water Pump 1	772
P-0132 A/B/C	01	Absorber Overhead Wash Water Pump 2	818
P-0133 A/B/C	01	Acid Wash Pump	623
P-0141 A/B/C	01	Lean Solvent Pump	3,585
P-0151 A/B	01	Regenerator Reflux Pump	3.1
P-1101 A/B	11	Service Water Pump	28
P-1102 A/B	11	Fire Water Pump (321 kW)	-
P-1103 A/B	11	Fire Water Jockey Pump	32
P-1104 A/B	11	Demineralized Water Pump	19.6
P-1105 A/B	11	Potable Water Pump	5.4
P-1201 A/B	12	BFW Pump	179
P-1203 A/B	12	Condensate Pump	54
P-1401 A/B	14	Solvent Transfer Pump	0.4
P-1402	14	Solvent Sump Pump	6.3
P-1403 A/B	14	Caustic Transfer pump	0.1
P-1404 A/B	14	Sulfuric Acid Transfer Pump	0.2
P-1801 A/B	18	Process water Pump	18.2
P-2002	20	KO Drum Aqueous Phase Pump	0.7
Air Coolers			
E-0112	01	Feed Scrubber Wash Cooler	1,432
E-0121	01	Absorber Interstage Air Cooler 1	3,356
E-0122	01	Absorber Interstage Air Cooler 2	1,745
E-0142	01	Lean Solvent Air Cooler	3,356
E-0151	01	Regenerator Overhead Condenser	149
		Total	**63146**

Appendix B.11 Catalyst and Chemical Summary

CATALYST AND CHEMICALS SUMMARY

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A	30-OCT-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	
B	11-DEC-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	
C	10-APR-25	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	30-OCT-2024	ALL	IFD – Issue for Design
B	11-DEC-2024	ALL	Updated V-0221 and A-1101, added chemical consumption rates
C	10-APR-2025	Table 2 Notes	Updated amine, sulfuric acid, caustic usage per latest design basis

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1.0 CATALYST

Description	PFD	Mass (lb)	Bulk Density (lb/ft^3)	Rx Cat Vol (ft^3)	Life (yr)
V-0134 Activated Carbon Beds	DE-FE0032220-KBR-01-PR-D-PFD-302	187071 (per bed)	29.8	6280 (per bed)	By Vendor
V-0221 O_2 Polishing Reactor Catalyst (BASF DeOxo RS, 0.3% Pt/AS R4758)	DE-FE0032220-KBR-02-PR-D-PFD-103	1303	40.6	32.1	5 (1)
A-1101 Demineralized Water Package, Cation Beds (Qty 2)	DE-FE0032220-KBR-11-PR-D-UFD-002	By Vendor	By Vendor	325 (per bed)	By Vendor
A-1101 Demineralized Water Package, Anion Beds (Qty 2)	DE-FE0032220-KBR-11-PR-D-UFD-002	By Vendor	By Vendor	162 (per bed)	By Vendor

Notes

1) Typical lifetime is 5 years. Lifetime is guaranteed for 4 years.

2.0 CHEMICALS

Chemical(s)	Description	PFD / UFD
Demineralized Water Chemicals	To A-1101, Demineralized Water Package to remove minerals from service water. Chemicals include sodium bisulfate for oxygen scavenger, H_2SO_4 for cation bed regeneration, and NaOH for anion bed regeneration. (1), (2)	DE-FE0032220-KBR-11-PR-D-UFD-002
BFW Chemical Package (A-1201)	To V-1201, Deaerator outlet to control boiler feed water corrosion	DE-FE0032220-KBR-12-PR-D-UFD-001
BFW Chemical Package (A-1202)	To V-1201, Deaerator inlet to remove oxygen from demineralized water	DE-FE0032220-KBR-12-PR-D-UFD-001
NAS Solvent	To V-1401, Solvent Storage Tank to supply amine makeup to T-0141, Lean Solvent Surge Tank	DE-FE0032220-KBR-14-PR-D-UFD-001
Caustic Solution	To V-1402, Caustic Storage Tank to supply V-0111, Feed Direct Contact Cooler for cooling the flue gas and neutralizing SO_2	DE-FE0032220-KBR-14-PR-D-UFD-002
Sulfuric Acid	To V-1403, Sulfuric Acid Storage Tank to supply C-0121, Absorber Column for acid wash and neutralizing amines	DE-FE0032220-KBR-14-PR-D-UFD-003
Cooling Water Chemicals	To A-1501, Cooling Tower Package for biocide and corrosion control	DE-FE0032220-KBR-15-PR-D-UFD-001
Air Dryer Absorbent	To A-1602, Instrument Air Dryer Package to remove moisture from air	DE-FE0032220-KBR-16-PR-D-UFD-001

Chemical(s)	Description	PFD / UFD
Wastewater Treatment Chemicals	To A-1801, Wastewater Treatment Package for pH control and to purify wastewater	DE-FE0032220-KBR-18-PR-D-UFD-001
Lube Oil	For rotating equipment	Various

Notes

1) Regen Frequency = Once per day. Requires 7.5 lbs of 100% H_2SO_4 per ft^3 resin to regenerate or 2487 lbs @ 98 wt%. Acid should be diluted to 7-10 wt%.
2) Regen Frequency = Once per day. Requires 7.6 lbs of 100% NaOH per ft^3 resin to regenerate. Caustic should be diluted to 4 wt%.

Appendix B.12 Overpressure Protection and Vent Philosophy

OVERPRESSURE PROTECTION AND VENT PHILOSOPHY

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A	30-OCT-24	IFD – ISSUE FOR DESIGN	SP	SB	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	30-OCT-2024	ALL	IFD – Issue for Design

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1. PURPOSE AND SCOPE

For this project we followed KBR standard over pressure protection and vent philosophy as outlined in document P50-1D-US-BO-M&U. See Attachment 1.

2. ABBREVIATIONS

Term	Definition
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
FEED	Front End Engineering Design
ISBL	Inside Battery Limits
MAWP	Maximum Allowable Working Pressure
OSBL	Outside Battery Limits
PRV	Pressure Relief Valve
Std	Standard
Built-Up Back Pressure	The additional back pressure at the relieving device discharge flange after the relieving device opens as a result of additional flow to the header (constant).
Overpressure	The pressure increase over the set pressure of the relieving device during discharge, expressed as a percentage of set pressure.
Accumulation	The pressure increase over the MAWP permitted by the pressure vessel design code for emergency operating and fire contingencies.

3. APPENDIX

Attachment 1 - P50-1D-US-BO-M&U – Overpressure Protection and Vent Philosophy document.

Spec. Number Suffixes: US based on US Codes and Standards, BO applicable for onshore and offshore Projects, M&U units used: M SI metric and U US Customary Units

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1. GENERAL

1.1 Scope

1.1.1 This document (P50-1D) states the standard BR overpressure protection and vent philosophy. Overpressure protection is provided in accordance with this document, but is limited to the project scope as defined in the project contract and/or subsequent project documentation related to this subject. Overpressure protection is also limited to scenarios considered credible incidents identified in industry codes and standards. The Owner has the authority and responsibility to identify, document, and communicate to BR scenarios that are not to be considered credible for overpressure protection because other protective measures, such as administrative procedures or instrumentation, are sufficient to prevent the overpressure scenario. The Owner is responsible for ensuring that administrative procedures are followed and protective instrumentation is adequately maintained to provide sufficient overpressure protection. BR is not responsible for overpressure consequences that occur because these conditions are violated. Such special requirements shall be reviewed and approved by the Office of the Chief Engineer.

1.1.2 The safety of personnel, the protection of equipment from damage due to overpressure, and the protection of the environment due to loss of containment are the basis for the designing, sizing, and selection of pressure relieving systems.

1.1.3 All systems and pressure relief devices shall meet applicable codes, industry standards and practices, and related Owner job instructions.

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1.1.4 The objective is to apply a systematic examination to all modes of operations and engineering intentions to protect the mechanical integrity of the equipment and piping systems based on all credible incidents. Provisions shall be made to contain or safely relieve any excessive pressures in the system. These provisions may include the utilization of an emergency shutdown and depressuring system at the discretion of the Owner.

1.1.5 Statutory Requirements: BR and the Owner shall mutually determine the measures that must be taken to comply with all applicable governmental codes, regulations, ordinances, and rules, which shall be applied as a first precedence.

1.1.6 The equipment and piping systems shall be designed, fabricated, tested, and assembled in accordance with the job specifications and shall be subject to the Supplier s quality assurance and control procedures, including third party inspection.

1.1.7 The practices outlined in this document shall be followed for all process unit areas, including related utilities and offsites, and licensor and non licensor packages.

1.1.8 Owner specifications or other practices, which represent a clearly hazardous condition to personnel or plant safety, shall be brought to the attention of BR Chief Engineer for review and resolution.

1.1.9 The following defines BR s scope of responsibility for projects that require BR to provide purchasing input only. BR will purchase parts to be used for repair of existing relief valves and purchase new relief valves as replacement-in-kind for existing relief valves as indicated by our scope of work documents. In these specific situations, the BR scope of work will not include the following engineering activities or the engineering responsibility for any possible deficiencies in the existing system such as:

a. Sizing of relief valves or selection of type suitable for application.
b. Establishing the set pressures.
c. Define the sizing scenarios.
d. Overpressure protection.
e. Checking sizing of existing flare header and resulting back pressures.
f. Checking existing flare capacity.
g. Any consideration of the materials being flared and their properties.
h. Any evaluation or consideration of any needed mitigation measures (such as operating procedures or control systems) that may be required to assure the integrity of the systems.

1.2 KBR Documents, Codes, and Industry Standards

The design of the pressure relieving systems is based on the following codes, industry standards, specifications, and recommended practices. The applicable dates of issue including addenda, modifications, or additional requirements for the project are identified in the Project Design Data document.

KBR DOCUMENTS

I47-1E, Pressure Relief Valves
P40 1D, Piping for Hydrocarbon and Chemical Processing Facilities (Onshore)

AMERICAN PETROLEUM INSTITUTE (API)

API RP 14C, Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms
API RP 14E, Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems
API STD 520, Sizing, Selection, and Installation of Pressure Relieving Devices in Refineries
Part I, Sizing and Selection
Part II, Installation

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API STD 521, Pressure-Relieving and Depressuring Systems
API STD 526, Flanged Steel Pressure Relief Valves
API STD 527, Seat Tightness of Pressure Relief Valves
API STD 2000, Venting Atmospheric and Low Pressure Storage Tanks

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME Boiler and Pressure Vessel Code, including all mandatory addenda in effect on the date of the Order
Section I, Power Boilers
Section VIII, Pressure Vessels Division 1 including Appendix M

ASME B31.1, Power Piping
ASME B31.3, Process Piping

2. CAUSES OF OVERPRESSURE

2.1 General

2.1.1 All equipment and piping systems must be protected when the internal or external pressure can exceed the design condition of the system due to an emergency, upset condition, operational error, instrument malfunction, or fire. Possible scenarios are discussed in API STD 521 and API 14E.

2.1.2 All equipment items shall be protected from overpressure. This overpressure protection shall be provided by a pressure relief device system. A single pressure relief device system may be used to protect a group of equipment items (a separate pressure relief device system is not required for each equipment item) if there is no means of isolating the equipment from the pressure relief device system (see Paragraph 2.4.4) or if isolating the equipment from the pressure relief device system also removes the source of overpressure. Per ASME Section VIII Division 1, UG-140, overpressure protection may also be provided by system design. The decision to limit the pressure by system design is the responsibility of the user. If the pressure is self-limiting (e.g., pump shut-off less than downstream equipment MAWP), UG-140(a) shall be used with agreement from the Owner. If the pressure is not self-limiting, (e.g., high integrity instrumentation is used to replace or supplement relief devices for overpressure protection), UG-140(b) shall not be used unless directed by the Owner.

2.1.3 For offshore production facilities, per API 14C, the safety system should provide two levels of protection. In general, the primary protection shall be a separate, safety designated, high pressure trip that will initiate actions to remove the high pressure source. The secondary protection shall be a pressure relief device.

2.1.4 Pressure relieving devices are installed to ensure that a system or any of its components are not subjected to pressures, which exceed the allowable pressure accumulation per applicable Code requirements (e.g., ASME Boiler and Pressure Vessel Code Section I and Section VIII, ASME B31.1, and ASME B31.3).

2.1.5 Any circumstance which reasonably constitutes an overpressure type hazard under the prevailing conditions shall be analyzed and evaluated. In support of this statement, it is assumed that the plant will be staffed by trained operators and that administrative procedures will be followed. For example, it is assumed that a trained operator may close a normally open valve by mistake, but will not close a valve designated as locked open without following the prescribed administrative procedures. Also, it is assumed that no willful sabotage occurs and that no one will perform an operation for the purpose of damaging equipment or harming the plant.

2.2 Assumptions

2.2.1 The simultaneous occurrence of two or more conditions which could result in overpressure is not to be considered if the causes are unrelated, i.e., if no process, mechanical, or electrical commonality exists among the causes.

2.2.2 Control response and the automatic start up of equipment are not to be considered as a substitute for pressure relieving devices for equipment protection. As a general rule, final overpressure protection shall be provided by means of a mechanical pressure relieving device.

2.2.3 Equipment not affected by a utility failure being evaluated is to be considered to remain in normal operation.

2.2.4 Flow rates through the equipment and other conditions during the emergency are to be assumed to remain at the normal rates and conditions occurring prior to the upset condition unless the particular emergency case under consideration alters the flow rate or conditions. In case of fire, the flow is to be assumed to stop and be contained within a defined system.

2.2.5 The possibility of an operator inadvertently opening or closing any one valve or taking any incorrect action in the wrong sequence or at the wrong time must be considered. However, block valves, electric switches, and other equipment items that are locked or car sealed in the safe position are not to be considered involved in any case of operator error.

2.3 Principal Causes

2.3.1 General

The following describes some common principal causes of overpressure, which shall be analyzed to determine the individual relieving flow rates for pressure relieving devices. Also, clarification of the analysis method and type of overpressure protection device to be used are provided if applicable. The list is not intended to be all inclusive, but is intended to serve as a guide.

2.3.2 Power Failure (Steam or Electric)

a.Plant-wide, plant section-wide, and individual equipment failures (i.e., total and partial failures) shall be considered. Equipment which is not affected by the failure of concern is to be considered to remain in normal operation. Electrical one-line diagrams shall be examined to determine common mode and related failures.

b.A maximum credit of 25 percent cooling duty should be allowed for the effect of natural draft in the event of a loss of an air cooler due to power failure unless specifically advised otherwise by the Owner. The amount of credit is affected by the type of air cooler design.

2.3.3 Cooling Water Failure

a. Total or partial loss of cooling water, depending on pump installation, individual exchangers, and power source of drivers shall be considered. Partial credit may be taken if the cooling water circulating system consists of two or more pumps in parallel and continuous service with drivers having independent power sources. Generally, if only one of two 50% pumps is considered to fail, 50% cooling water flow is assumed to continue.

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b. The pump(s) with the unaffected driver(s) are to be assumed to continue to operate. Credit shall not be taken if the unaffected pump(s) are on standby because standby devices are not considered totally reliable. Credit shall not be taken if the unaffected pump(s) can be removed from service for maintenance and the remaining operating pumps are dependent on the same power source.

c. Total cooling water failure must be considered simultaneous with power failure if the common pump power source is lost during a power failure. The loss of individual cooling water supply to exchangers, compressors, etc., shall be considered.

2.3.4 Column Reflux or Pump-around Failure

Loss of column reflux, whether supplied by the overhead circuit, sidestream reflux, and/or by the top tower pump-around, shall be considered. Other facilities associated with column operation are to be considered to continue to function as designed.

2.3.5 Open External Fire

a. It is to be assumed that all fluid flow to the equipment has stopped and at the time of stoppage, the equipment contains a normal liquid level. Only the internally wetted portion of the equipment, elevated 7.6 m (25 ft) or less above the source of the flame, shall be considered in determining the wetted surface area.

b. The source of flame base elevation shall be considered any level on which a substantial spill or pool fire can accumulate and be sustained. Portions of equipment higher than 7.6 m (25 ft) above the flame base elevation, including that portion of liquid full vessels, shall be excluded. The liquid hold up on tower trays and the liquid inventory of any integral reboiler shall be included for determining the wetted surface up to 7.6 m (25 ft).

c. Unless a finite curbed area is established, a fire circle of 21.3 m (70 ft) diameter shall be used to determine the amount of equipment affected by a single pool fire. If no source of a pool fire can be established or if it can be established that the excess flow caused by the fire is relieved through the process without causing an overpressure condition, and this flow passage cannot be shut in during normal plant operation or because of fire effects, then no fire relief protection needs to be provided. Jet fires are generally not considered except under special circumstances.

d. If the only time an equipment item can be shut in is during isolation for maintenance purposes, fire relief protection is not required if administrative controls ensure that the equipment item is vented and drained immediately when removed from service.

e. Equipment which normally operates dry must be evaluated for the vapor expansion fire case.

f. Equipment which is located entirely above the 7.6 m (25 ft) elevation limit may still be provided with some degree of relief protection from external fire. The impact of fire on such equipment is to be considered on a case by case basis.

g. The extent of the pool fires underneath equipment should be minimized (e.g., by sloping the paving and ground away from the equipment, not locating other equipment directly underneath, etc.). If exposure to fire from adjacent equipment provides significant relief loads, water sprays are to be considered. However, no reduction in relief load can be taken because of the addition of water sprays.

h. The insulation system for an equipment item is to be considered individually. Credit shall be taken for equipment insulation if the requirements of insulation integrity during a fire are met, including the ability to withstand fire hose stream impact.

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i. Piping and piping components are generally not considered to require separate protection for fire, but shall be included if they are part of a group of interconnected equipment items protected by a single pressure relieving system.

2.3.6 Refrigerant Failure

In addition to a total refrigeration loss, a loss of refrigerant to individual exchangers shall be considered.

2.3.7 Blocked Outlet

Normally, equipment and piping should be designed for the maximum possible pressure resulting from a single blocked outlet. However, if the accidental closure of a block valve subjects the equipment or piping to overpressure, relief protection must be provided. If the closure of a single block valve during normal operation causes a significant plant upset, the use of a locked open (LO) or car sealed open (CSO) valve may be considered necessary for operational purposes and may provide a relief path that replaces the requirement for a relief device. CSO or LO valves should not be specified to replace relief devices, but can be considered to provide an open relief path if specified for operational purposes.

2.3.8 Centrifugal Pump Shut in

A pressure relief valve is not required to protect the equipment in the discharge system of a centrifugal pump from a blocked in case if the equipment design pressure is greater than or equal to the pump shut in pressure because the pressure is self-limiting. Per ASME Section VIII Division 1, UG-140(a), unless there is an additional scenario that requires a relief device, the Owner must agree that the pressure is limited by system design and that the Owner will follow the proper administrative and documentation procedures. If the Owner does not agree to follow the requirements of this section of the Code, then a minimum size pressure relief valve is required. In addition, the suction lead piping and the pump suction connections should be checked for the discharge pressure rating. Normal variations in liquid gravity, maximum suction pressure and temperature, and maximum continuous speed shall be considered.

2.3.9 Instrument Air/Electric Supply Failure

In the event of a plant wide instrument air or instrument electric power failure, all affected valves shall be considered to fail in their specified failure positions. Instrument air and instrument electric power are considered to be two unrelated sources of energy. Thus, simultaneous failure shall not be considered a viable contingency.

2.3.10 Control Valve Failure

a. The failure mode (air to open, close, or last position) on loss of motive power shall be evaluated for each valve. Each control valve should have its fail-safe characteristics properly established to minimize the hazard to plant operation.

b. The effect of a mechanical failure of the control valve shall always be considered when evaluating the need for overpressure protection of systems associated with the valve.

c. Control valves with a bypass (as required per BR Standard P40-1D): Provisions for overpressure protection of a system downstream of a control valve station with a bypass shall be based on the flow rate equivalent of either the control valve or the bypass valve being fully open and the other being fully closed.

2.3.11 Inadvertent Valve Opening

The inadvertent opening of any valve from a source of higher pressure shall be considered, unless provisions are made for locking or car sealing the valve closed.

2.3.12 Check Valve Leakage or Failure

Total failure of a single check valve or leakage through more than one check valve in series shall be considered as a viable overpressure contingency in systems with high pressure differential (defined for this possible scenario as the high pressure side operating pressure greater than the low pressure side hydrotest pressure), pressure surges, or dirty service. Two check valves in series shall be considered sufficient to eliminate the total failure scenario, but shall not be considered sufficient to eliminate the leakage scenario.

2.3.13 Hydraulic Expansion

a. Use of pressure relief valves for thermal expansion should be minimized. Within process areas, the requirement for thermal pressure relief valves shall be evaluated for piping, pressure vessels, and equipment, which can be manually blocked in while filled with liquid and subsequently heated by heat tracing, process, or atmospheric effects. Such equipment includes the cold side of heat exchangers that can be blocked in.

b. Documented administrative control procedures stipulating that the system is to be drained whenever it is blocked in are an acceptable alternative solution to prevent overpressure due to hydraulic expansion.

c. Thermal relief shall be provided for piping outside of the process areas if the piping design pressure can be exceeded as a result of a blocked-in condition. Piping outside of the process areas is considered not to be drained when taken out of service because of remote location and lack of facilities to contain the liquid volume from long pipe runs.

2.3.14 Pressure Transients

a. Normally, a pressure transient analysis is not to be provided for liquid filled systems in process plants. In general, these systems should not have quick closing valves and overpressure protection for a pressure transient should not be required. For upstream oil and gas production facilities (offshore or onshore), a transient analysis is normally required for large liquid filled systems such as seawater and firewater systems.

b. Utility distribution systems which are subject to pump failure (e.g., water, liquid feed, or rundown from or to offsites), normally require a pressure transient analysis. Such systems shall be designed for expected dynamic impact forces if the analysis determines that the peak pressure varies significantly from operating conditions. Short term overpressure allowance within ASME Piping Code rules should be utilized in preference to pressure relief protection if approved by the Owner.

2.3.15 Runaway Reactions

If runaway chemical reaction is determined to be a credible overpressure scenario and the process causing the reaction is not a BR-developed process, the Owner or process developer is responsible for providing the required heat release curves and/or flow rates and conditions to be used for relief device sizing. BR is not responsible for overpressure consequences that occur because of any inaccuracies in the information provided.

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2.4 Equipment Protection

2.4.1 Heat Exchangers

a. BR standard shall be to provide overpressure protection for tube failure in shell and tube exchangers if the low pressure side MAWP, including upstream and downstream systems, can be exceeded. Unlike API STD 521, ASME Code does not permit pressure accumulation above the MAWP for exchanger internal failure. Tube failure can vary from a pinhole leak to a complete tube diameter failure and is subject to the following considerations:

1. Pressure relief protection shall be specified if the flow through a complete tube failure cannot be absorbed by the low pressure system without causing overpressure. A complete tube diameter failure is an unlikely event and shall not be considered simultaneous with a blocked in condition.

2. If applicable, pressure relief shall be specified and located to adequately provide protection from maximum dynamic pressures caused by high pressure vapor or flashing liquid flowing through a complete tube rupture to a much lower pressure liquid full system. Complete and sudden tube rupture transient effects shall not be considered if the differential between the high pressure side and low pressure side operating pressure is less than 6895 kPa (1000 psi).

3. A small tube leak (i.e., undetected during operation) shall be considered simultaneous with a blocked in condition if the exchanger can be blocked in during operation (e.g., caused by an inadvertent closure of one block valve or a control valve). Therefore, pressure relief shall be provided for a leaking tube or tubesheet if a blocked in condition can cause overpressure. However, if the exchanger need only be blocked in for maintenance, overpressure protection shall not be provided for a small tube leak because administrative procedures are expected to avoid the overpressure condition.

b. Double pipe exchangers are considered to be piping components if they are designed using schedule pipe or equivalent heavy gauge tubes for the inner conduit. As such, they are not likely to rupture and shall not be protected from an internal failure.

c. Exchangers shall be protected if one stream can be blocked in during operation (e.g., caused by an inadvertent closure of one block valve or a control valve), and the vapor pressure at maximum ambient design temperature exceeds the design pressure.

d. Exchangers shall be protected if the cold side can be blocked in during operation (e.g., caused by an inadvertent closure of one block valve or a control valve), and the cold side liquid vapor pressure at the inlet temperature of the hot side exceeds the cold side design pressure (See Paragraph 2.3.13: Hydraulic Expansion).

e. Overpressure due to an open external fire shall not be considered a viable contingency for spared exchangers that are drained and vented when not in service.

2.4.2 Air Coolers

During emergencies, reduced duty of air cooled heat exchangers when sizing pressure relief systems could be caused by:

a. 100% failure of fans
b. Louvers closed because of process control
c. See Paragraph 2.3.5 on external fire and Paragraph 2.3.2 on power failure for other considerations

2.4.3 Vessels

Vessels shall be protected against all causes of overpressure as outlined in the preceding sections. However, protection shall not be provided for a vacuum condition caused by draining water after testing or condensing steam after steam out. The Owner s administrative procedures will provide adequate protection.

2.4.4 Multiple Equipment

Parallel equipment or inter connected equipment may be protected by a common relieving device provided that they are connected by a line of sufficient size with no intervening isolation valves and the set pressure is such that no equipment can be overpressured or that the relieving device prevents the pressure source from overpressuring the equipment (e.g., a pressure relief device on a steam header that is set to protect all of the downstream exchangers in that steam service from a blocked outlet case).

2.4.5 Furnace Coils

Fired coils in process service shall not be provided with overpressure protection, except when mandatory under the applicable code. Overpressure and safety protection for superheaters and boiler feedwater preheat coils shall be considered in accordance with the applicable code.

2.4.6 Steam Turbines

The need for overpressure protection shall be based on the pressure rating of the turbine casing and the closing of the outlet block valve. If required, the pressure relief valve shall be located in the exhaust piping upstream of the block valve and shall be sized to relieve the actual steam flow rate through the turbine at the allowable outlet overpressure. Sentinel valves are warning devices only and should not be used for overpressure protection.

2.4.7 Reciprocating and Positive Displacement Pumps

These pumps shall be protected with a pressure relieving device. Dynamic fluid pulsations shall be taken into account when determining a suitable margin between the set pressure and the overall peak to peak fluid pressure pulsations.

2.4.8 Centrifugal Compressor Circuits

a. If possible, the compressor casing design pressure for each stage should be higher than the maximum pressure, which can be developed by that compressor stage during any upset or normal operating condition. Examples of upset conditions are inadvertent closing of valves, loss of cooling, or unscheduled compressor trips. The maximum discharge pressure of each stage is the maximum possible suction pressure of that stage during any upset or normal operating condition plus the largest pressure differential of that stage coincident with that condition. The largest pressure differential occurs with simultaneous conditions of maximum continuous rated speed, maximum molecular weight, and minimum suction temperature at the incipient surge point of the compressor stage (surge differential head).

b. The maximum operating pressure is compared with the maximum settling out pressure, which occurs during a compressor trip or shutdown. Increase of settling out pressure caused by warm up to the maximum design ambient temperature shall be considered for colder than ambient systems, such as refrigeration systems. The discharge piping for each stage shall be designed for the maximum potential discharge pressure for that stage or the compressor casing design pressure for that stage, whichever is less.

c. As a minimum, the compressor stage shall be designed for the initial settling out pressure or the normal operating pressure plus a suitable margin, whichever is larger. If it is not practical for the compressor stage design pressure to be higher than the maximum pressure, which can be developed by the compressor, overpressure protection shall be provided by a pressure relieving system.

d. To estimate the maximum discharge pressure and/or relieving load the characteristic curve of the proposed machine or a similar one should be used. This data shall be confirmed on receipt of Supplier data.

3. PRESSURE RELIEF DEVICES

3.1 General

a. This section summarizes the design approach to the sizing and selection of pressure relief devices to protect equipment against overpressure from operating and fire contingencies.

b. All pressure relief devices shall be stamped with the ASME Code Symbol for Section I or for Section VIII applications as required.

c. All pressure relief valves shall be bench tested by the Owner, or by a representative designated by the Owner, to verify the set pressure prior to final installation, except those requiring in situ testing for ASME Section I applications.

d. In specifying and purchasing pressure relief valves, BR and API standards shall be used as appropriate (e.g., BR Standard I47-1E, and API 526 and API 527).

3.2 Sizing

The various sizing methods for pressure relief valves used in liquid, two-phase, steam, gas, or vapor service shall meet the requirements of the codes and practices as listed in Article 1.2 (e.g., API 520 Part I and API 2000).

3.3 Selection

3.3.1 General

a. For reasons of standardization, pressure relief valves shall be selected according to the standard size range provided in API 526, Flanged Steel Safety Relief Valves , not exceeding 8T10 size.

b. Valve material shall be suitable for the inlet and outlet temperatures that result from the extremes of operating and emergency conditions. These include the effect of cooling as a result of reducing pressure through the valve during relief, but do not include the effect of chilling as a result of valve leakage. A fire condition resulting in a temperature above equipment design conditions is excluded from consideration for material selection.

c. Typically, inlet pressure loss shall be limited to less than 3% of the valve set pressure (gage) per API 520 Part II requirements. If suitable for the application, a remote sensing pilot type valve can be specified for systems with excessive inlet pressure loss.

d. Unless determined to be larger by calculation, the standard size to be used for a thermal pressure relief valve is a 3/4 inch x 1 inch threaded valve with a minimum orifice area of 0.71 cm^2 (0.11 in^2).

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e. A pressure relief valve provided with an upstream rupture (burst) disk shall have, as a minimum, a pressure gauge and a free vent to safe location between the two devices to prevent pressure build up and to detect premature disk failure or leakage. A local or control room alarm on high pressure (10% of set pressure) should be considered.

3.3.2 ASME Section I Applications Steam Services

a. All safety valves shall be of the direct spring loaded pop action type.

b. A weld end inlet connection shall be provided and the valve shall be mounted directly to the vapor space of a steam boiler drum.

c. The spring shall be fully exposed outside of the valve casing.

d. Multiple valves shall be mounted on individual inlet connections. The smaller of two valves of different sizes shall have a relieving capacity not less than 50% of the larger valve. Set pressures shall be staggered.

e. The valves shall discharge the required flow rate at no more than 6% above the maximum allowable working pressure.

f. All safety valves shall have a plain lifting lever by which the valve disk may be positively lifted from its seat to ensure the valve is free to operate. Test gags shall be provided on all steam drum and superheater safety valves.

3.3.3 ASME Section VIII Applications

a. Conventional or Balanced Type

1. Generally all valves shall be direct spring loaded, pop action type for steam, vapor, and gas services.

2. Normally, for conventional valves, built up backpressure is limited to 10% of the set pressure.

3. Valves in steam and air service shall have a plain lifting lever and may have an exposed spring (open bonnet). Valves in hot water (60 C (140 F) and above) service shall have a packed lifting lever and a closed bonnet.

4. The blowdown shall be set and sealed between 5% to a maximum 7% of the set pressure or 3 psi, whichever is greater.

5. The difference between the set pressure and the maximum expected operating pressure should be greater than the blowdown, e.g., typically 10% or 69 kPa (10 psi) whichever is greater. This requirement provides adequate operating margin and assurance that the valve is capable of reclosing.

6. The main reasons for balanced valves are to:

   i. reduce the size of the discharge system (relief discharge manifold and header) by allowing a higher back pressure.

   ii. prevent the corrosion of the valve internals.

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7. Balanced bellows or balanced piston valves should not be used in services where there is potential for bellows damage or failure. Examples are coking, fouling, waxy, polymerizing, or vibrating service, or freezing of the fluid on the bellows.

b. Pilot Operated Type

1. The use of pilot operated valves should be selective and is to be based on the operating characteristics. If selected, these valves shall normally be specified to have no-flow pop action type pilots, adjustable blowdown, a backflow preventer, and elastomer seat and seals. Integral pressure pick-up points shall normally be specified unless remote sensing is required because of excessive inlet pressure loss.

2. Typically, these valves shall only be used in clean vapor service, where plugging and freezing of the pilot line is not anticipated. It is recommended that these valves should not be used in crude oil separator systems where they may be exposed to wax or solid contaminants. Their use is recommended for any of the following conditions:

Built up backpressure exceeds that allowed by other valve types.

The margin between the set pressure and the maximum operating pressure is less than that recommended by ASME Section VIII, Appendix M, which requires reduced blowdown (repeatable as low as 3% for most pilots).

Reduced simmer and fluid loss at operating pressures close to the set pressure are desirable.

Low set pressures are required (offsite storage tanks).

3.3.4 Rupture Disks/ Buckling Pins

a. Generally, rupture disks shall not be installed in the pressure relief valve inlet or discharge piping.

b. Installation of rupture disks should be considered for slurry, corrosive and erosive services, or to minimize leakage of valuable, hazardous, or toxic fluids. The use of a pressure relief valve combined with an inlet rupture disk shall be evaluated on a case by case basis if corrosive fluids dictate the valve metallurgy.

c. Generally, buckling pins shall only be considered on a case by case basis and shall not be specified without approval of the Owner.

4. INSTALLATIONS

4.1 General

Pressure relief valves should be located such that the fluid temperature at the valve during normal plant operation is near ambient conditions when the valve is inactive to minimize thermal cycling. If ambient conditions affect performance, the valves shall be suitably (e.g., heat tracing might be provided to prevent liquid solidification and subsequent valve blockage in a freezing climate). Inlet line installation and insulation details should be reviewed by Process Engineering when piping is finalized.

4.2 Inlet/Discharge Piping

4.2.1 For ASME Section I applications, code requirements shall be followed. For ASME Section VIII applications, basic design features shall include:

a. Inlet piping tie in should be located in the piping system as near as practical to the equipment protected. Equivalent length of the inlet piping should be kept to a minimum in order to avoid increasing the line size due to inlet pressure loss limitation.

b. The nominal flow area through all pipe and fittings between a pressure vessel and its pressure relief valve shall be equal to or greater than the valve inlet nominal flow area. For compressible flow from a non-modulating type relief valve, the pressure loss of the inlet piping shall be based on the pressure relief valve rated capacity.

c. When two or more pressure relief valves (spares not included) are placed on one connection, the cross sectional nominal area of this connection shall be at least equal to the combined nominal inlet areas of the valves, and the normal pressure loss requirement shall apply for the combined rated flow of the valves.

d. Piping swages at the inlet and discharge valve connections should be fitting to fitting.

e. Inlet and discharge piping shall be self draining from each valve.

f. Discharge piping to the atmosphere shall have a 6 mm (0.25 in) minimum diameter weep hole at the low point. The weep hole shall be located such that any leaking fluid does not impinge on equipment or personnel.

g. Inlet and discharge piping shall be insulated for heat traced systems. Only personnel protection insulation or guards shall be provided on hot service inlet leads 66 C (150 F). External heating or purging of the valve body shall be provided if determined that the discharged fluid may solidify.

h. Calculations for sizing the inlet and discharge leads shall be checked and updated as required to reflect the approved piping arrangements and to ensure a safe system design.

4.3 Multiple Valves (ASME Section VIII Applications)

4.3.1 Multiple valves which protect equipment requiring more than one valve for the same overpressure contingency should generally have staggered set pressures. For these applications, the maximum allowable pressure accumulation at the protected equipment shall be 16% of the MAWP (maximum allowable working pressure) for non-fire cases and 21% of the MAWP for fire cases. If practical, inlet leads from the piping branch connection should be routed separately to each valve to mitigate excessive turbulence.

4.3.2 Attention shall be given to relief situations which result in a wide range of relieving flow rates for different viable upset conditions. In this case, consideration shall be given to the selection of two valves a smaller pressure relief valve set at the equipment design pressure to handle the upset conditions resulting in lower relieving rates, and a larger valve set at 105% of equipment design pressure for the largest relieving case. This arrangement minimizes the problems resulting from valve chattering.

4.4 Isolation Valves

4.4.1 Inlet or outlet block valves are not permitted for ASME Section I applications and are not recommended for ASME Section VIII applications.

4.4.2 Should the Owner provide a written request for the installation of block valves for ASME VIII applications, the following applies:

a. Inlet block valves shall have a port cross sectional nominal area equal to or greater than the cross sectional nominal area of the inlet of the pressure relief valve and shall be locked open (LO) for all applications.

b. Outlet block valves shall be locked open (LO) for all applications and shall have, as a minimum, a port cross sectional area that cannot reduce the relieving capacity below that required or otherwise adversely affect the proper operation of the pressure relieving device.

c. A valved vent connection is required between the pressure relief valve and the inlet and outlet block valves.

d. A pressure indicator shall be provided that can be monitored for operation of the bypass valve when the pressure relief valve is out of service.

e. Pressure relief valves which discharge via individual outlets to atmosphere shall have no outlet block valves.

f. The Owner assumes responsibility for the administrative control of these valves in strict accordance with ASME Section VIII, Appendix M.

4.5 Sparing Philosophy

4.5.1 Providing installed spare pressure relief valves is not permitted for ASME Section I applications and is not recommended for ASME Section VIII applications. It is assumed that routine or scheduled valve maintenance is done when the equipment is taken out of service.

4.5.2 Should the Owner provide a written request for installed spare pressure relief valves for ASME Section VIII applications, a mechanical linkage or key interlock/valving system is recommended such that the installed spare provides full overpressure protection before the operating valve can be removed from service without relying on the operator to follow administrative procedures.

4.5.3 Should the Owner provide a written request for installed spare pressure relief valves with non interlocked isolation valves for ASME Section VIII applications, the requirements for isolation valves stated in Article 4.4 of this document apply except that only the operating pressure relief valves isolation valves shall be locked open. It is recommended that the installed spare PRV isolation inlet valve be locked closed and its isolation outlet valve be locked open.

5. DISPOSAL SYSTEMS

5.1 General

5.1.1 This section outlines the general design approach and methods for the safe disposal of vapors, gases, and liquids to prevent hazardous conditions.

5.1.2 The system design approach includes provision for the disposal of warm or cold fluids to separate warm or cold closed collection systems discharging to a flare and the venting of gases directly to the atmosphere, depending on the fluid properties, molecular weight, and temperature without compromising safety to equipment or personnel.

5.1.3 All direct atmospheric releases shall be made within the limitations of environmental regulations. The safe disposal approach includes an analysis for thermal radiation levels from flares and atmospheric vents which can ignite. This analysis determines the location and elevation at the point of discharge to ensure that the allowable levels as specified are not exceeded. Noise levels from operational vent systems shall be analyzed to ensure compliance with the allowable levels.

5.1.4 The following guidelines shall be considered in the design of closed disposal systems:

a. The sub headers shall be free draining toward the main headers.

b. All relief headers shall be free draining toward their respective knock out receivers.

c. Locating a pressure relief device below a header in closed systems must be avoided. Laterals from a device that absolutely must be located below the header shall rise continuously to the top of the header entry point and means shall be provided to prevent condensate accumulation in the valve discharge.

d. Discharge piping from operational vents shall be insulated for a certain length where prevention of external ice formation is desirable in a specified plot area for personnel protection. Similarly, discharge piping from operational vents in hot service shall be insulated or shielded for personnel protection.

5.1.5 Nitrogen or natural gas from a reliable source shall be continuously introduced as a purge into the vapor disposal systems. Purge gas connections shall be provided in every disposal system at the header extremities depending on final plant layout. A minimum velocity shall be maintained at the flare tip to minimize ambient air ingress. This flow velocity shall be verified based on the selected proprietary flare tip or molecular seal design. A separate seal drum or an automatically controlled emergency purge gas source may be required to avoid vacuum and subsequent air ingress into the flare header caused by hot relief vapors condensing.

5.1.6 The hydraulic profile of the closed disposal systems shall be verified and calculations updated as required to reflect the approved piping arrangements, blowdown receiver drums, and flare installation. Also, the system shall be designed according to criteria for avoiding fatigue failure from acoustically and flow induced vibration.

5.2 Flare Header Sizing

5.2.1 General

Typically, all fluids discharged to the closed disposal system from pressure relief devices or vent valves within the process and utility areas are routed via one header to the main flare header located outside unit battery limits. Separate vapor collection systems are provided for warm, cold, high pressure, and low pressure releases as required. Sometimes a separate disposal or flare system is provided because of the specific fluid being discharged (e.g., acid gas is normally segregated from other systems). The following flare header sizing philosophy is considered BR standard practice:

a. Individual relief valves and leads to unit header

Individual relief valves shall be designed to relieve the required flow rate determined from the controlling cause of overpressure. For compressible flow from a non-modulating type relief valve, the outlet lead(s) from the valve(s) to the sub-header or main header is sized based on the rated capacity of the device which is consistent with the value used to size the inlet lead. No allowance is taken for any mitigating action from installed trip systems.

b. Individual unit headers

1. Each individual unit flare header shall be designed to handle the worst single relief rate or the largest combined rate from the relief valves within that unit as a result of any common event.

2. Partial credit may be taken for the operation of dedicated shutdown/trip devices that are actuated as a result of the event being considered. Because of the number of safety shutdown/trip systems that may be part of the unit instrumentation system, there is always the possibility that one or more of these systems may not work when required. For determining flare loading, a dedicated shutdown/trip device is defined as a single valve and transmission source that are both dedicated to shutdown and operate separately from the basic process control of the unit. The transmission source is preferred to be two out of three voting to minimize spurious trips.

3. In establishing the unit flare loading, credit may be taken for all of the shutdown/trip systems excluding that one system or device that causes the highest loading if it fails to operate, providing that this single case is a large proportion of the total load. For example, a separate trip to close could be provided on each of the reboiler heating medium sources for a group of fractionation columns. If more than one trip device is provided for the same reboiler heating medium source only one is assumed to fail to operate.

4. The single failure case is considered to be the trip responsible for the largest relieving flow. Therefore, the individual column with the largest overhead vapor flow of all of the columns will normally be included in the controlling cooling water or power failure case (loss of reflux).

5. The signal source activating the trips may originate from pressure, temperature, power loss, cooling water flow, or any combination of these. If the common event involves many individual systems in which the failure of each one would result in only a small percent increase of the total load, more than a single system failure should be considered. BR Office of the Chief Engineer shall be consulted for clarification of the criteria.

c. Main flare header

1. For facilities consisting of a number of interrelated process units, the main relief header shall be sized for rates that are the sum of the worst case loads from each of the individual units for the common event(s) being considered, or the worst case sum of related events that are not necessarily common to all units. Credit for the operation of the shutdown/trip systems for each unit shall be as defined above when determining each unit s worst case loading.

2. Where it can be demonstrated that a single unrelated event within any one unit does not affect the total facilities, appropriate consideration of this fact shall be given in determining the loads. In sizing the main flare header, it is not required to combine the total loadings resulting from all single unrelated events in each of the different units because the simultaneous occurrence of these unrelated events is not considered credible. BR Office of the Chief Engineer shall be consulted for clarification of the criteria.

5.2.2 Dynamic Analysis

Dynamic analysis of the events occurring during a plant wide failure scenario may indicate reduced overall loads based upon the sequence of the relief loadings considered. This type analysis is considered to be valid for a plant wide upset event providing it is reviewed and approved by BR Office of the Chief Engineer.

5.3 Flare Systems

5.3.1 General

Flare systems shall be designed to meet the minimum requirements of API STD 521. The exit flow velocity for an emergency case may exceed the limits of this recommended practice as considered prudent to improve the performance of the overall flare system. This philosophy follows common recent industry practice.

5.3.2 Warm Relief (Hydrocarbon Vapor) Collection

a. The warm relief collection system terminates in a warm knock out receiver where disengaging liquid particles are separated and collected. Condensed liquid in the warm header system drains to and collects in the receiver. All vapors, gases, and vapor/liquid mixtures which contain components likely to condense, form hydrates, or freeze at 0 C (32 F) or above are routed to the warm header system. The pipe shall be free draining towards the receiver.

b. The warm knock out receiver shall be sized based on the calculation method presented in API STD 521.

5.3.3 Cold Relief Collection

a. Similar to the warm system, the cold vapor collection system terminates in a cold knock out receiver. All vapors, gases, and vapor/liquid mixtures which expand isenthalpically through the relieving devices to a downstream temperature of less than 0 C (32 F) not containing any components likely to freeze, are routed to the cold header system. The cold vapor collection system shall be uninsulated. This is inclusive of the receiver, blowdown vaporizer and superheater.

b. The cold knock out receiver shall be sized based on the calculation method presented in API STD 521.

5.3.4 Liquid Disposal

a. Liquid relief to the flare collection system should be avoided. If this cannot be prevented, careful consideration shall be given to potential problems associated with liquid disposal from pressure relief devices and liquid de inventorying into the flare systems. Appreciable quantities of liquid discharged to the flare during an emergency vapor release could cause an undesirable flow regime in the horizontal line and the entrance to the knock out receivers, raising the risk that the receivers may not drop out the entrained liquid droplets down to a size the flare can handle.

b. Alternative installations which reduce this potential risk shall be considered in the design. These include:

   1. Discharging liquid streams via a closed system to a lower pressure system or vessel.

   2. Providing separate liquid collection systems to the respective knock out receivers.

   3. Providing disengaging drums and collecting liquids separated with overhead vapor or gas vented to the disposal systems.

5.4 Atmospheric Vents

5.4.1 Steam, instrument/plant air and nitrogen vapors shall be discharged to the atmosphere through a tail pipe terminating at safe location. Refer to Article 4.2 for condensate or rain water removal (i.e., weep hole).

5.4.2 Air or steam used during start up operations or for maintenance or for decoking and regeneration purposes shall be discharged to the atmosphere and not to the closed disposal system.

5.4.3 In general, hydrocarbons or other non-hazardous flammable vapor mixtures shall be permitted to vent to the atmosphere at a safe location only if all of the following apply:

a. The released gases are diluted to below the lower flammable limit before creating a hazard at grade or other plant operating level. API STD 521 states that such dilution occurs for any vapor which meets a minimum Reynolds number requirement at the exit point as defined by API STD 521. Discharge velocities greater than 30.5 m/s (100 ft/sec) are jet dominated and satisfy this API criterion. However, the lowest velocity release case must be known and checked against this criterion if it is to be applied.

b. The released gases do not condense. API STD 521 states that vapor condensation in appreciable quantities depends on many factors. Because a specific criteria is not defined and because the factors involved are difficult to identify for all possible release cases. BR conservatively assumes that no condensation occurs only if the lowest defined atmospheric temperature (i.e., in the project design data) is above the dew point of the vapor released. Also, condensation resulting from auto-refrigeration effects must not occur.

c. The gases are permitted to be released to atmosphere per environmental regulations. The duration, quantity, type (i.e., emergency), and location of the release may have to be analyzed before the exact environmental requirements to be applied are known.

d. Ignition of the emission at the outlet point does not occur, or if it occurs, the heat radiation produced is within the allowable limits. According to BR standards, inert gas shall be provided as a means of purging the outlet piping and shall be controlled from grade. Special consideration should be given to releases containing hydrogen or other very volatile gases because they are susceptible to auto ignition or by static electricity.

5.5 Thermal Radiation

5.5.1 General

a. The following information shall be the basis for selecting the allowable thermal radiation levels emitted from any flare plume and the duration of exposure to protect operating personnel under administrative control of the plant from the effects of radiation.

b. The effects of solar radiation for any plant location shall be included in the assessment of acceptable time exposure. Solar radiation is typically in the range of 788 - 945 W/m (250 to 300 Btu/hr ft^2).

c. Refer to API STD 521 for full details. General guidelines are:

1. 0 - 1577 W/m (0 - 500 Btu/hr ft^2): A level generally taken to be acceptable for continuous exposure at any location.

2. 1580 - 2524 W/m (501 to 800 Btu/hr ft^2): An exposure level recommended for the public or personnel not under the administrative control of the plant outside the property perimeter. Warning signs shall be provided at public roads or perimeter access areas. This level also applies where operators would be required to perform duties without the benefit of protective clothing. The recommended exposure time is no more than 15 minutes.

3. 2527 - 4732 W/m^2 (801 to 1500 Btu/hr ft^2): A level recommended in operating areas at grade or on elevated operating platforms where operators are under administrative control by the plant and are wearing appropriate protective clothing. Any ladders, platforms, or equipment in this area of radiation requiring an operator s presence should be oriented in such a manner that operators are shielded from the flame radiation. As an alternate, nearby shelters or radiation shields should provide cover for the operator.

   A level recommended at the edge of the nearest plant roadway to the flare, at the blowdown receivers, and at the flame front generators.

   The recommended exposure time is no more than 3 minutes. This limit provides personnel ample time to seek cover or leave the area.

4. 4735 - 6309 W/m (1501 to 2000 Btu/hr ft^2): A level recommended in areas requiring emergency actions only up to a maximum of 30 seconds for operators under administrative control of the plant and wearing appropriate protective clothing.

5. Above 6309 W/m^2 (Above 2000 Btu/hr ft^2): Radiation levels above this heat intensity are not acceptable at any location to which operators need access. Injury to personnel can occur due to insufficient time to seek cover.

d. Calculation method

API STD 521 shall be used to determine the flame radiation levels at all points of interest, e.g., at grade and elevated platforms. Suppliers proprietary calculations based on the selected equipment shall be obtained for verification.

Appendix B.13 Isolation Philosophy

ISOLATION PHILOSOPHY

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	22-MAR-24	ICR – ISSUE FOR CLIENT REVIEW	SP	JRZ	DDB	
B	30-OCT-24	IFD – ISSUE FOR DESIGN	SP	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	22-MAR-2024	ALL	ICR – ISSUE FOR CLIENT REVIEW
B	30-OCT-2024	Cover	Updated confidentiality and export compliance statements

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1. PURPOSE AND SCOPE

The purpose of this document is to provide guidelines for specifying isolation devices to be provided in the facilities design to isolate equipment or sections of plant to permit a safe operation and working environment and provide safe access for maintenance or inspection to the process production and utility systems.

It also serves as design guidelines to assist in the development of a consistent set of P&IDs, allowing segregation of process units and utility systems to avoid contamination and provide adequate isolation for hydraulic testing, pre-commissioning, commissioning, and operational requirements.

This philosophy applies to process and utility piping, equipment, and units but specifically excludes isolation requirements for instrumentation and electrical components.

2. ABBREVIATIONS

Term	Definition
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
FEED	Front End Engineering Design
ISBL	Inside Battery Limits
OSBL	Outside Battery Limits
P&ID	Piping and Instrumentation Diagram
XV	Emergency Valve

3. GUIDELINES

3.1 METHODS OF ISOLATION

Maintenance shall be performed when unit or a system is shutdown, isolated, and depressurized to atmosphere, drained and free from flammable and toxic gas. It is necessary that items of equipment or groups of equipment can be isolated in order to facilitate their shutdown for maintenance, inspection, tie-ins, and loss prevention. The requirement for isolation to enable maintenance or inspection is dependent on the operating philosophy, extent of shutdown, nature of the fluids, and operating pressure of the system. As the degree of risk increases, so does the required effectiveness and security of the isolation method. Note that high risk is not only associated with traditional hazards such as harmful fluids, high pressures, and high temperatures. There are also other risks, such as the likelihood of a production outage, which results in a quantifiable loss of revenue, a lower production figure, and damage to the environment.

Isolation philosophy is based mainly on fluid characteristics, pressure class related to the maximum operating pressure, and equipment / piping work involved. Isolation methods are as listed below:

- Positive isolation.
- Double block and bleed.
- Single block and bleed.
- Single block valve.

Above mentioned may be applied singularly or in combination.

3.1.1 POSITIVE ISOLATION

Positive isolation is a method of isolation that removes all practical risk of accidental reconnection to source of risk. These are used where no leakage can be tolerated for safety and/or contamination reasons. Positive isolation is a mandatory provision for the following instances:

- Confined space entry.
- Long duration isolation (greater than 1 week).
- Process fluids above auto-ignition temperature.
- Equipment mothballing.
- Hot work.

- Where risk assessment is determined is necessary.

Positive isolation would include:

- Insertion of spectacle blind or spade.
- Removal of pipe spool and installation of blind flanges.

Spectacle blinds, ring spacer and removable pipe spools to be used for positive isolation are shown in Figure 3-1.

FIGURE 3-1 POSITIVE ISOLATION FITTINGS

Spectacle blinds are preferred method of isolation in comparison with separate spades and spacers as they provide immediate visual determination that positive isolation is in place.

Spectacle blinds shall be designed such that the pressure rating is equal to the flange rating of the system. It shall not be designed to meet the system process design pressure.

Spectacle blind material shall be of same material group as the pipe flanges (ASME B.16.5 & B16.47). All sealing surfaces of spectacle blinds shall be machined in accordance with the same standard and surface used for the system pipe flanges.

Spades and spacers are the least preferred option when compared with spectacle blinds because of the risk of miss-identification. Identification of spades and spacers is possible by markings on the handle, which could vary between different manufacturers. In order to minimize the risk of miss identification it is recommended to have a double hole in the handle to represent a spacer; and a single hole to represent a spade. Spades shall be supplied with a hook for ease of installation / removal for 10” and above lines.

3.1.2 DOUBLE BLOCK AND BLEED (DBB)

In double block and bleed arrangement - isolation integrity is provided by the bleed valve preventing a high differential pressure across the second isolation valve in case the upstream valve leaks in tight closed position. The bleed valve shall be terminated locally such that it can be monitored to confirm that the isolation valve is effective. The distance between two block valves shall be the minimum practicable. Double block and bleed arrangements can also be used for positive isolation when blinds are inserted between the blocks and generally used at battery limits and for isolation. This arrangement is shown in Figure 3-2. This application could be with one or two blinds as the case warrants. Without the blind, this arrangement is used for general isolation of start-up lines, to prevent contamination between streams, etc.

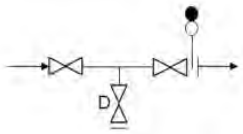


FIGURE 3-2 DOUBLE BLOCK AND BLEED

Double block valves and double block bleeders shall be provided with spectacle blinds or spade/spacers for systems of ANSI Class 600 rating and above. If process lines are required to have double block valves (for example ANSI Class 900 and above), then the drains and vents should also follow this requirement.

Double valves below 600# rating shall be considered for:

- Toxic service.
- Sour service.
- Systems isolating high temperature fluids at or above auto ignition.
- Systems which are regularly isolated for routine operations/maintenance.
- Drains in lethal service.
- Other hazardous services.

Lethal Fluid

- Fluids with health risk in accordance with Category 4 of NFPA 704, whichever is more stringent.

Sour Fluid

- Fluids with health risk in accordance with Category 3 of NFPA 704, whichever is more stringent.

3.1.3 SINGLE BLOCK AND BLEED (SBB)

The principle is similar to the double block and bleed arrangement but without the second valve. The bleed valve is used to drain and depressurize the piping work downstream of the block valve. A single block and bleed is adequate for enabling the installation of a spectacle blind.

A spectacle blind is used to further isolate hydrocarbons or fluids from entering the maintenance side of the valve.

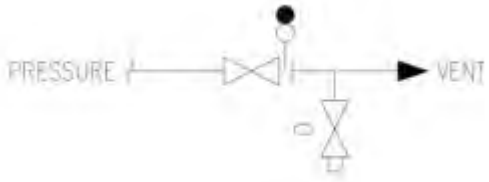


FIGURE 3-3 SINGLE BLOCK AND BLEED

3.1.4 SINGLE BLOCK VALVE

Single block valves provide the most common process isolation where the pressure boundary downstream of the valve is secure.

4. ISOLATION PHILOSOPHY

Maintenance or inspection work shall be implemented on process units or systems which are to be isolated and shutdown, depressurized to atmospheric pressure, drained, and purged out.

It may be impractical or uneconomical to shutdown complete facilities or systems for maintenance or inspection. Equipment could remain connected to live facilities or systems during inspection or maintenance, with consequent potential for hazard to personnel and process unit. In these cases, the design of the facilities shall incorporate means of positive isolation of individual equipment undergoing inspection or maintenance from remaining live facilities, to protect personnel from hazards of flammable and / or toxic liquids and gases.

The method of isolation is dependent on factors such as type of maintenance and inspection work involved, i.e. of a major, routine, or minor nature; the properties of the process fluid in operation; and the operating pressure / temperature. These factors determine whether isolation should consist of single or double block valves, together with bleeds and inserted spades or closed spectacle blinds.

It is necessary to isolate the systems and equipment for maintenance to enable the activity in a safe manner. All factors affecting isolation shall be considered prior to determining the required type of isolation. The factors would include but are not limited to the following:

- Equipment and pipe size.
- Operating pressure.
- Duration of maintenance.
- Maintenance frequency.
- Type of service that is to be isolated, e.g. fuel gas, crude oil, etc.

4.1.1 ISOLATION FOR SHUTDOWN MAINTENANCE

Shutdown means the Plant, Unit, or System has been isolated and that it is at atmospheric pressure, drained, purged, and free of hydrocarbons or chemicals. For complete unit shutdown, the feed, products, and utility lines shall be isolated at unit battery limit. Spectacle blinds or spade / spacers shall be fitted on the battery limit lines. During the swinging of the blind, both the block valves will be closed, and bleed valve will be left open. It is important that the isolation is positive and does not rely on valves alone, which may leak.

4.1.1.1 ISOLATION AT UNIT BATTERY LIMIT (B/L)

The battery limit arrangement is shown below for hydrocarbons and utility. It includes block valve, spectacle blind, and vent and / or drain. The requirement for a check valve is to be decided on a case-by-case basis and is not required in majority of cases.

Check valve in battery limit is required for:

- Nitrogen service connection.
- Incoming line is connected to a common header inside battery limit without any check valve.
- Outgoing line is connected to a common header outside battery limit without any other check valve and there is possibility of back flow.

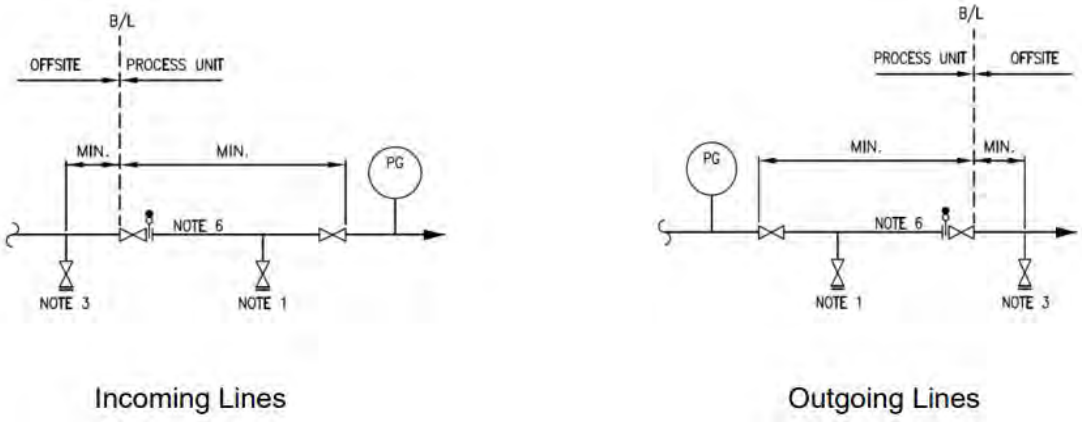


FIGURE 4-1 PROCESS BATTERY LIMITS – GENERAL LOW-PRESSURE HYDROCARBON

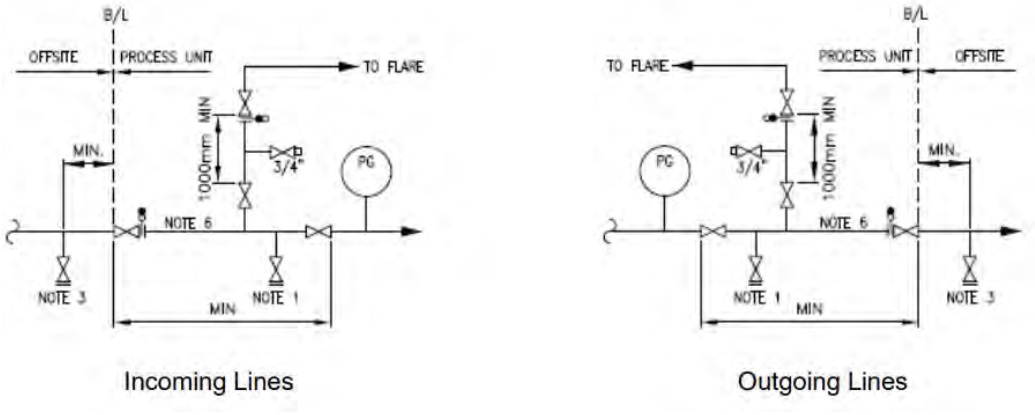


FIGURE 4-2 PROCESS BATTERY LIMITS – HIGH VAPOR PRESSURE HYDROCARBON SERVICE (LPG)

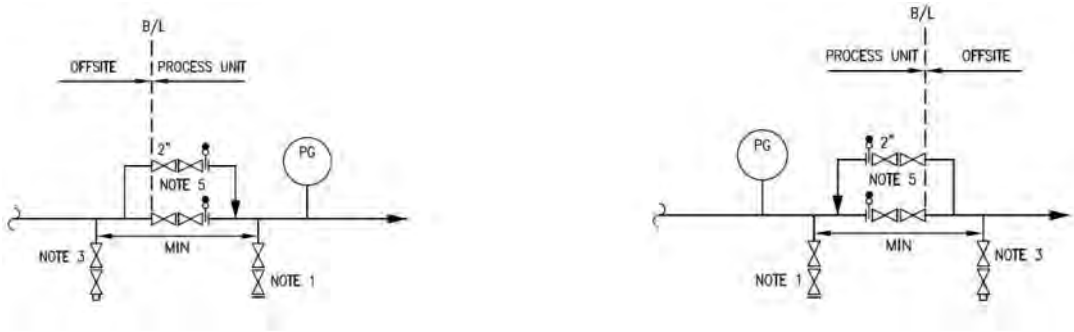


FIGURE 4-3 PROCESS BATTERY LIMITS – HIGH PRESSURE HYDROCARBON (NOTE 8)

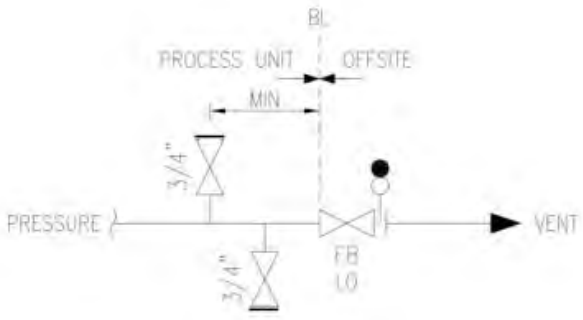


FIGURE 4-4 PROCESS BATTERY LIMITS – FLARE HEADER

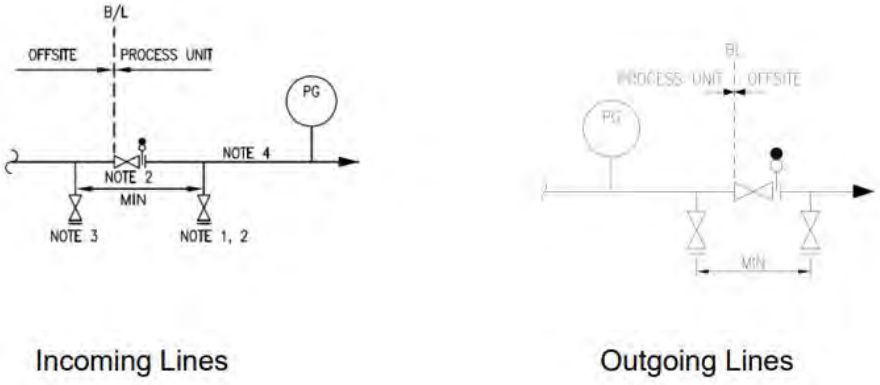


FIGURE 4-5 UTILITY BATTERY LIMITS

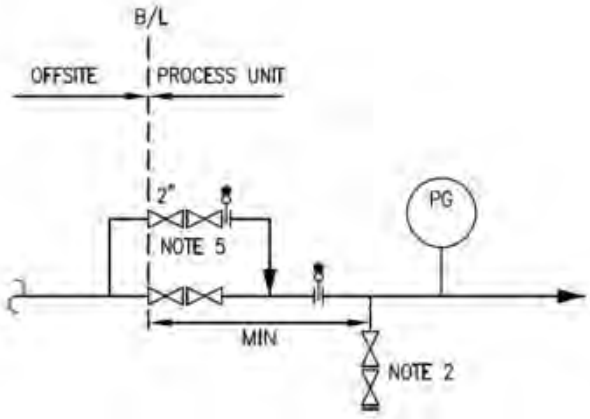


FIGURE 4-6 UTILITY BATTERY LIMITS – HP STEAM AND HP BFW CONNECTION

Utility	Type of Valve Isolation	Bleed Type		B/L Bypass
		Vent	Drain	
HP Steam (1500 psig)	DBB	No	Yes	Yes (Note 5)
MP Steam (250 psig)	DBB	No	Yes	Yes (Note 5)
LP Steam (50 psig)	SBB	No	Yes	No
HP, MP, & Clean Condensate	SBB	No	Yes	No
LP & LLP Condensate	SBB	No	Yes	No
Raw, Service, Fire, Stripped Sour Water	SBB	No	Yes	No
Sour Water	DBB	No	Yes	No
Cooling Water	SBB	No	Yes	No
Demin. Water	SBB	No	Yes	No
HP / MP BFW (Note 8)	SBB	No	Yes	No
Instrument / Plant Air	SBB	Yes	Yes	No
Nitrogen (Note 4)	SBB	Yes	No	No
Fuel Gas	SBB	Yes	No	No
Amine	DBB	No	Yes	No
Chemical (Acid, Caustic)	DBB	No	Yes	No

TABLE 4-1 DETAILS OF REQUIREMENT OF VALVES, VENTS, DRAIN & BYPASS FOR GENERAL UTILITIES

Notes:

1. Drain valve size is dependent on process line size. The minimum size is 3/4". A bleed may be installed at the bottom of the line provided that a gland sealed rod out device can be attached to the drain valve.
2. Refer Table 4-1 for type of valve isolation requiring for Utilities battery limit isolation.
3. Offsite connection (typical 3/4") is required in hydrocarbon services for purging etc.
4. Nitrogen lines to have NRV.
5. Warm up / pressurizing bypass (2") to be provided if main header size is 8" or above. For lines less than 8" provide a 1" warm up line.
6. Requirement of NRV to be decided on a case by case basis.
7. Locked open valve to be installed with wheel in vertical and downward position.
8. Double block valves at battery limit to be provided for:
    - All service ANSI Class 900# and above.
    - Toxic and sour service (e.g. acid gas flare).

4.1.1.2 ISOLATION OF PERSONNEL PROTECTION

Entry by personnel to enclosed spaces shall be permitted only after positive isolation (or deemed necessary by risk assessment) by installing blinds, blind flanges, or other means of positive isolation at all connections, except those used for atmospheric ventilation.

For entry into single items of equipment it should be noted with respect to pipe specifications that:

- All vessels, columns, reactors, drums and confined spaces which have man-ways and hand-holes shall be designed for positive isolation by blinding or spool removal, etc.
- Provision for isolating all inlet and outlet lines to and from the item should be made.
- Vents should be available on the equipment side of the isolation (e.g. on a vessel).
- In the case of a pumped liquid outlet from a vessel, isolation may be achieved at the pump suction to isolate pump only. Ensure the pump suction line can be drained.
- Permanent spectacle blinds shall be included in the design.
- Spades shall be of standard thickness for the line piping class.
- Permanent spectacle blinds are installed where piping is too stiff to “spring”. Ring spacers will be specified for large pipe sizes where spectacle blinds would not be handled easily. The basis shown in Table 4-2 below may be used as a guide.
- Relief valve nozzles whether on the vessel or the piping shall not have spectacle blinds or blind spacers.
- Block valves shall not be provided on vessel overhead vapor lines, transfer lines, reboiler lines, or side stream vapor return lines as means of isolation unless the line can be isolated with the vessel in operation (e.g. spare reboiler). When the isolation valves are not required, removable spool pieces or ring spacers shall be provided for positive isolation.

Size	Piping Class		
	150 lbs - 300 lbs	600 lbs	≥ 900 lbs
<3"	Spec Blind	Spec Blind	Spec Blind
3"-8"	Spec Blind	Spec Blind	Ring Spacer
>8"	Ring Spacer	Ring Spacer	Ring Spacer

TABLE 4-2 APPLICATION OF TYPE OF BLINDS

4.1.1.3 ISOLATION FOR SPECIAL OPERATION

Examples of special operations requiring provision of positive isolation are as follows:

- Regeneration, unloading, and replacement of catalyst.
- Tower packing unloading / loading.
- Furnace decoking.

These activities would be expected to occur regularly during turnarounds but may occur at other times. Normally the necessary positive isolation will be permanently installed, examined on a case-by-case basis.

4.1.1.4 ISOLATION FOR PRESSURE TESTING

Generally, pressure (strength) test blinds are not provided. However, where heat exchangers and other equipment may require maintenance testing with the plant on-line, isolation blinds may be provided for leak testing and pressure testing.

Isolation for operational tightness testing will be against valves; however, where necessary temporary blinds will be installed at flanges not fitted with a permanent blind or suitable valve.

4.1.2 ISOLATION FOR ON-STREAM MAINTENANCE

For equipment isolation, more specific isolation needs to be made (e.g. isolating a pump whilst standby pump is operating) either during normal operation or on shutdown when this isolation is to remain in place after plant start-up. The generic method identifies the system to be shutdown and provides positive isolation. A positive means of isolation with a ring spacer, spade, removable spool, etc. is normally required.

Typically, equipment maintained on-stream will be as follows where there is provision for spare equipment:

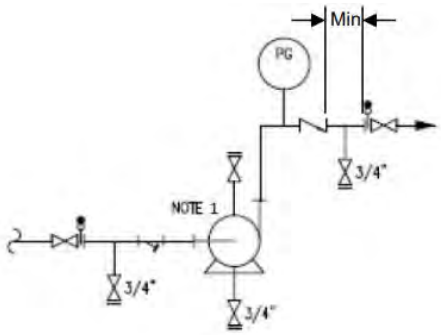
- Parallel reactors / treaters, etc.
- Parallel fired heaters.

- Pumps with a spare.
- Compressor with a spare.
- Parallel exchangers.
- Control valves.
- Filters.

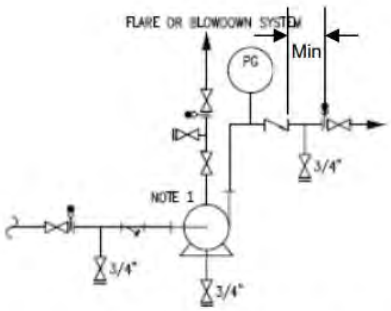
Special equipment (e.g. recycle compressors, standby steam/fuel gas turbine drivers etc.), which may be repaired with plant under pressure.

For control valves and smaller pumps only isolation valves are normally provided. Requirements for major pumps and special equipment shall be considered on an individual basis.

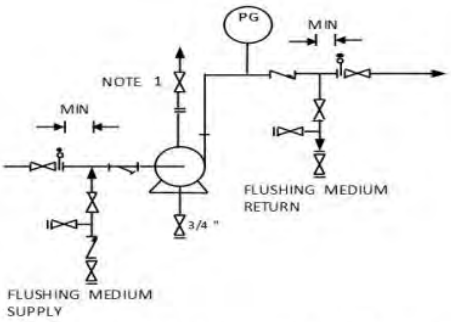
As a minimum, pumps in hot hydrocarbon service (operating temperature 150°C and above) shall be provided with spectacle blinds / ring spacers at suction and discharge valves in accordance with the size / rating criteria given in Table 4-2 Application of Type of Blinds. Figure 4-7 shows typical sketches for pumps.



General Service



High Vapor Pressure / Bubble Point Service



High temperature (>230°C) / High Pour Point service

FIGURE 4-7 PUMP ISOLATION

Notes:

1. End suction top discharge pumps are self-venting.

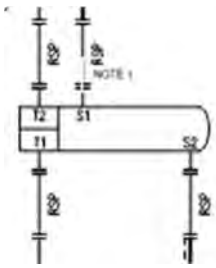


FIGURE 4-8 HEAT EXCHANGER ISOLATION

Notes:

1. Removable spool piece.

4.1.3 ISOLATION FOR CONTROL VALVE

Double block and bleed valves required for 600# and above or in toxic service, see section 3.1.2.

Control valve bypass is not provided in the following instances.

- If the control valve can be taken out of service without reducing safety, reliability, or capacity, then no bypass or handwheel is required. Control valve bypasses shall not be installed if manual control of the bypass is difficult or not desirable, e.g. anti-surge control or fuel control to boilers that may result in a hazardous situation.
- If the control valve is part of non-critical or intermittently operated equipment, which can be isolated by other means without affecting capacity.
- A bypass is not required if it would adversely affect the process because of pressure drop, residence time, dead legs, etc.
- Control valves which are part of a trip system shall not be provided with a bypass. Control valves used for safety instrumented systems (SIS) and credit is taken for the control valve in the SIL verification calculations. The control valve will be closed or opened from the SIS to the DCS then to the solenoid valves on the air supply. SIL verification calculations shall determine if the single control valve is adequate or additional ESD valve(s) are required to meet the SIL classification.
- Emergency shutdown system valves shall not be provided with bypass.
- Bypasses are not required around pressure let down valves for continuous operation purposes. For utility services, on sizes smaller than 6-inch by-pass with restriction orifice may be installed. This criterion does not exclude installation of pressure equalization bypasses when the conditions require.

If a bypass is provided follow the details below.

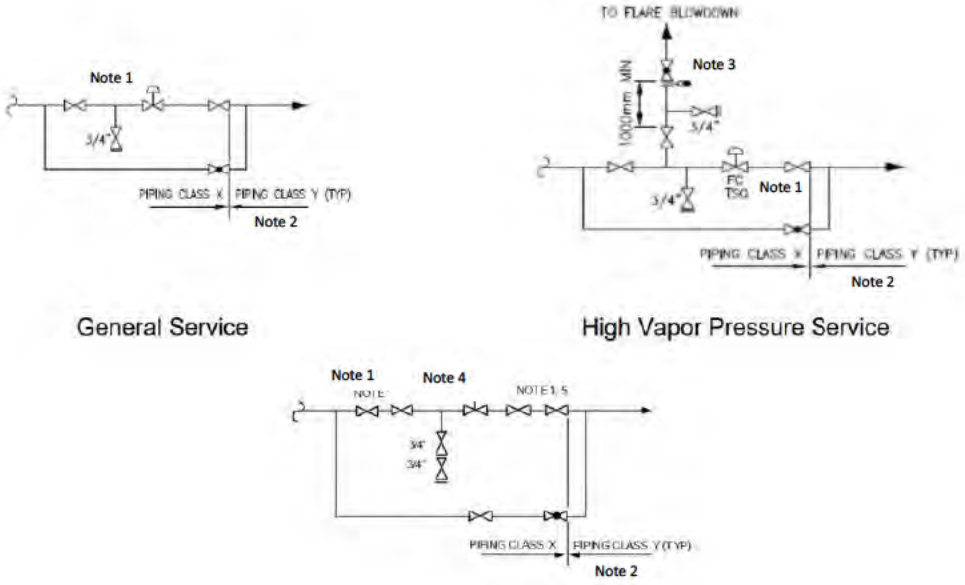


FIGURE 4-9 CONTROL VALVES

Notes:

1. Control valve failure action to be shown, e.g. fail open (FO). Also, any tight shut-off (TSO) and TSO class requirements.
2. Piping class may not necessarily change across the control valve. Where the downstream system has a higher rating the spec breaks need to be reviewed.
3. Flare vent facility may be required for large systems, etc.
4. As an alternative consider:
   - Provision of double valves on the upstream system only.
   - Two control valves in parallel (smaller size) each with single isolation valves.

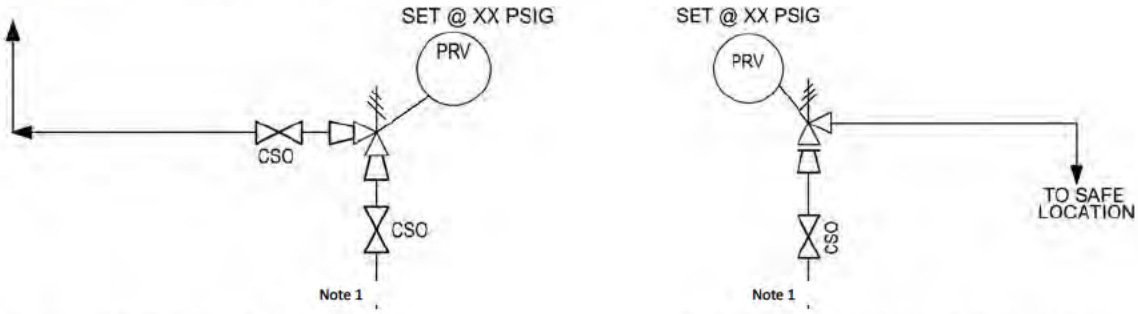
4.1.4 ISOLATION FOR RELIEF VALVES

4.1.4.1 RELIEF VALVE FOR SERVICES OTHER THAN THERMAL RELIEF

A block valve shall be specified on both the inlet and outlet lines of the RV. Both inlet and outlet block valves shall be car sealed open (CSO).

Spectacle blinds shall not be provided in the relief flow path.

The arrangement for relief valve isolating valves and connections shall be shown in the P&IDs as in Figure 4-10.



Thermal Relief and Other Services

Relief to Atmosphere/Safe Location

FIGURE 4-10 RELIEF VALVE ISOLATION

Notes:

1. From vessel or from piping on vessel without intervening valves.
2. Isolation valves may be locked. Double block and bleed valve should be used for high pressure applications.
3. Isolation valves shall be full port and must be equal to or a greater flow area than the relief device. Butterfly valves are not permitted. When gate valves are used for isolation in the relief system for relief devices, flare laterals, flare headers, and KO vessels, they shall have their stems in the horizontal position, up to a maximum of 45 degrees downward from the horizontal for non-cryogenic services.
4. See section 4.1.4.4. If the valve is not flanged, break flanges are to be provided to allow positive isolation from the flare for maintenance of equipment upstream of the valve.

4.1.4.2 RELIEF VALVE FOR THERMAL RELIEF

Relieving to flare or process.

A single block valve with a CSO facility shall be specified for both inlet and outlet lines. See Figure 4-10.

4.1.4.3 RELIEVING TO ATMOSPHERE

A single block valve with a CSO facility shall be specified only on the inlet line. See Figure 4-10.

4.1.4.4 RELIEF VALVE BYPASS LINE

A bypass blow down valve line around the relief valve(s) with a single isolation valve shall be specified only where there is a requirement to vent the gas in the system to flare and no other connection to flare is provided nearby. For wet liquid butane service, double bypass valves with a minimum spacing (> 4in.) shall be specified in order to avoid freezing. One of these valves shall be a globe valve to control the rate of depressurization. A gate valve and spectacle blind or spade is required for personnel entry into upstream equipment.

Relief valves fitted to steam turbine low pressure exhausts may be equipped with a full flow by-pass valve for temporary operation, exhausting to atmosphere.

These services requiring relief valve bypass lines are not applicable to this project so relief valve bypass lines are not required.

4.1.4.5 BONNET VENTS

Balanced bellows valves have a vent connection from the bonnet. These should be piped to a safe location and should not be provided with isolation valves.

4.1.5 ISOLATION OF START-UP BYPASSES DURING NORMAL OPERATIONS

Isolation philosophy for start-up bypass lines during normal operations is as follows:

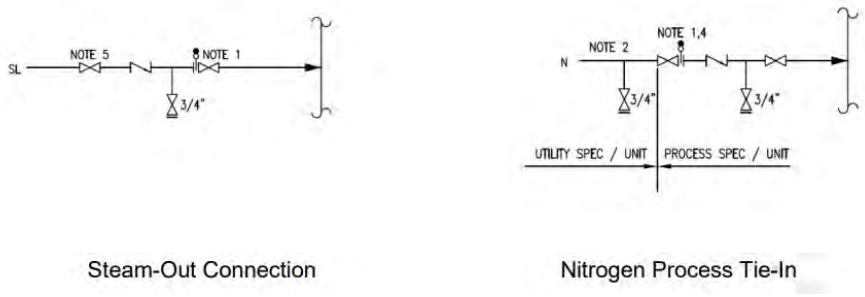
- Isolation is normally by valve closure for any lines to be used during normal operation, or in reaction to emergency conditions. The fluid remaining in the piping shall be left in-situ.
- If the fluid has a high pour point, the line should be either heat traced or provision made for the line to be flushed and drained down.
- Thermal relieving facility may need to be provided for a liquid, if the line can be isolated and subjected to heat input from any source.
- Where the line is used only for pre-start-up circulation and flushing, blind isolation should be provided for closure in normal operation.
- A blind shall be installed where leakage through any start-up or bypass line can cause product contamination. Typically, a blind shall be provided inside a double block and bleed arrangement.
- Temporary piping shall be removed.
- Swing elbows / removable spools may be employed where practical.

4.1.6 ISOLATION OF A SINGLE TRAIN OF A MULTI-TRAIN UNIT

In units which have two or more trains, there is a possibility that one train is shut down while the other is in operation. Accordingly, isolation philosophy for one of the two or more trains shall be as follows:

- Spectacle blinds, spades, or removable spools, with suitable valving shall be specified where isolation is required when one train is shutdown.
- Adequate vents and bleeds should be provided for safe installation and removal of blinds.

4.1.7 TYPICAL ISOLATION OF UTILITIES FROM PROCESS SYSTEMS



Steam-Out Connection

Nitrogen Process Tie-In

FIGURE 4-11 TYPICAL ISOLATION OF UTILITIES

Notes:

1. The valve is to be included in the higher specification.
2. A removable spool or swing elbow may be provided for maintenance isolation.
3. Use of temporary piping / hoses for steam out and purging is to be considered during detailed engineering.
4. When nitrogen may be frequently used during normal operation use this detail. When used just as an alternate to steam out use same detail as for steam out.
5. Header valve. This may be used for a group of users. Shut during normal operation.
6. Steam pipes connected to process pipes shall meet the following:
   - If the pressure of the process system can be higher than that of the steam system, provide the steam line with two check valves upstream of the block valve(s) with a bleed valve between the downstream check valve and the (last) block valve.
   - Position the block valve and check valve close together and close to the process pipe.

4.1.8 EMERGENCY ISOLATION

There are no systems above auto-ignition temperature; therefore, API 553 does not apply.

Appendix B.14 Heat Tracing and Winterization Philosophy

HEAT TRACING AND WINTERIZATION PHILOSOPHY

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	30-OCT-24	IFD – ISSUE FOR DESIGN	IV	JRZ	DDB	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	30-OCT-2024	ALL	IFD – Issue for Design

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1. PURPOSE AND SCOPE

This document covers the minimum requirements for protection of process and utilities and all associated equipment, flow lines, and instruments against the temperature which would cause congealing or freezing of contents, interfere with operation or cause damage to equipment or pipelines and for heat conservation requirement as would be determined by process conditions. The heat conservation system shall be designed for continuous operations while winterizing shall be for seasonal operation.

2. ABBREVIATIONS

DMinDBT – Design Minimum Dry Bulb Temperature

ExMinDBT – Extreme Minimum Dry Bulb Temperature

3. DEFINITIONS

3.1 TERMS

Freeze Protection - Heat tracing used to prevent liquid contents from freezing.

Process Temperature Maintenance - Heat tracing used to prevent an undesirable property change to a process fluid due to ambient temperature.

Heat Tracing - Any combination of steam, electric, or other medium traced on piping or equipment for the purpose of maintaining a temperature for freeze protection or process considerations.

Design Minimum Dry Bulb Temperature - The ambient temperature at a particular site used to determine the need for protection from cold weather for each fluid service.

Extreme Minimum Dry Bulb Temperature - The coldest recorded ambient temperature at a particular site.

Winterization - A generic term referring to a number of techniques, including, but not limited to heat tracing that can be used to prevent undesirable occurrences in fluid contents due to cold ambient temperature.

4. WINTERIZATION AND FREEZE PROTECTION

4.1 GENERAL REQUIREMENTS

The need for winterization will be identified during process design and when applicable indicated on the P&ID.

4.1.1 FLUIDS REQUIRING WINTERIZATION

Typical fluids that require freeze protection:

- Liquids that freeze above the Design Minimum Dry Bulb Temperature or the Extreme Minimum Dry Bulb Temperature.
- Liquids that change important process properties (such as high viscosity or precipitation of dissolved chemicals) above the DMinDBT.
- Vapors that condense above the DMinDBT or ExMinDBT if the resulting liquid interferes with proper operation (such as leads to sampling systems or leads to differential pressure instruments).
- Vapors that can cause corrosion if condensation occurs above the DMinDBT.

4.1.2 WINTERIZATION TECHNIQUES

Winterization can be provided in several different ways. Generally, the least expensive method that is practical for all plant operating modes should be chosen. Heat tracing or insulation shall be used only if other freeze protection techniques are not applicable.

Freeze protection equipment (tracing, insulation, etc.) should be eliminated when operating procedures are sufficient to provide freeze protection.

The following list of freeze protection methods is given in order of increasing cost.

- Vary liquid composition to avoid freezing.
- Provide for draining of pipe and equipment when not in service. Draining includes opening a low point valve or designing the line to be free draining. Draining must be consistent with plant operating procedures and must be reasonable to accomplish in case of an unplanned shutdown.
- Blow liquid out of the line by gas pressure. Blowing must be consistent with plant operating procedures and must be reasonable to accomplish in case of an unplanned shutdown.
- Install bypass lines around equipment that may be isolated to maintain circulating flow in the pipe (such as water lines around exchangers).

- Continuous circulation of fluid during temporary interruptions of the process. Continuous circulation must be consistent with plant operating procedures.
- Insulate lines to preserve the available heat. Many lines that have available heat are already insulated for heat conservation. The heat conservation insulation may be sufficient for freeze protection.
- Provide heat tracing with the appropriate insulation.
- Provide heat jacketing.
- Bury lines underground below the freeze line. This option is rarely used except for severe climates. Portions of cooling water and firewater lines are sometimes buried for other reasons and consequently are also protected from freezing.
- Different portions of the same line or lines in the same service do not always need the same winterization technique. Above ground portions of mostly buried systems may require draining or heat tracing. A service constantly operating at elevated temperature may be in jeopardy during a planned or unplanned shutdown.

4.2 FREEZE PROTECTION DESIGN REQUIREMENTS

Service fluids, such as cooling water, that are maintained at a temperature above the DMinDBT while flowing, may use freeze protection techniques of insulating, draining, blowing clear, or bypassing. However, lines in these services may freeze, where or when the fluid becomes stagnant and cools. The locations where or the occasions when these conditions occur need additional provision for freeze protection.

To avoid freezing in water lines, electrical tracing will be added on water lines with diameters 4" or below. Electrical tracing is not required on water lines with diameter 6” or greater.

The following is a list of some special situations that may also require freeze protection.

- Dead legs in lines and lines used for draining upstream of the drain valve. However, standard low point drains are not considered dead legs (i.e., minimal amount of piping) and are winterized the same as the main line.
- Lines that have stagnant fluid during a planned/unplanned shutdown or maintenance.
- Inactive condensate lines and non-self-draining steam traps (such as bucket type).
- Liquid lines from liquid knockout drums or water draw off lines from vessels or tanks.
- Flush and purge lines or other lines that are typically in intermittent use.
- Relief valve inlet lines.
- Safety showers, underground valves, and hydrants are to be self-draining.

- Pump minimum flow bypasses. Even if the bypass flow is normally continuous (i.e., bypass has a restriction orifice), heat tracing may be required if the bypass is not flowing and cannot be completely drained during pump maintenance.
- Pipe leads upstream of inlet valves and downstream of outlet valves for spared equipment (including pumps). When the equipment block valves are closed for maintenance, these lines become stagnant and cannot be drained, assuming the other equipment item is operating. The same applies for equipment items which can be bypassed during plant operation.
- Liquid outlet lines from separation vessels which normally contain minimal amounts of liquid such that the outlet valve, even if a level control valve, can remain closed for indefinite periods of time (e.g., liquid outlet lines from fuel gas knockout drums or compressor suction drums).
- Non-operating vapor lines in which condensation can occur and collect (e.g., normally closed, pressure-controlled vent systems).
- Potable water systems (i.e., supply to safety shower and eyewash stations use some type of protection that prevents overheating and provides a temperate flow of water to personnel).
- Intermittent blow-off lines upstream of the blow-off valve and, unless the line is self-draining, also downstream of the blow-off valve.
- Instrument bridles.
- Control valve bypasses and portions of control valve stations that cannot be drained during maintenance.
- A water/hydrocarbon solution not normally subject to freezing that produces a water portion subject to freezing if allowed to separate. For example, a vessel containing a hydrocarbon/water interface has associated piping, such as the level bridle and drain attached to the water boot or vessel bottom, containing only water that will freeze unless proper winterization is applied.
- A heat tracing medium that has a maximum temperature hot enough to adversely affect the system (e.g., via thermal expansion or changes in protected fluid properties).
- Startup/shutdown operations. Examples are if a liquid subject to freezing is used instead of normal process fluid or if systems containing continuously flowing liquid subject to freezing during normal operation are stagnant during startup/shutdown. If freezing can occur during other than normal operations, proper winterization must be applied.

4.3 WINTERIZATION OF EQUIPMENT

The following winterization techniques are for equipment containing fluids that require

protection.

Tanks - The contents are warmed using internal coils.

Vessels - Vessel mounted instruments (such as for level or pressure), their associated leads, and bridles containing a fluid requiring freeze protection should be heat traced.

Exchangers - The contents are drained when the exchanger is not in operation. Air coolers may require freeze protection techniques incorporated into the design, such as warm air recirculation.

Pumps - Pumps with spare pumps on ready standby containing a liquid requiring freeze protection should have either the suction and discharge manifold piping to both pumps heat traced or a restricted flow bypass (normally ¾" with restriction orifice) around the discharge check valve to ensure continuous circulation. Usually in this type of service the pump bodies are insulated but not traced. Pumps that are normally idle and not subject to immediate startup are freeze protected by draining.

Machinery - Sometimes a shelter against freezing weather is provided for major machinery. For "severe" climate: air intakes on fans, blowers, and compressors should be fitted with an inverted hood arrangement, or equivalent, to minimize intake of rain, snow, and dust. Warm air recycling, direct suction heating, or other means should be provided to prevent ice buildup at air intakes, e.g., suction screens or filters.

4.4 FREEZE PROTECTION OF INSTRUMENTS AND INSTRUMENT LINES

The P&ID identifies all instruments that require heat tracing. If the line is traced, the instrument is traced with the same type of tracing. If the line is not traced but the instrument requires tracing, the P&ID indicates tracing type for the instrument. Local instruments and their leads are freeze protected using the same technique as the attached line. Vessel mounted instruments (such as for level or pressure), their associated leads, and bridles containing a fluid requiring freeze protection are heat traced. Instrument leads on process air lines are sometimes heat traced to prevent freezing of accumulated water.

5. HEAT TRACING AND CONSERVATION

5.1 HEAT TRACING METHODS

5.1.1 STEAM TRACING

Steam tracing systems utilize steam at elevated temperatures to transfer heat to a pipeline. The steam is contained in a tube or a small pipe attached to the pipe being traced. The condensate is recovered in the condensate system.

5.1.2 ELECTRIC TRACING

Electric tracing systems convert electric power to heat and transfer it to the pipe and its contained fluid. The majority of commercial electric heat-tracing systems in use today are of the resistive type and take the form of cables placed on the pipe. When current flows through the resistive elements, heat is produced. Other specialized electric tracing systems make use of impedance, induction, and skin conduction effects to generate and transfer heat.

5.2 SELECTION CRITERIA FOR TRACING METHODS

Factors to consider in selecting a heat tracing system.

- Relative cost of different types of heat-tracing.
- Availability of steam and/or electricity.
- Amount of heat loss which must be made up.
- Requirements for temperature control.

5.3 SPECIAL TRACING METHODS

Additional heating methods that may be considered.

5.3.1 JACKETED PIPE

Jacketed piping provides the most uniform application of heat to the process and maintains the most uniform process temperatures. Jacketed piping is used most frequently with processes that have a narrow temperature range, require very uniform temperature maintenance, and/or must have maximum heat input for melt-out or heat exchanger service. Jacketed piping features a core pipe, which is completely surrounded by a jacket pipe. Process flows through the core pipe, while a heating medium (or cooling medium) flows in the annular space between the core and jacket pipes.

5.3.2 SKIN EFFECT HEAT TRACING

The skin effect current tracing system is an electrically traced pipe heating system designed to provide heat to the carrier pipe evenly along the insulated pipeline.

The heating element consist of a ferromagnetic tube, that is welded to the pipe which needs to be heated, and a special electrical cable that is placed into the ferromagnetic tube. When the electricity is on, the electrical power flows over the inside of the ferromagnetic tube and generates heat that is carried over through contact to the pipe surface.

This type of system is used for long pipelines.

5.4 HEAT CONSERVATION

Heat conservation insulation is used for all vessels, equipment and piping where the fluid temperature is required to be maintained or heat loss is not expected. Heat conservation will be applicable for:

- Fluid which has been heated by passing through heat exchange equipment.
- Fluid from which process heat is to be recovered.
- Fluid which will become too viscous if allowed to cool.
- Superheated or saturated steam lines.

6. OTHER TYPES OF INSULATION

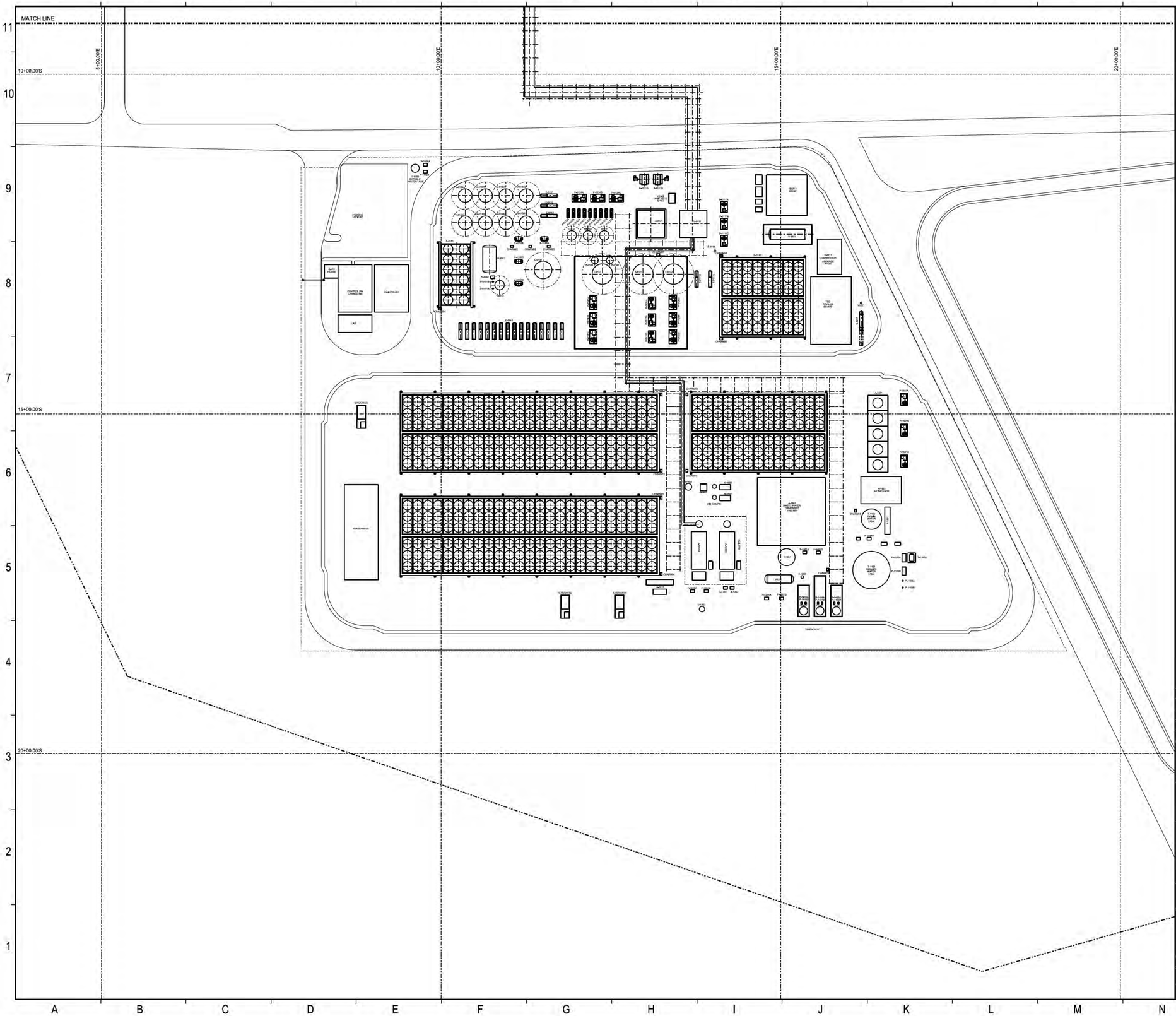
6.1 PERSONNEL PROTECTION

Personnel protection insulation shall be used for accessible piping and equipment (including vendor packages) operating above 140°F or at 14°F or below:

- Application of personnel protection shall be restricted to locations within 6.6 ft vertically and 3.3 ft horizontally from any platform, stairway passageway, ladders and stairs, which are normally used by operating personnel during normal plant operation.
- Insulation for personnel protection shall only be applied if the surface is not insulated for other reasons (e.g. heat conservation/cold conservation or noise).

Appendix C Mechanical Engineering

Appendix C.1 Plot Plan Layout



C-0121 ABSORBER COLUMN
C-0151 REGENERATOR COLUMN

K-0111A-B FLUE GAS BLOWER
K-0211 CO2 COMPRESSOR PACKAGE
K-1601 PRIMARY AIR COMPRESSOR PACKAGE
K-1602 SECONDARY AIR COMPRESSOR PACKAGE

V-0101 FEED DIRECT CONTACT COOLER
V-0131 ABSORBER OVERHEAD WASH WATER SURGE DRUM 1
V-0132 ABSORBER OVERHEAD WASH WATER SURGE DRUM 2
V-0134A-H ACTIVATED CARBON BEDS
V-0151 REGENERATOR OVERHEAD CONDENSATE DRUM
V-0221 02 POLISH REACTOR
V-1201 DEAERATOR
V-1202 BLOWDOWN DRUM
V-1203 CONDENSATE FLASH DRUM
V-1401 SOLVENT SUMP
V-1601 AIR RECEIVER
V-2001 KO DRUM

E-0111 FEED SCRUBBER WASH COOLER
E-0112 FEED SCRUBBER WASH AIR COOLER
E-0121 ABSORBER INTERSTAGE AIR COOLER 1
E-0122 ABSORBER INTERSTAGE AIR COOLER 2
E-0131 ABSORBER OVERHEAD WASH WATER COOLER 1
E-0132 ABSORBER OVERHEAD WASH WATER COOLER 2
E-0133 ACTIVATED CARBON BED COOLER
E-0141 LEAN/RICH SOLVENT HEAT EXCHANGER
E-0142 LEAN SOLVENT AIR COOLER
E-0151 REGENERATOR OVERHEAD CONDENSER
E-0152 REGENERATOR REBOILER
E-0221 STEAM HEATER

P-0111A-C FEED SCRUBBER WASH CIRCULATION PUMPS
P-0121A-C ABSORBER INTERSTAGE CIRULATION PUMPS 1
P-0122A-C ABSORBER INTERSTAGE CIRCULATION PUMPS 2
P-0124A-C RICH SOLVENT PUMPS
P-0131A-C ABSORBER OVERHEAD WASH WATER PUMPS 1
P-0132A-C ABSORBER OVERHEAD WASH WATER PUMPS 2
P-0133A-C ACID WASH PUMPS
P-0141A-C LEAN SOLVENT PUMPS
P-0151A-B REGENERATOR REFLUX PUMPS
P-1101A-B SERVICE WATER PUMPS
P-1104A-B DEMINERALIZED WATER PUMPS
P-1105A-B POTABLE WATER PUMPS
P-1201A-B BFW PUMPS
P-1203A-B CONDENSATE PUMPS
P-1401A-B SOLVENT TRANSFER PUMPS
P-1402 SOLVENT SUMP PUMP
P-1403A-B CAUSTIC TRANSFER PUMPS
P-1404A-B SULFURIC ACID TRANSFER PUMPS
P-1802A-B WASTE WATER PUMPS
P-2002 KO DRUM AQUEOUS PHASE PUMP

F-0111A-B FEED SCRUBBER CIRCULATION FILTER
F-0141 LEAN SOLVENT PARTICULATE FILTER
F-0142 LEAN SOLVENT CARBON FILTER
F-1401 SOLVENT SUMP FILTER

T-0121 ABSORBER INTERSTAGE SURGE TANK 1
T-0122 ABSORBER INTERSTAGE SURGE TANK 2
T-0141 LEAN SOLVENT SURGE TANK
T-1101 SERVICE WATER TANK
T-1102 DEMINERALIZED WATER TANK
T-1103 POTABLE STORAGE TANK
T-1401 SOLVENT STORAGE TANK
T-1402 CAUSTIC STORAGE TANK
T-1403 SULFURIC ACID STORAGE TANK
T-1801 WASTE WATER TANK

A-0221 TEG DEHYDRATION PACKAGE
A-0231 ELECTROLYZER PACKAGE
A-1101 DEMINERALIZED WATER PACKAGE
A-1201 BFW CHEMICAL PACKAGE (OXYGEN SCAVANGER)
A-1202 BFW CHEMICAL PACKAGE (CORROSION INHIBITOR)
A-1203 NATURAL GAS BOILER PACKAGE
A-1501 COOLING WATER PACKAGE
A-1601 NITROGEN GENERATION SKID
A-1602 INSTRUMENT AIR DRYER PACKAGE
A-1801 WASTE WATER TREATMENT PACKAGE
A-2301 BACKUP POWER GENERATION SKID

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	C	09/16/24	ISSUED FOR DESIGN	GK	DDB	MW	
ICR	B	04/18/24	ISSUED FOR CLIENT REVIEW	GK	DDB	MW	
ICR	A	04/02/24	ISSUED FOR CLIENT REVIEW	GK	DDB	MW	

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RTI INTERNATIONAL

KBR
Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

PLOT PLAN

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT: DE-FE0032220	CLIENT: DE-FE-0032220-KBR-01-PR-D-P0A-001	1 OF 2	C
KBR: N-429	KBR:		

0+00.00'S

5+00.00'S

10+00.00'S

10+00.00'E

15+00.00'E

20+00.00'E

MATCH LINE

MATCH LINE

K1 - STACK

K2 - STACK

CONTROL ROOM

WORKSHOPS

ELECTRICAL SUBSTATION EXPANSION

IFD	B	09/16/24	ISSUED FOR DESIGN	GK	DDB	MW	
ICR	B	04/18/24	ISSUED FOR CLIENT REVIEW	GK	DDB	MW	
ICR	A	04/02/24	ISSUED FOR CLIENT REVIEW	GK	DDB	MW	
ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT

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RTI INTERNATIONAL

KBR

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE

Balcones Cement Plant, New Braunfels, TX, USA

PLOT PLAN

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT DE-FE0032220	CLIENT DE-FE-0032220-KBR-01-PR-D-P0A-001	2 OF 2	C
KBR N-429	KBR		

Appendix C.2 Capital Spare Parts List

Capital Spares Parts List

DOCUMENT NO: DE-FE0032220- BR-00-ME-G-LST-003

PROJECT: CARBON CAPTURE PROJECT

PROJECT NO.: N429

PROJECT LOCATION: TEXAS, USA

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REV	DATE	PREPARED BY	REVIEWED BY	APPROVED BY	DESCRIPTION
A	10/4/2024	LN	JP	JH	Issued for Information

CAPITAL SPARE PARTS LIST - Developed for FEED Estimate

TOTAL NUMBER OF EQUIPPED PARTS	VENDOR LONG TEXT DESCRIPTION	Equipment Name	REFERENCE or ITEM NUMBER on DRAWING	QUANTITY RECOMMENDED BY SUPPLIER A Capital	QUANTITY VALUES UNITS OF MEASURE	CURRENCY USD PRICE EACH PART OR SET		TOTAL PRICE
1	ID Fan rotor Asembly	ID Flue Gas Fan	-0111	1	EA	$330,000		$330,000
1	Set of Impellers, pinions, gear - Compressor	CO2 Compressor	-0211	1	EA	$2,000,000		$2,000,000
1	Rotor Asembly	Feed Scrubber Wash Circulation Pump	P-0111	1	EA	$301,271		$301,271
1	Rotor Asembly	Absorber Interstage Circulation Pump 1	P-0121	1	EA	$293,126		$293,126
1	Rotor Asembly	Absorber Interstage Circulation Pump 2	P-0122	1	EA	$293,126		$293,126
1	Rotor Asembly	Rich Solvent Pump	P-0124	1	EA	$293,126		$293,126
1	Rotor Asembly	Absorber Overhead Wash Water Pump 1	P-0131	1	EA	$201,011		$201,011
1	Rotor Asembly	Absorber Overhead Wash Water Pump 2	P-0132	1	EA	$247,197		$247,197
1	Rotor Asembly	Acid Wash Pump	P-0133	1	EA	$192,611		$192,611
1	Rotor Asembly	Lean Solvent Pump	P-0141	1	EA	$286,250		$286,250
1	it - H2 Generator	Electrolyzer	A-0232	1	EA	$105,000		$105,000
1	Complete Assembly(Gear/Housing) - Stage 1 Compressor	N2 Generation Skid	A-1601	1	EA	$61,545		$61,545
1	Complete Assembly(Gear/Housing) - Stage 2 Compressor	N2 Generation Skid	A-1601	1	EA	$35,536		$35,536
1	Complete Plate Pack - Plate and Frame Heat Exchager	Lean Solvent Air Cooler	E-0141	1	EA	$240,000		$240,000
1	Complete Plate Pack - Plate and Frame Heat Exchager	Feed Scrubber Wash Cooler	E-0111	1	EA	$100,000		$100,000
1	Complete Plate Pack - Plate and Frame Heat Exchager	Absorber Overhead Wash Water Cooler 1	E-0131	1	EA	$85,000		$85,000
1	Complete Plate Pack - Plate and Frame Heat Exchager	Absorber Overhead Wash Water Cooler 2	E-0132	1	EA	$85,000		$85,000
1	Complete unit	Regenerator Reboiler	E-0152	1	EA	$482,500		$482,500
								0
								0
								0
								0
								0
								0
								0
							TOTAL	$5,632,299

Note: Captial Spare Parts List is in compliance with BR policy DM-GL- BR-PM-1201. This list does not include, nor consider, commissioning or 2-year spares(operational/maintenenace).

Per BR policy, critical spare equipment, parts, components or assemblies are considered to be Capital Spares if they are essential to the continuity of plant operations and one or more of the following criteria is applicable:

Items are complete warehouse spares (i.e., pumps, motors, valves, etc.) that were identified as required by reliability modeling, value engineering or other means but not required to be installed.

It is expected that if these equipment items fail catastrophically, failure will occur in such a way as to make repairs financially unattractive, costing 50% of new component purchase price.

The equipment is a supplier proprietary design, for which a replacement unit or parts delivery is long lead due to sole or limited Suppliers as may have, for instance, been mandated by the licensor (or long lead due to the complexity of the design and long fabrication cycle, e. g., a compressor rotor).

Equipment or part is customized and specially fabricated for the Project, requiring a long lead time to procure

No installed spare provided

Appendix D.1 Piping - Tie-in List

Piping - Tie-In List

KBR Job Number: N429

KBR Document N0.: DE-FE0032220-KBR-00-PI-L-TIE-001 REV A

RTI International

Project: DE-FEL0032220

Carbon Capture Plant FEED Study for Cement Manufacturing

Balcones Cement Plant, New Braunfels, TX, USA

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KBR Job No.: N-429 Client Proj. No.: DE-FE0032220		KBR Document No.: DE-FE0032220-KBR-00-PI-L-TIE-001				
Rev.	Date	Issued for	Prepared	Reviewed	Approved	Approved
A	8/29/2024	IFR	GK	JZ	MW	
B	10/10/2024	IFD	GK	JZ	MW	

SUMMARY OF DOCUMENT REVISIONS

Rev. No.	Date Revised	Section Revised	Quality Purpose
B	10/10/2024		REVISED PER COMMENTS

Version 1.0

TIE-IN NUMBER	LINE NUMBER	P & ID NUMBER	LINE SERVICE	Comments
01A-FG	01-FG-002-XX"	01-PR-D-PID-102	FLUE GAS	TIE-IN TO NO.1 KILN FLUE GAS DUCTWORK
01B-FG	01-FG-191-XX"	01-PR-D-PID-102	FLUE GAS	TIE-IN TO NO.1 KILN FLUE GAS DUCTWORK
02A-FG	01-FG-001-XX"	01-PR-D-PID-102	FLUE GAS	TIE-IN TO NO.2 KILN FLUE GAS DUCTWORK
02B-FG	01-FG-192-XX"	01-PR-D-PID-102	FLUE GAS	TIE-IN TO NO.2 KILN FLUE GAS DUCTWORK
04-CO2	02-HPC-003-XX"	02-PR-D-PID-102	COMPRESSED CO2	CO2 TO CO2 PIPELINE
05-NG	12-NG-017-XX"	12-PR-D-PID-002	NATURAL GAS	EXISTING NATURAL GAS LINE SOUTH OF NEW PLANT
06A-PRW	18-PRW-002-8"	18-PR-D-PID-001	PROCESS WATER	SUPPLY WATER FROM CEMEX POND
06B-PRW	18-PRW-008-3"	18-PR-D-PID-001	PROCESS WATER	RECIRC WATER TO CEMEX POND
07A-PW	11-PW-026-3"	11-PR-D-PID-002	POTABLE WATER	MUNICIPAL WATER LINE NORTH OF WALD ROAD AT
08A-SS	XX-SS-XXX	00-CV-D-K22-001	SANITARY SEWER	MUNICIPAL WATER LINE AT WALD ROAD

Appendix E.1 Topographical Survey Report

Braun Intertec Corporation
3503 Crosspoint, Suite 2
San Antonio, TX 78217

Phone: 210.625.4900
Web: braunintertec.com

August 9, 2024 Project B2404451

Kevin Happ
Cemex
2580 Wald Road
New Braunfels, TX 78132

Re: Preliminary Geotechnical Evaluation
Cemex Carbon Capture Facility
2580 Wald Road
New Braunfels, Texas

Dear Mr. Happ:

Braun Intertec Corporation is pleased to provide a transmittal of the attached Topography Survey that was performed during our Preliminary Geotechnical Evaluation. Should you have any questions or need additional information, please contact us at 210.625.4900, or email Alexandra Lucas at alucas@braunintertec.com or Bryan Rose at brose@braunintertec.com.

Sincerely,

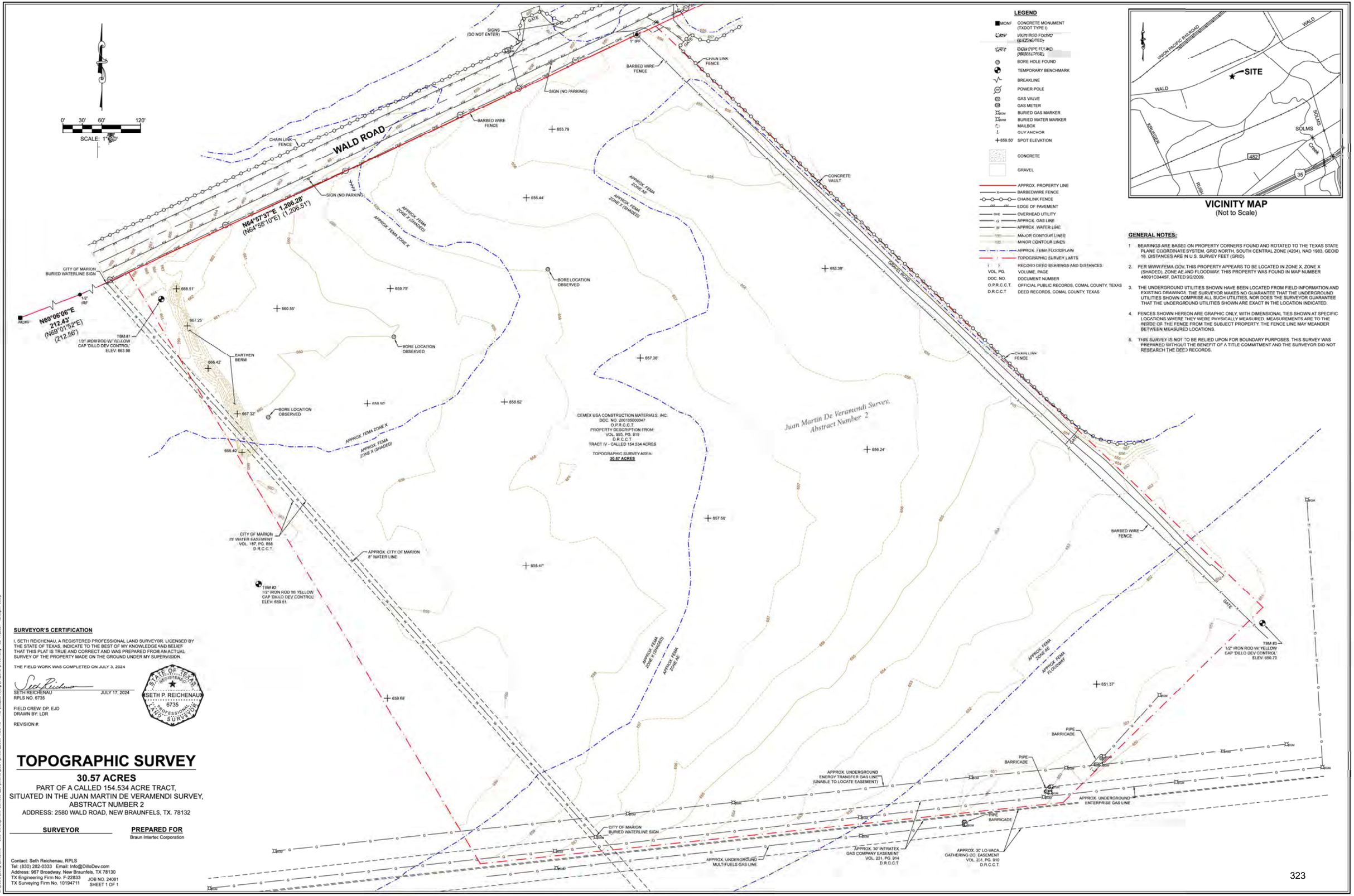
BRAUN INTERTEC CORPORATION
TBPELS Firm Registration No. F-12228

Bryan Rose
Principal Engineer

Alexandra Lucas
Staff Engineer

Attachments:
Topographic Survey (7/7/24)

AA/EOE



LEGEND

- MONF — CONCRETE MONUMENT (TXDOT TYPE I)
- IRON ROD FOUND (SIZE NOTED)
- IRON PIPE FOUND (SIZE NOTED)
- BORE HOLE FOUND
- TEMPORARY BENCHMARK
- BREAKLINE
- POWER POLE
- GAS VALVE
- GAS METER
- BGM — BURIED GAS MARKER
- BWM — BURIED WATER MARKER
- MAILBOX
- GUY ANCHOR
- 659.50' — SPOT ELEVATION
- CONCRETE
- GRAVEL
- APPROX. PROPERTY LINE
- BARBEDWIRE FENCE
- CHAINLINK FENCE
- EDGE OF PAVEMENT
- OHE — OVERHEAD UTILITY
- APPROX. GAS LINE
- APPROX. WATER LINE
- MAJOR CONTOUR LINES
- MINOR CONTOUR LINES
- APPROX. FEMA FLOODPLAIN
- TOPOGRAPHIC SURVEY LIMITS
- ( ) — RECORD DEED BEARINGS AND DISTANCES
- VOL, PG. — VOLUME, PAGE
- DOC. NO. — DOCUMENT NUMBER
- O.P.R.C.C.T. — OFFICIAL PUBLIC RECORDS, COMAL COUNTY, TEXAS
- D.R.C.C.T — DEED RECORDS, COMAL COUNTY, TEXAS

VICINITY MAP
(Not to Scale)

GENERAL NOTES:

1. BEARINGS ARE BASED ON PROPERTY CORNERS FOUND AND ROTATED TO THE TEXAS STATE PLANE COORDINATE SYSTEM, GRID NORTH, SOUTH CENTRAL ZONE (4204), NAD 1983, GEOID 18. DISTANCES ARE IN U.S. SURVEY FEET (GRID).
2. PER WWW.FEMA.GOV, THIS PROPERTY APPEARS TO BE LOCATED IN ZONE X, ZONE X (SHADED), ZONE AE AND FLOODWAY. THIS PROPERTY WAS FOUND IN MAP NUMBER 48091C0445F, DATED 9/2/2009.
3. THE UNDERGROUND UTILITIES SHOWN HAVE BEEN LOCATED FROM FIELD INFORMATION AND EXISTING DRAWINGS. THE SURVEYOR MAKES NO GUARANTEE THAT THE UNDERGROUND UTILITIES SHOWN COMPRISE ALL SUCH UTILITIES, NOR DOES THE SURVEYOR GUARANTEE THAT THE UNDERGROUND UTILITIES SHOWN ARE EXACT IN THE LOCATION INDICATED.
4. FENCES SHOWN HEREON ARE GRAPHIC ONLY, WITH DIMENSIONAL TIES SHOWN AT SPECIFIC LOCATIONS WHERE THEY WERE PHYSICALLY MEASURED. MEASUREMENTS ARE TO THE INSIDE OF THE FENCE FROM THE SUBJECT PROPERTY. THE FENCE LINE MAY MEANDER BETWEEN MEASURED LOCATIONS.
5. THIS SURVEY IS NOT TO BE RELIED UPON FOR BOUNDARY PURPOSES. THIS SURVEY WAS PREPARED WITHOUT THE BENEFIT OF A TITLE COMMITMENT AND THE SURVEYOR DID NOT RESEARCH THE DEED RECORDS.

SURVEYOR'S CERTIFICATION

I, SETH REICHENAU, A REGISTERED PROFESSIONAL LAND SURVEYOR, LICENSED BY THE STATE OF TEXAS, INDICATE TO THE BEST OF MY KNOWLEDGE AND BELIEF THAT THIS PLAT IS TRUE AND CORRECT AND WAS PREPARED FROM AN ACTUAL SURVEY OF THE PROPERTY MADE ON THE GROUND UNDER MY SUPERVISION.

THE FIELD WORK WAS COMPLETED ON JULY 3, 2024

SETH REICHENAU — JULY 17, 2024
RPLS NO. 6735

FIELD CREW: DP, EJD
DRAWN BY: LDR

REVISION #:

STATE OF TEXAS — REGISTERED — SETH P. REICHENAU — 6735 — PROFESSIONAL LAND SURVEYOR

TOPOGRAPHIC SURVEY

30.57 ACRES

PART OF A CALLED 154.534 ACRE TRACT,
SITUATED IN THE JUAN MARTIN DE VERAMENDI SURVEY,
ABSTRACT NUMBER 2
ADDRESS: 2580 WALD ROAD, NEW BRAUNFELS, TX. 78132

SURVEYOR

Contact: Seth Reichenau, RPLS
Tel: (830) 282-0333 Email: Info@DilloDev.com
Address: 967 Broadway, New Braunfels, TX 78130
TX Engineering Firm No. F-22833
TX Surveying Firm No. 10194711

JOB NO. 24081
SHEET 1 OF 1

PREPARED FOR
Braun Intertec Corporation

DILLO DEVELOPMENT SERVICES, LLC
C:\Users\Seth\Dillo Development Services LLC\Dillo\2024\24081 2580 Wald Rd – NB\03_Survey\04_CAD\24081.dwg Jul 17,2024–12:30pm Seth

Appendix E.2 Stormwater Runoff Plan

WALD ROAD

8FT HIGH SECURITY FENCE

PARKING

GATED ENTRANCE

4'x4' CATCH BASIN (TYPICAL)

CHARM04

CHARM07

CHARM08

CHARM09

4FT WIDE SIDEWALK (TYP.)

CHARM10

CHARM12

CHARM13

CHARM05

CHARM06

CHARM15

CHARM14

8FT HIGH SECURITY FENCE

PARKING

4FT WIDE SIDEWALK (TYP.)

FLARES END SECTION (FES) —MATCH PIPE SIZE. (TYPICAL)

STORMWATER MANAGEMENT BASIN SURFACE AREA ± 1 AC

8FT HIGH SECURITY FENCE

LEGEND

- PROPOSED CATCH BASIN
- PROPOSED CATCH BASIN
- 12" HDPE PIPE @ 1%
- 15" HDPE PIPE @ 1%
- 18" HDPE PIPE @ 1%
- 21" HDPE PIPE @ 1%
- 24" HDPE PIPE @ 1%
- 30" HDPE PIPE @ 1%
- 36" HDPE PIPE @ 1%
- PROPOSED 6" CURB
- PROPOSED 4 FT WIDE SIDEWALK

ROAD AND STORM SEWER PLAN
SCALE: 1"=40'

ARCH D
24X36

GENERAL NOTES: **NOTES**

HDPE STORM PIPE DATA TABLE

PIPE SIZE (INCHES)	PIPE LENGTH (FT)	PIPE SLOPE (%)
12	2330	1.00%
15	1772	1.00%
18	503	1.00%
21	90	1.00%
24	667	1.00%
30	645	1.00%
36	168	1.00%

STORM STRUCTURES

TYPE	NOTE	COUNT
INLETS	4'x4' STRUCTURES W/ GRATES	96 UNITS
FLARED END SECTION	HDPE 36"	4 UNITS

0 40' 80'

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
ICA	A	02AUG2024	ISSUED FOR INFORMATIONL	GSM			

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE

Balcones Cement Plant, New Braunfels, TX, USA

CIVIL DRAWING

STORMWATER RUNOFF PLAN
PRELIMINARY

PROJECT NUMBER		DOCUMENT NUMBER		SHEET	REVISION
CLIENT	DE-FE0032220	CLIENT	DE-FE0032220-KBR-00-CV-D-K22-001	1 OF 1	A
KBR	N-429	KBR			

Appendix E.3 Materials Take-offs

CSA MTO- ISBL

REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	16-SEP-2024	IFI	CRS			
B	26-SEP-2024	IFI	CRS			
C	14-NOV-2024	IFI	CRS			

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ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	0	Units	Sketches	Comments
ISBL1.1	C-0121	Absorber Column Perimeter Platforms (6 Total)	Platform Steel (Positive)	6	50	50	x	0.008625	129 38	29.19	Tons	N/A	
			Platform Steel (Negative)	-6	44	44	x	0.008625	-100.19				
			Platform Grating (Positive)	6	50	50	x	x	15000.00	3384.00	FT2		
			Platform Grating (Negative)	-6	44	44	x	x	-11616.00				
			Platform HR	6	200	x	x	x	1200.00	1200.00	LF		
		Absorber Column Stairtowers (2 total)	2*Stairtower Run Steel	14	23	10	x	0.008625	27.77	78.68	Tons	N/A	
			2*Stairtower Columns	8	140	x	x	0.0345	38.64				
			2*Vertical Bracing	28	30.4795	x	x	0.014375	12.27				
			2*Stairtower Grating	14	23	10	x	x	3220.00	3220.00	FT2		
			2*Stairtower HR (Stringers)	112	17	x	x	x	1904.00	2352.00	LF		
			2*Stairtower HR (Landings)	28	16	x	x	x	448 00				
		Absorber Column Top Platform	Stairs to Top	1	30	3	x	0.00575	0.52	15 52	Tons	N/A	
			Top Platform Allowance	15	x	x	x	x	15.00				
			Grating	1	30	3	x	x	90.00	90 00	FT2		
			HR	2	30	x	x	x	60.00	60 00	LF		
		Foundations	Pile Cap	1	60	60	4	0.037037	533 33	570.67	YD3	See Sketch	
			Perimeter Wall (Positive)	1	44	44	3	0.037037	215.11			DE-FE0032220-KBR-00-CV-D-C23-003	
			Perimeter Wall (Negative)	-1	40	40	3	0.037037	-177.78				
			2' Dia x 35' deep concrete shafts	100	x	x	x	x	100 00	100.00	EA		
ISBL1.2	C-0151	Foundations	Pile Cap	1	32	32	4	0.037037	151.70	229.15	YD3	See Sketch	
			Octagon	1	697	x	3	0.037037	77.44			DE-FE0032220-KBR-00-CV-D-C23-004	
			2' Dia x 35' deep concrete shafts	25	x	x	x	x	25.00	25 00	EA		

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL2.1	V-0111	Feed Direct Contact Cooler	Pile Cap	1	48	48	4	0 037037	341.33	378.67	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-009	
			Perimeter Wall (Positive)	1	44	44	3	0 037037	215.11				
			Perimeter Wall (Negative)	-1	40	40	3	0 037037	-177.78				
			2' Dia x 35' long shafts	64	x	x	x	x	64 00	64 00	EA		
ISBL2.2	V-0131 V-0132 V-0133	Absorber Overhead Wash Water Surge Drums Foundations	Concrete Mat	3	17	17	2	0 037037	64 22	72 56	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-010	
			Tank Piers	12	2.5	2 5	3	0 037037	8.33				
ISBL2.3	V-0134 A/B/C/D/E/F/ G/H	Activated Carbon Beds	Mat Foundation	1	120	70	3	0 037037	933.33	1198.81	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-011	
			Octagons	8	438	x	2	0 037037	259.56				
			Pipe Bridge Piers	10	2	2	4	0 037037	5.93				
			Walkway Steel (assume supported by tanks)	2	106	4	x	0.00575	4.88	4 88	TONS	N/A	
			Grating	2	106	4	x	x	848.00	848.00	FT2		
			E/W Handrail	4	106	x	x	x	424.00	440.00	LF		
			N/S Handrail	4	4	x	x	x	16 00				
			25' tall caged ladder	4	x	x	x	x	4.00	4.00	EA		
ISBL2.4	V-0151	Regenerator Overhead Condensate Drum	Mat Foundation	1	16	16	3	0 037037	28.44	29.44	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-007	
			Piers	4	1.5	1 5	3	0 037037	1.00				
ISBL2.5	V-0221	O_2 Polishing Reactor	Mat Foundation	1	7	7	3	0 037037	5.44	5.44	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-007	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL3.1	-0111A/B	Flue Gas Blower	Mat Foundation	1	54	18	4	0.037037	144.00	144.00	YD3	N/A	
ISBL3 2	-0211	CO_2 Compressor Package Shed	Mat Foundation (Covered in OSBL PEMB Foundations)	X	X	X	X	X	0.00	0.00	YD3	N/A	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL4.1	E-0111A/B	Feed Scrubber Wash Cooler	Pad	2	14	8	3	0.037037	24.89	24.89	YD3	N/A	
ISBL4.2	E-0112	Feed Scrubber Wash Air Cooler	Single Spread Foundation	10	7	7	2	0.037037	36.30	279.26	YD3	N/A	
			Single Pier	10	2	2	3	0.037037	4.44				
			Double Spread Foundation	35	10	8	2	0.037037	207.41				
			Double Pier	35	4	2	3	0.037037	31.11				
ISBL4.3	E-0121	Absorber Interstage Air Cooler 1	Single Spread Foundation	10	7	7	2	0.037037	36.30	858.52	YD3	N/A	
			Single Pier	10	2	2	3	0.037037	4.44				
			Double Spread Foundation	120	10	8	2	0.037037	711.11				
			Double Pier	120	4	2	3	0.037037	106.67				
ISBL4.4	E-0122	Absorber Interstage Air Cooler 2	Single Spread Foundation	10	7	7	2	0.037037	36.30	449.63	YD3	N/A	
			Single Pier	10	2	2	3	0.037037	4.44				
			Double Spread Foundation	60	10	8	2	0.037037	355.56				
			Double Pier	60	4	2	3	0.037037	53.33				
ISBL4.5	E-0131	Absorber Overhead Wash Water Cooler 1	Pad	1	15	8	3	0.037037	13.33	13.33	YD3	N/A	
ISBL4.6	E-0132	Absorber Overhead Wash Water Cooler 2	Pad	1	15	8	3	0.037037	13.33	13.33	YD3	N/A	
ISBL4.7	E-0133	Activated Carbon Bed Cooler	Pad	1	15	8	3	0.037037	13.33	13.33	YD3	N/A	
ISBL4.8	E-0141	Lean/Rich Solvent Heat Exchanger	Mat	1	160	13	3	0.037037	231.11	231.11	YD3	N/A	
ISBL4.9	E-0142	Lean Solvent Air Cooler	Single Spread Foundation	10	7	7	2	0.037037	36.30	858.52	YD3	N/A	
			Single Pier	10	2	2	3	0.037037	4.44				
			Double Spread Foundation	120	10	8	2	0.037037	711.11				
			Double Pier	120	4	2	3	0.037037	106.67				
ISBL4.10	E-0151	Regenerator Overhead Condenser	Single Spread Foundation	6	7	7	2	0.037037	21.78	126.67	YD3	N/A	
			Single Pier	6	2	2	3	0.037037	2.67				
			Double Spread Foundation	15	10	8	2	0.037037	88.89				
			Double Pier	15	4	2	3	0.037037	13.33				
ISBL4.11	E-0152A/B/C/D	Regenerator Reboiler	Pad	4	15	10	3	0.037037	66.67	66.67	YD3	N/A	
ISBL4.12	E-0221	Steam Heater	Footing	2	10	5	2	0.037037	7.41	7.41	YD3	N/A	
			Saddle Piers	2	10	1.5	4	0.037037	4.44	4.44	YD3	N/A	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL5.1	P-0111A/B/C	Feed Scrubber Wash Circulation Pump	Pad	3	20	12	3	0.037037	80.00	80.00	YD3	N/A	
ISBL5.2	P-0124A/B/C	Rich Solvent Pump	Pad	3	25	14	3	0.037037	116.67	116.67	YD3	N/A	
ISBL5.3	P-0131A/B/C P-0132A/B/C P-0133A/B/C	Absorber Overhead Wash Water Pump 1,2 Acid Wash Pump	Pad	1	70	15	3	0.037037	116.67	116.67	YD3	N/A	
ISBL5.4	P-0151A/B	Regenerator Reflux Pump	Pad	2	4	4	3	0.037037	3 56	3.56	YD3	N/A	
ISBL5.5	P-0121A/B/C	Absorber Interstage Circulation Pump 1	Pump Pads (Covered in tank dike concrete)	x	x	x	x	x	0 00	0.00	YD3	N/A	Pump Pads (Covered in tank dike concrete)
ISBL5.6	P-0122A/B/C	Absorber Interstage Circulation Pump 2		x	x	x	x	x	0 00	0.00	YD3	N/A	
ISBL5.7	P-0141A/B/C	Lean Solvent Pump		x	x	x	x	x	0 00	0.00	YD3	N/A	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Comments
ISBL6.1	F-0111A/B	Feed Scrubber Circulation Filter		2	4	4	3	0.037037	3.56	3.56	YD3	
ISBL6.2	F-0141	Lean Solvent Particulate Filter	Shown as part of tank dike foundation	x	x	x	x	x	0.00	0.00	-	Shown as part of tank dike foundation
ISBL6.3	F-0142	Lean Solvent Carbon Filter		x	x	x	x	x	0.00	0.00	-	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL7.1	T-0121 T-0122 T-0141	Absorber Interstage Surge Tank 1	Concrete Mat (North)	1	167	53	3	0.037037	983.44	2612.96	YD3	See Sketch	
			Concrete Mat (South)	1	167	84	1 5	0.037037	779 33			DE-FE0032220-KBR-00-CV-D-C23-005	
			South Perimeter Haunch	1	335	4.75	1 5	0.037037	88.40				
		Absorber Interstage Surge Tank 2	N/S Walls	2	53	1	4	0.037037	15.70				
			E/W Walls	2	167	1	4	0.037037	49.48				
		Lean Solvent Surge Tank	T-0141, F-0141, F-0142 Pad	1	1300	x	2	0.037037	96.30				
			T-0121, T-0122 Tank Octagons	2	902	x	2	0.037037	133.63				
		P-0121A/B/C	Pump Pads	3	25	14	4	0.037037	155 56				
		P-0122A/B/C	Pump Pads	3	25	14	4	0.037037	155 56				
		P-0141A/B/C	Pump Pads	3	25	14	4	0.037037	155 56				

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
ISBL8.1	A-0221	TEG Dehydration Package	Concrete Mat	1	100	60	3	0.037037	666.67	666.67	YD3	N/A	
ISBL8.2	A-0232	Electrolyzer Package	Mat Foundation	1	46	26	3	0.037037	132.89	132.89	YD3	N/A	
			Pad1	1	40	8	1	0.037037	11.85			N/A	
			Pad2	1	20	8	1	0.037037	5.93			N/A	
ISBL8.3	CEMS Analyzer Shed	Foundation	Pad	1	15	10	3	0.037037	16.67	16.67	YD3	N/A	

CSA MTO- OSBL

REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	16-SEP-2024	IFI	CRS			
B	26-SEP-2024	IFI	CRS			
C	15-NOV-2024	IFI	CRS			

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ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL1.1	-1601, -1602 Compressor Shed	-1601, -1602 Primary & Secondary Air Compressor Package	Mat Foundation (Covered in OSBL PEMB Foundations)	x	x	x	x	x	0.00	0.00	YD3		

Scope ID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL2.1	V-1201	Deaerator	Foundation	2	12	12	2 5	0.037037	26.67	30.67	YD3	N/A	
			Piers	2	12	1.5	3	0.037037	4.00				
OSBL2.2	V-1202	Blowdown Drum	Pad	1	7	7	3	0.037037	5.44	6.44	YD3	See Sketch	
			Piers	4	1.5	1.5	3	0.037037	1.00			DE-FE0032220-KBR-00-CV-D-C23-007	
OSBL2.3	V-1203	Condensate Flash Drum	Octagon Pad	1	129	x	3	0.037037	14.33	15 33	YD3	See Sketch	
			Piers	4	1.5	1.5	3	0.037037	1.00			DE-FE0032220-KBR-00-CV-D-C23-007	
OSBL2.4	V-1401	Solvent Sump (b/sump concrete at -24 below grade)	Sump Floor	1	86.5	46 5	4	0.037037	595 89	970.60	YD3	See Sketch	
			Walls (Positive)	1	76.5	36 5	20.5	0.037037	2120.04			DE-FE0032220-KBR-00-CV-D-C23-012	
			Walls (Negative)	-1	72	32	20.5	0.037037	-1749.33				
			Saddle Supports	2	18	1.5	2	0.037037	4.00				
			Perimeter Fence	2	123	x	x	x	246 00	246.00	LF		
OSBL2.5	V-1601	Air Receiver	Octagon Pad	1	162	x	3	0.037037	18.00	18 00	YD3	See Sketch	
												DE-FE0032220-KBR-00-CV-D-C23-007	
OSBL2.6	V-2001	O Drum	Pad	1	25	30	3	0.037037	83.33	94.44	YD3	See Sketch	
			Saddle Supports	2	25	2	3	0.037037	11.11			DE-FE0032220-KBR-00-CV-D-C23-007	

Scope ID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL5.1	P-1101A/B	Service Water Pump	Pump Pad	2	6	8	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.2	P-1102A	Fire Water Pump	Pump Pad	1	10	6	3	0.037037	6.67	6.67	YD3	N/A	
OSBL5.3	P-1102B	Fire Water Pump	Pump Pad	1	14	6	3	0.037037	9 33	9.33	YD3	N/A	
OSBL5.4	P-1103A/B	Fire Water Jockey Pump	Pump Pad	2	3	3	3	0.037037	2 00	2.00	YD3	N/A	
OSBL5.5	P-1104A/B	Demineralized Water Pump	Pump Pad	2	6	8	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.6	P-1105A/B	Potable Water	Pump Pad	2	6	8	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.7	P-1106A/B	Raw Water Pump (not in model)	Pump Pad	2	8	6	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.8	P-1201A/B	BFW Pump	Pump Pad	2	8	12	3	0.037037	21.33	21.33	YD3	N/A	
OSBL5.9	P-1203A/B	Condensate Pump	Pump Pad	2	8	12	3	0.037037	21.33	21.33	YD3	N/A	
OSBL5.10	P-1401A/B	Solvent Transfer Pump	Pump Pad	2	6	8	4	0.037037	14.22	14.22	YD3	N/A	
OSBL5.11	P-1402A/B	Solvent Sump Pump	Pump Pad	2	6	8	4	0.037037	14.22	14.22	YD3	N/A	
OSBL5.12	P-1403A/B	Caustic Transfer Pump	Pump Pad	2	6	8	4	0.037037	14.22	14.22	YD3	N/A	
OSBL5.13	P-1404A/B	Sulfuric Acid Transfer Pump	Pump Pad	2	6	8	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.14	P-1501A/B/C	Cooling Water Pumps	Pump Pad	3	22	15	3	0.037037	110.00	110 00	YD3	N/A	
OSBL5.15	P-1801A/B	Waste Water Pump	Pump Pad	2	6	8	3	0.037037	10.67	10.67	YD3	N/A	
OSBL5.16	P-2002	O Drum Aqueous Phase Pump	Pump Pad	1	6	8	3	0.037037	5 33	5.33	YD3	N/A	

Scope ID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Comments
OSBL6.1	F-1401	Solvent Sump Filter	Pad	1	4	4	3	0.037037	1.78	1.78	YD3	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL7.1	T-1101	Service Water Tank	Pile Cap	1	60	60	4	0.037037	533 33	533.33	YD3	See Sketch	
			2' dia x 35' long piles	64	x	x	x	x	64.00	64 00	EA	DE-FE0032220-KBR-00-CV-D-C23-008	
OSBL7.2	T-1102	Demineralized Water Tank	Octagon	1	958	x	3	0.037037	106.44	106.44	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-007	
OSBL7.3	T-1102A	FW Diesel Tank	Mat	1	12	8	2	0.037037	7.11	8.44	YD3	N/A	
			Saddle Piers	2	6	1 5	2	0.037037	1.33				
OSBL7.4	T-1103	Potable Water Tank	Octagon	1	212	x	3	0.037037	23.56	23 56	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-007	
OSBL7.5	T-1401	Solvent Storage Tank	Dike Floor	1	61	21	2	0.037037	94.89	127.21	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-006	
			Long Walls	2	61	0.833333	4	0.037037	15.06				
			Short Walls	2	21	0.833333	4	0.037037	5.19				
			Octagon	1	163	x	2	0.037037	12.07				
OSBL7.6	T-1402	Caustic Storage Tank	Dike Floor	1	47	21	2	0.037037	73.11	101.98	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-006	
			Long Walls	2	47	0.833333	4	0.037037	11.60				
			Short Walls	2	21	0.833333	4	0.037037	5.19				
			Octagon	1	163	x	2	0.037037	12.07				
OSBL7.7	T-1403	Sulfuric Acid Storage Tank	Dike Floor	1	47	21	2	0.037037	73.11	101.98	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-006	
			Long Walls	2	47	0.833333	4	0.037037	11.60				
			Short Walls	2	21	0.833333	4	0.037037	5.19				
			Octagon	1	163	x	2	0.037037	12.07				
OSBL7.8	T-1801	WW Tank	Octagon	1	649	x	3	0.037037	72.11	72.11	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-007	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL8.1	A-1101	Demineralized Water Package	Pad	1	44	12	3	0.037037	58.67	58.67	YD3	N/A	
OSBL8.2	A-1201	BFW Chemical Package (Oxygen Scavanger)	Pad	1	6	4	3	0.037037	2.67	2.67	YD3	N/A	
OSBL8.3	A-1202	BFW Chemical Package (Corrosion Inhibitor)	Pad	1	6	4	3	0.037037	2.67	2.67	YD3	N/A	
OSBL8.4	A-1203	Natural Gas Boiler Package	Mat Foundation	1	100	90	3 5	0.037037	1166.67	1295.85	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-002	
			Pad1	2	56	23	1	0.037037	95.41				
			Pad2	2	20	12	1	0.037037	17.78				
			Pad3	2	12	6	1	0.037037	5.33				
			Pad4	2	12	12	1	0.037037	10.67				
OSBL8.5	A-1501	Cooling Water Package	Footing	12	10	10	2	0.037037	88.89	94 22	YD3	See Sketch DE-FE0032220-KBR-00-CV-D-C23-001	
			Pier	12	2	2	3	0.037037	5.33				
OSBL8.6	A-1601	Nitrogen Generation Skid	Mat Foundation	1	60	40	3 5	0.037037	311.11	311.11	YD3	N/A	
OSBL8.7	A-1602	Instrument Air Dryer Package		x	x	x	x	x	0.00	0.00	YD3	N/A	Part of K-1601/K-1602 Shed
OSBL8.8	A-1801	Waste Water Treatment Package	Mat Foundation	1	100	75	3 5	0.037037	972 22	972.22	YD3	N/A	
OSBL8.9	A-2001	Stack	On top of C-0121	x	x	x	x	x	0.00	x	x	N/A	
OSBL8.10	XFRM-B1	ECR Transformer	Pad	1	14.16667	10 58333	3	0.037037	16.66	16.66	YD3	N/A	
OSBL8.11	XFRM-B2	ECR Transformer	Pad	1	14.16667	10 58333	3	0.037037	16.66	16.66	YD3	N/A	
OSBL8.12	XFRM-C1	ECR Transformer	Pad	1	10	7.333333	3	0.037037	8.15	8.15	YD3	N/A	
OSBL8.13	XFRM-C5	ECR Transformer	Pad	1	7 083333	4.75	3	0.037037	3.74	3.74	YD3	N/A	
OSBL8.14	XFRM-C2	E-Room-1 Transformer	Pad	1	10	7.333333	3	0.037037	8.15	8.15	YD3	N/A	
OSBL8.15	XFRM-C3	E-Room-2 Transformer	Pad	1	10	7.333333	3	0.037037	8.15	8.15	YD3	N/A	
OSBL8.16	XFRM-C4	E-Room-3 Transformer	Pad	1	10	7.333333	3	0.037037	8.15	8.15	YD3	N/A	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
OSBL9.1	Control Room/Change Room	Foundation	Mat Foundation	1	70	50	1	0.037037	129.63	174.07	YD3	See Sketch	
			Perimeter Turn-down	2	120	2.5	2	0.037037	44.44			DE-FE0032220-KBR-26-CV-D-C25-001	
OSBL9.2	Maintenance Bldg	Foundation	Mat Foundation	1	70	50	1	0.037037	129.63	182.96	YD3	See Sketch	
			Perimeter Turn-down	2	120	3	2	0.037037	53.33			DE-FE0032220-KBR-26-CV-D-C25-002	
OSBL9.3	ECR	Foundation	Mat Foundation	1	60	60	1.5	0.037037	200.00	246.67	YD3	See Sketch	
			Perimeter Turn-down	2	120	2.5	2	0.037037	44.44			DE-FE0032220-KBR-26-CV-D-C25-003	
			Perimeter Curb	2	120	0.5	0.5	0.037037	2.22				
OSBL9.4	Gate House	Foundation	Mat Foundation	1	20	20	1	0.037037	14.81	29.63	YD3	See Sketch	
			Perimeter Turn-down	2	40	2.5	2	0.037037	14.81			DE-FE0032220-KBR-26-CV-D-C25-004	
OSBL9.5	K-0211 Compressor Shed	Foundation	Mat Foundation	1	52	36	2.5	0.037037	173.33	196.15	YD3	See Sketch	
			Turndown	2	88	3.25	1	0.037037	21.19			DE-FE0032220-KBR-26-CV-D-C25-005	
			Curb	2	88	0.5	0.5	0.037037	1.63				
OSBL9.6	K-1601 & K-1602 Compressor Shed	Foundation	Mat Foundation	1	60	40	1.5	0.037037	133.33	179.50	YD3	See Sketch	
			Perimeter Turn-down	2	100	2.375	1.5	0.037037	26.39			DE-FE0032220-KBR-26-CV-D-C25-006	
			Perimeter Curb	2	100	0.5	0.5	0.037037	1.85				
			Compressor Pads 1	2	16	8	1	0.037037	9.48				
			Compressor Pads 2	2	8	8	1	0.037037	4.74				
			A-1602 Pad	1	10	10	1	0.037037	3.70				
OSBL9.7	Lab	Foundation	Mat Foundation	1	50	26	1	0.037037	48.15	76.30	YD3	See Sketch	
			Perimeter Turn-down	2	76	2.5	2	0.037037	28.15			DE-FE0032220-KBR-26-CV-D-C25-007	
OSBL9.8	Warehouse	Foundation	Mat Foundation	1	140	50	1.5	0.037037	388.89	462.78	YD3	See Sketch	
			Perimeter Turn-down	2	190	2.5	2	0.037037	70.37			DE-FE0032220-KBR-26-CV-D-C25-008	
			Perimeter Curb	2	190	0.5	0.5	0.037037	3.52				
OSBL9.9	E-Rooms (3 total)	Foundation	Mat Foundation	3	20	12	1	0.037037	26.67	62.22	YD3	See Sketch	
			Perimeter Turn-down	6	32	2.5	2	0.037037	35.56			DE-FE0032220-KBR-26-CV-D-C25-009	

ScopeID	Description	Item	SubItem	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches
OSBL10.1	ECR	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-001
OSBL10 2	E-Rooms	Void	Scope covered in Electrical	x	x	x	x	x	0.00	0.00	EA	Void
OSBL10 3	Warehouse	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-003
OSBL10.4	Gate House	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-004
OSBL10 5	K-0211 Compressor Shed	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-005
OSBL10.6	K-1601 Compressor Shed	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-006
OSBL10.7	Control Room/Change Room	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-007
OSBL10 8	Maintenance Bldg	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-008
OSBL10 9	Lab	PEMB		1	x	x	x	x	1.00	1.00	EA	DE-FE0032220-KBR-26-CV-D-S22-009

CSA MTO – Pipe & Duct Supports

REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	16-SEP-2024	IFI	CRS			
B	26-SEP-2024	IFI	CRS			
C	15-NOV-2024	IFI	CRS			

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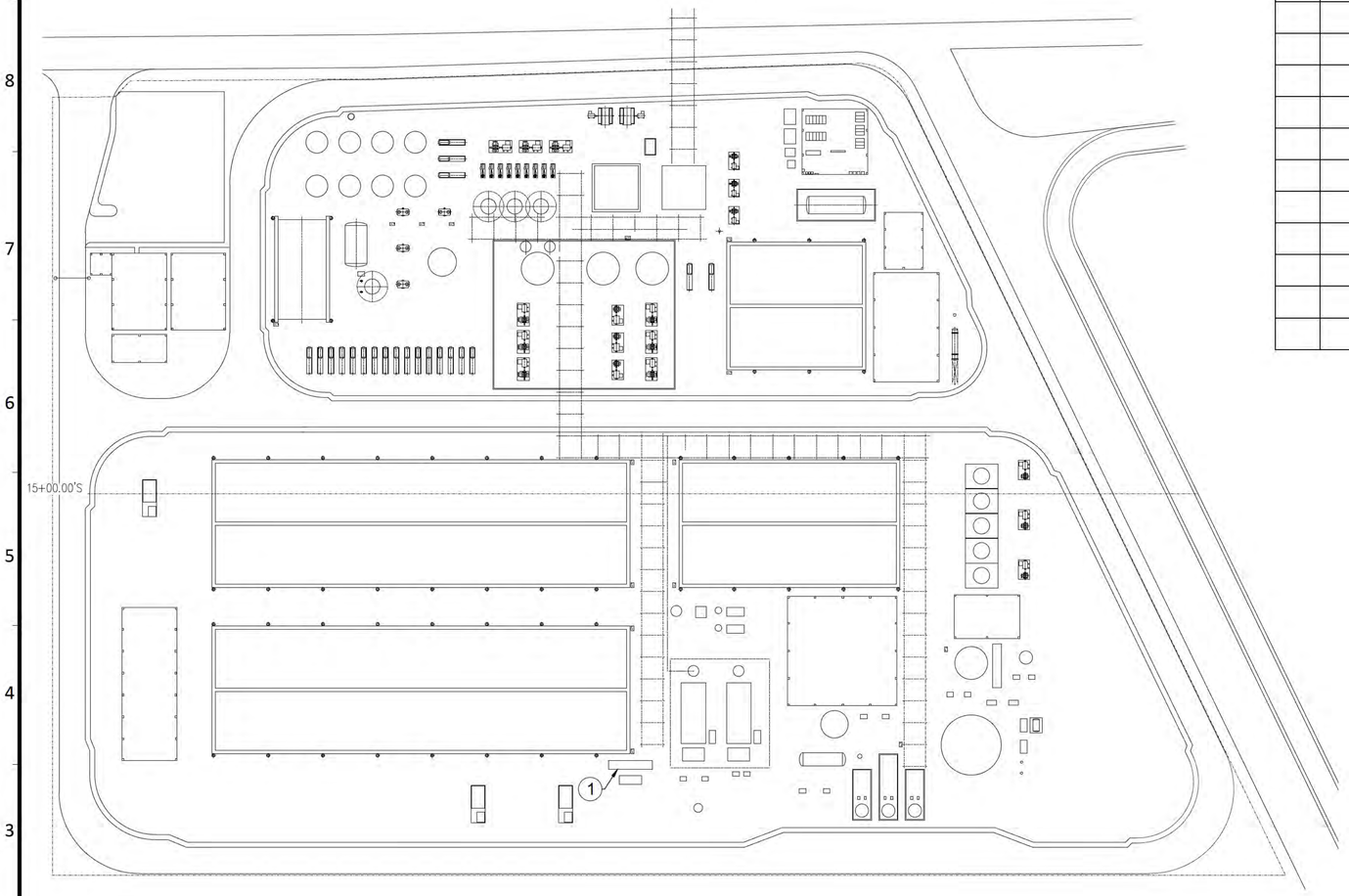
ScopeID	Description	Item	SubItem	Multiplier	Quantity	L	W	H	Factor	SubTotal	Total	Units	Sketches	Comments
SUPT1.1	Rack 1	Steel	From STAAD	8.28	133	x	x	x	0.5	550.62	550.62	TONS	DE-FE0032220-KBR-00-CV-D-S21-001	MTO is per 100' and estimated length is 828'
		Foundations	Spread Footings	8.28	8	10	10	1.5	0.037037	368.00	1600.03	YD3	DE-FE0032220-KBR-00-CV-D-C24-001	
			Spread Footing Piers	8.28	8	2.5	2.5	3	0.037037	46.00				
			Combined Footing	8.28	1	42	36	2.5	0.037037	1159.20				
			Combined Footing Piers	8.28	4	2.5	2.5	3.5	0.037037	26.83				
SUPT1.2	Rack 2	Steel	From STAAD	2.666667	120	x	x	x	0.5	160.00	160.00	TONS	DE-FE0032220-KBR-00-CV-D-S21-002	MTO is per 60' and estimated length is 160'
		Foundations	Spread Footings	2.666667	4	9	9	1.5	0.037037	48.00	381.83	YD3	DE-FE0032220-KBR-00-CV-D-C24-002	
			Spread Footing Piers	2.666667	4	2.5	2.5	3	0.037037	7.41				
			Combined Footing	2.666667	1	38	34	2.5	0.037037	319.01				
			Combined Footing Piers	2.666667	4	2.5	2.5	3	0.037037	7.41				
SUPT1.3	Rack 3	Steel	From STAAD	8.27	75	x	x	x	0.5	310.13	310.13	TONS	DE-FE0032220-KBR-00-CV-D-S21-003	MTO is per 100' and estimated length is 827'
		Foundations	Spread Footings	8.27	8	7	7	1.5	0.037037	180.10	853.19	YD3	DE-FE0032220-KBR-00-CV-D-C24-003	
			Spread Footing Piers	8.27	8	2.5	2.5	3	0.037037	45.94				
			Combined Footing	8.27	1	28	28	2.5	0.037037	600.34				
			Combined Footing Piers	8.27	4	2.5	2.5	3.5	0.037037	26.80				
SUPT1.4	Rack 4	Steel	From STAAD	39.07	40	x	x	x	0.5	781.40	781.40	TONS	DE-FE0032220-KBR-00-CV-D-S21-004	MTO is per 100' and estimated length is 3900'
		Foundations	Strip Footing	39.07	4	14	6	1.5	0.037037	729.31	3243.53	YD3	DE-FE0032220-KBR-00-CV-D-C24-004	
			Strip Footing Piers	39.07	8	2.5	2.5	3	0.037037	217.06				
			Combined Footing	39.07	1	30	20	2.5	0.037037	2170.56				
			Combined Footing Piers	39.07	4	2.5	2.5	3.5	0.037037	126.62				
SUPT1.5	Low Duct Supports	Spread Foundations	Footing	8.24	12	12	12	1.5	0.037037	791.04	859.71	YD3	DE-FE0032220-KBR-00-CV-D-C24-005	MTO is per 100' and estimated length is 824'
			Pier	8.24	12	2.5	2.5	3	0.037037	68.67				
SUPT1.6	High Duct Supports	Steel	From STAAD	10.26	160	x	x	x	0.5	820.80	820.80	TONS	DE-FE0032220-KBR-00-CV-D-S21-005	MTO is per 100' and estimated length is 1026'
		Foundations	Pile Caps	10.26	12	12	11.25	3	0.037037	1846.80	1932.30	YD3	DE-FE0032220-KBR-00-CV-D-C24-006	
			Piers	10.26	12	2.5	2.5	3	0.037037	85.50				
			2'-0" dia x 35' long piles	10.26	36	x	x	x	x	369.36	369.36	EA		

Appendix F Electrical Engineering

Appendix F.1 Hazardous Area Classification Plan



SITE HA ARDOUS AREA CLASSIFICATION PLAN
1/64 1-0

HAZARDOUS AREA CLASSIFICATION SCHEDULE

LOC. SYMB.	AREA DESCRIPTION	DESCRIPTION
(1)	A-0232 ELECTROLYZER PACKAGE	THIS EQUIPMENT SHALL BE CONSIDERED CLASS I DIV II

ISSUE	REV	DATE	REVISION DESCRIPTION	BY	CHK	APP	CLIENT
IFD	A	20NOV24	ISSUED_FOR_DESIGN	MS	AJ	AJ	CLT_01

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RTI INTERNATIONAL

Engineering Services
By KBR Sustainable Technology Solutions

RTI NAS CARBON CAPTURE
Balcones Cement Plant, New Braunfels, TX, USA

HAZARDOUS AREA CLASSIFICATION PLAN

ELECTRICAL

PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REVISION
CLIENT DE-FE0032220	CLIENT DDE-FE0032220-KBR-00-SE-D-ZF2-001	1 OF 1	A
KBR N-429	KBR		

Appendix F.2 Electrical Load List

ELECTRICAL LOADLIST

REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	20NOV24	ISSUED FOR DESIGN	MS	AJ	AJ	

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SUMMARY OF DOCUMENT REVISIONS

Rev.	Date Revised	Section Revised	Revision Description

Tag Number	PID	Equipment Description	Voltage (AC/60Hz)	Non-motor Load (kW)	Motor Load (HP)	Starter (Type / NEMA Size)	Switch gear	MCC/ PDJB/UPS	Duty Cycle
A-0221-01		TEG Dehydration Package	460V/3P		75	FVNR/4	SWGR-C1	MCC-01	
A-0221-02		TEG Dehydration Package	460V/3P		75	FVNR/4	SWGR-C1	MCC-01	
A-0232-01		Electrolyzer Package EOL Loads	4.16kV/3P				SWGR-B1		
A-0232-02		Electrolyzer Package - Backup Power	480V/3P				SWGR-C1		
A-0232-03		Electrolyzer Package - Normal power	480V/3P				SWGR-C1		
A-0232-04		Electrolyzer Package - TCU	480V/3P				SWGR-C1		
A-1201	12-001	BFW Chemical Package - Oxygen Scavenger (By Vendor)	460V/3P		5	FVNR/0	SWGR-C2	MCC-02	
A-1202	12-001	BFW Chemical Package - Corrosion Inhibitor (By Vendor)	460V/3P		5	FVNR/0	SWGR-C2	MCC-03	
A-1203A	12-002	Natural Gas Boiler Package	4.16kV/3P		500	400A/150-5R/100	SWGR-B1		Continuous
A-1203B	12-002	Natural Gas Boiler Package	4.16kV/3P		500	400A/150-5R/100	SWGR-B2		Stand-by
A-1501-01	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-02	
A-1501-02	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-02	
A-1501-03	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-02	
A-1501-04	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-03	
A-1501-05	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-03	
A-1501-06	15-001	Cooling Tower Package (By Vendor)	460V/3P		100	FVNR/4	SWGR-C2	MCC-03	
A-1601-01	16-002	Nitrogen Generation Skid Compressor	4.16kV/3P		450	400A/150-5R/100	SWGR-B1		Continuous
A-1601-02	16-002	Nitrogen Generation Skid Compressor	4.16kV/3P		450	400A/150-5R/100	SWGR-B2		Continuous
A-1601-03	16-002	Nitrogen Generation Skid Fan	460V/3P		15	FVNR/2	SWGR-C2	MCC-02	Continuous
A-1601-03	16-002	Nitrogen Generation Skid Dryer	460V/3P		2	FVNR/0	SWGR-C2	MCC-02	
A-1601-04	16-002	Nitrogen Generation Skid Fan	460V/3P		15	FVNR/2	SWGR-C2	MCC-03	Continuous
A-1601-04	16-002	Nitrogen Generation Skid Trim Cooler	460V/3P		10	FVNR/1	SWGR-C2	MCC-03	
A-1601-05	16-002	Nitrogen Generation Skid Control Panel	460V/3P	4.8			SWGR-C2		
A-1601-06	16-002	Nitrogen Generation Skid Freeze Protection	460V/3P	2.4			SWGR-C2		
A-1601-07	16-002	Nitrogen Generation Skid Freeze Protection	460V/3P	2.4			SWGR-C2		
K-1601	16-001	Primary Air Compressor Package	480V/3P		150	FVNR/5	SWGR-C2	MCC-02	
K-1602	16-001	Secondary Air Compressor Package	480V/3P		150	FVNR/5	SWGR-C2	MCC-03	
K-1602	16-001	Secondary Air Compressor Package	480V/3P		150	FVNR/5	SWGR-C2	MCC-03	
		CO2 Capture Unit			41570				

Tag Number	PID	Equipment Description	Voltage (AC/60Hz)	Non-motor Load (kW)	Motor Load (HP)	Starter (Type / NEMA Size)	Switch gear	MCC/ PDJB/UPS	Duty Cycle
P-1101A	11-001	Service Water Pump Motor	460V/3P		40	FVNR/3	SWGR-C2	MCC-02	Continuous
P-1101B	11-001	Service Water Pump Motor	460V/3P		40	FVNR/3	SWGR-C2	MCC-03	Continuous
P-1102A	11-001	Fire Water Pump Motor	4.16kV/3P		500	400A/150-5R/100	SWGR-B1		Intermittent
P-1102B	11-001	Fire Water Pump Motor	4.16kV/3P		500	400A/150-5R/100	SWGR-B2		Intermittent
P-1103A	11-001	Fire Water Jockey Motor	460V/3P		50	FVNR/3	SWGR-C1	MCC-01	Continuous
P-1103B	11-001	Fire Water Jockey Motor	460V/3P		50	FVNR/3	SWGR-C1	MCC-01	Continuous
P-1104A	11-002	Demineralized Water Pump Motor	460V/3P		30	FVNR/3	SWGR-C2	MCC-02	Continuous
P-1104B	11-002	Demineralized Water Pump Motor	460V/3P		30	FVNR/3	SWGR-C2	MCC-03	Continuous
P-1105A	11-003	Potable Water Pump Motor	460V/3P		10	FVNR/1	SWGR-C2	MCC-02	Continuous
P-1105B	11-003	Potable Water Pump Motor	460V/3P		10	FVNR/1	SWGR-C2	MCC-03	Continuous
P-1201A	12-001	BFW Pump Motor	4.16kV/3P		300	400A/100-3R/50	SWGR-B1		Continuous
P-1201B	12-001	BFW Pump Motor	4.16kV/3P		300	400A/100-3R/50	SWGR-B2		Continuous
P-1203A	12-003	Condensate Pump Motor	460V/3P		100	FVNR/4	SWGR-C2	MCC-02	Continuous
P-1203B	12-003	Condensate Pump Motor	460V/3P		100	FVNR/4	SWGR-C2	MCC-03	Continuous
P-1401A	14-001	Solvent Transfer Pump Motor	460V/3P		5	FVNR/0	SWGR-C1	MCC-01	Intermittent
P-1401B	14-001	Solvent Transfer Pump Motor	460V/3P		5	FVNR/0	SWGR-C1	MCC-01	Intermittent
P-1402	14-001	Solvent Sump Pump Motor	460V/3P		10	FVNR/1	SWGR-C1	MCC-01	Intermittent
P-1403A	14-002	Caustic Transfer Pump Motor	460V/3P		1	FVNR/00	SWGR-C1	MCC-01	Continuous
P-1403B	14-002	Caustic Transfer Pump Motor	460V/3P		1	FVNR/00	SWGR-C1	MCC-01	Continuous
P-1404A	14-003	Sulfuric Acid Pump Motor	460V/3P		1	FVNR/00	SWGR-C1	MCC-01	Continuous
P-1404B	14-003	Sulfuric Acid Pump Motor	460V/3P		1	FVNR/00	SWGR-C1	MCC-01	Continuous
P-1501A	15-001	Cooling Water Pump	4.16kV/3P		1500	400A/230-12R/300	SWGR-B1		Continuous
P-1501B	15-001	Cooling Water Pump	4.16kV/3P		1500	400A/230-12R/300	SWGR-B2		Continuous
P-1501C	15-001	Cooling Water Pump	4.16kV/3P		1500	400A/230-12R/300	SWGR-B2		Stand-by
P-1801A	18-001	Waste Water Pump	460V/3P		30	FVNR/3	SWGR-C2	MCC-02	Continuous
P-1801B	18-001	Waste Water Pump	460V/3P		30	FVNR/3	SWGR-C2	MCC-03	Continuous
P-2002	20-001	KO Drum Aqueous Phase Pump Motor	460V/3P		5	FVNR/0	SWGR-C1	MCC-01	Intermittent
		Distribution Panel - Maintenance, Control, Lab	480V/3P				SWGR-C4		
		Warehouse Distribution Panel	480V/3P				SWGR-C4		
		AHU for ECR	480V/3P	33			SWGR-C1	MCC-01	Continuous
		TOTAL LOAD – 87927 kVA							

Appendix G G Constructability

Appendix G.1 Constructability Report

CONSTRUCTABILITY REPORT

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A	5/29/24	IFI – ISSUE FOR INFORMATION	JP/AV	NW	JJH	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	5/29/24	ALL	IFI – Issued for Information

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1. CONSTRUCTABILITY VIP WORKSHOP SUMMARY

1.1 INTRODUCTION

RTI International, with CEMEX Inc., SLB, and KBR Inc., are participating in a joint effort to perform a Front-End Engineering Design (FEED) study for carbon dioxide (CO_2) capture from cement flue gas. The FEED study will evaluate the integration of a CO_2 capture system at the Balcones Cement Plant in New Braunfels, Texas. This document establishes the Constructability workshop basis for the NAS FEED study for the construction and operation of the proposed CO_2 capture unit.

KBR selected the Value Improving Practice (VIP) of Constructability as applied to major projects, and promulgated by the Construction Industry Institute, to conduct a project Constructability Review. Pinnacle Results, LLC was hired to facilitate this review.

1.2 OBJECTIVES

The Constructability VIP workshop, which was held on May 9-10, 2024 at the CEMEX Office in New Braunfels, Texas, included the assessment, development, and implementation of value improving items, and potential future design and execution decisions during the following stage of the project. The objectives of the Constructability VIP exercises are generally to:

- Provide insights that could provide a logical and systematic manner for integrating potential construction methods into the project as it moves forward.
- Matching the design intentions with good construction practices during the FEED study.
- Understand major construction methods suitable for this project.
- Identify various project site construction layout options.
- Identify construction methods that could improve the construction schedule.
- Examine alternative logistical opportunities available at the proposed site.
- Identify sources of materials and equipment that could be used for construction.

The following project specific information was available to the participants prior to the workshop to familiarize themselves with the project scope:

- Technical Basis of Design
- Plot Plan
- Equipment Lists
- Process Flow Diagrams

1.3 PARTICIPANTS

The following participants were in attendance either in person, or remotely via conference call. Workshop participants were selected based on their respective knowledge areas, potential to lead new and innovative thinking, and their respective project roles.

Full name	Company / Position	eMail
John Hughes (Remote)	KBR Sr. Project Manager	John.Hughes@kbr.com
David Barbee	KBR Lead Process Engineer	David.Barbee@kbr.com
John Pustay	KBR Mechanical Department Manager	John.Pustay@kbr.com
Abel Vera (day 1, Remote day 2)	KBR Principal Project Manager	abel.vera@kbr.com
~~Thomas Jones (Remote)~~	~~KBR Sr. Manager, Operations~~	~~thomas.jones@kbr.com~~
Nikki Wagner (Remote)	KBR Sr. Mechanical Engineer	Nikki.wagner@kbr.com
Vijay Gupta (day 1)	RTI Research Chemical Engineer	vgupta@rti.org
Paul Mobley (Remote)	RTI Research Chemical Engineer	pdmobley@rti.org
Abigail Mshelbwala	SLB Project Manager	amshelbwala@slb.com
Karuna Ganti	SLB Project Engineering Manager	kganti2@slb.com
Shailesh Mistry	SLB Principal Engineer	SMistry2@cameron.slb.com
Scott Murray	SLB Project Manager	smurray03@slb.com
~~Jason Doyle~~	~~SLB~~	~~jdoyle6@slb.com~~
Edmo Gutierrez (day 1 part-time)	Cemex CO2 Technologies and Digital Projects	edmo.gutierrezlz@cemex.com
Kevin Happ	Cemex Project Manager Sr	kevin.happ@cemex.com
Elizabeth Torres	Cemex CCUS Project Manager	elizabeth.torrese@cemex.com
Christian Valverde	Cemex Balcones Sr. Project Manager	christianvalverde.garza@cemex.com
Jonthan Hill	Cemex Balcones Project Manager	jonathand.hill@cemex.com
Lucia Renau	Cemex CCUS Project Developer	lucia.renaus@cemex.com
Kevin Leodinh	DOE Demonstrations Project Officer	kevin.leodinh@hq.doe.gov
John-timothy Anyanwu	DOE	john-timothy.anyanwu@hq.doe.gov
Fatma Sahin	Cemex CCUS Innovation Advisor	fatma.sahinf@cemex.com

Jak Tanthana (Remote 1st day)	RTI Project Officer	jtanthana@rti.org
James McCuish	Pinnacle Results LLC	jmccuish@msn.com
Charles Jennings	Pinnacle Results LLC	cwjennings@earthlink.net

1.4 FOCUS AREAS

The Constructability VIP Workshop focused on the following topics with a priority on Construction Access, Laydown Areas, and Construction Work Sequencing.

• **Construction Access**	• Architectural & Equipment
• **Laydown Areas**	• Piping
• **Construction Work Sequencing**	• Electrical
• General Design	• Instrumentation
• General Construction	• Steam Tracing & Paint
• Site Improvements	• Insulation
• Underground Utilities	• Structural Steel
• Civil	• CEMEX Constructability Key Activities
• Fireproofing	

1.5 FACILITATOR INSIGHTS

As the Project progresses after FEED, there is an opportunity to improve the Balcones Project Constructability understanding and potential design activities by periodically reviewing the Constructability Value Improving items captured during the workshop.

It is likely that future decisions about related business strategies and operator issues will clarify which Constructability items should be implemented.

Future schedule constraints may need to be balanced against the potential to modify the design-for-constructability and implement some selected Constructability items.

2. CONSTRUCTABILITY REVIEW SUMMARY

2.1 GENERAL

During the constructability review, several design/construction challenges were considered with their impacts to construction access, laydown areas, and construction sequencing. These design challenges were grouped into two categories: those due to site conditions or requirements, and those due to equipment size, as summarized below. Additional access, laydown, and sequencing considerations are further discussed in Sections 2.2, 2.3, and 2.4.

The proposed location for the CO2 capture plant is on a greenfield plot, South of the New Braunfels facility, with a plot plan of about 15 acres. Additional Cemex property is available to the South and West of the plot plan for potential laydown areas.

There are currently plans for Cemex to perform a Geotechnical survey of the plot area. It is also recommended that an exploratory excavation survey and soil testing for hazardous materials be performed based on greenfield unknowns.

2.1.1 DESIGN CHALLENGES DUE TO SITE CONDITIONS / REQUIREMENTS

2.1.1.1 Cooling Water Constraints

Due to limited make-up water availability at the New Braunfels facility, cooling water studies were conducted to determine the appropriate utility configuration for process cooling. The cooling system optimization study resulted in utilizing air coolers for a total of 5 services, with 146 bays of cooling, with an estimated total plot area of approximately 4 acres of the total 15-acre facility plot plan (not including retention pond or laydown areas).

- Potential Constructability Impacts: **ACCESS, LAYDOWN and SEQUENCING**

2.1.1.2 High Water Table Level

CEMEX advised during the constructability review that the proposed plot area has a high-water table of 7 feet. The project team agreed to minimize underground services to the maximum extent possible and only consider items such as equipment drains and grey water services. A high-water table could also potentially require an engineered drainage system, such as a well point system. This system may require a collection pond.

- Potential Constructability Impacts: **LAYDOWN and SEQUENCING**

2.1.1.3 Carbon Capture Plant Located Off-Site

Due to the limited available area at the existing Cemex plant for the carbon capture plant, the CC plant is remotely sited across WALD Road. This requires routing a large 10 ft x 10 ft cross sectional flue gas duct approximately 1,500 feet, across the road, to the DCC/absorber columns.

- Potential Constructability Impacts: **LAYDOWN and SEQUENCING**

2.1.1.4 CEMENT Facility is Governed by MSHA not OSHA

The CEMEX New Braunfels site falls under the jurisdiction of the Mine Safety and Health Administration (MSHA). The Project Team acknowledged there could be considerable differences between MSHA and OSHA regulations which may impact design, construction, commissioning, and eventual operations of the CC plant. MSHA or OSHA jurisdiction will need to be investigated and established to ensure design and construction safety implications are clearly understood by the detail design and construction stakeholders.

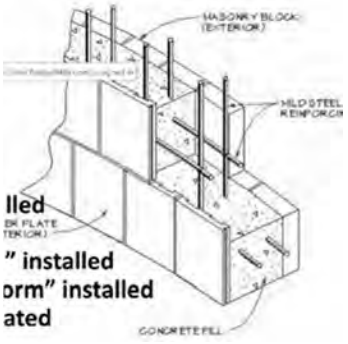
A high cement dust content exists in the plant and the adjacent quarries. Another safety consideration, whether MSHA or OSHA applies, is caution for proper protective personnel equipment due to the potential for air contaminants in the proposed work areas. An adverse effect on productivity, cost and schedule may be influenced by lack of training and PPE specifications.

- Potential Constructability Impacts: **SAFETY**

2.1.2 DESIGN CHALLENGES DUE TO EQUIPMENT SIZE

2.1.2.1 Absorber Column

The absorber column selected may be based upon construction technology developed over many years for FGD vessels. The concept is shown below.

o 

This field erection strategy including laydown and sequencing would require careful planning and execution as the absorber column is closely located with other critical processing equipment. The field fabrication of the Absorber Column must be supported by a detailed construction schedule. The erection strategy must consider the long-term impact on the rest of the project. The bidders shall provide the amount of area it requires at the foundation site for how long and the type of heavy equipment they plan to use.

- Potential Constructability Impacts: **LAYDOWN and SEQUENCING**

2.1.2.2 Packaged Boilers

Steam demand can be met with (2) 50% packaged boiler, each nominally rated at 300,000 Lbs/hr. This size is at the upper end of the boiler supplier's packaged boiler design capacity, each 25.5 ft H x 22.3 W x 52 ft L. Each boiler weighs approximately 150 tons. In the event the logistics study finds this size boiler is not truckable, smaller size boilers are available, in a (3) x 33% configuration. Cost impacts based upon previous studies are close between these two boiler configurations.

- Potential Constructability Impacts: **ACCESS**

2.1.2.3 Interchanger HX Quantity and Size

Due to the heat exchange required between the absorber column and regenerator, (16) plate and frame HXs are required. The HXs banks are in a section of the facility that facilitates construction access and laydown. Stacking of the plate and frame HXs was considered by the project team but determined to present concerns with maintenance access during the cleaning of the HX plates and subsequent draining of wastes and cleaning solvents in the structure.

- Potential Constructability Impacts: **ACCESS, LAYDOWN and SEQUENCING**

2.1.2.4 Stripper Column

The Stripper column due to its diameter is being evaluated for both shop fabrication and field erection execution strategy. Discussions with vessel fabricators in Texas suggest some shops can shop fab 26 ft. and preliminary feedback also suggests truck transport is feasible. A final decision on stripper column fabrication strategy will need to be made once logistics study is conducted.

- Potential Constructability Impacts: **ACCESS, LAYDOWN and SEQUENCING**

2.2 CONSTRUCTION ACCESS

2.2.1 LOGISTICS STUDY

Carbon Capture necessitates deployment of large equipment along with large pre-assembled units to drive a cost-effective solution. The logistics study will eventually be needed to determine the limitations for truckable modules and pre-assembles units (PAUs). There is no waterway access for barge shipment of units. Logistics study should be from point of origin to site (Logistics study establishes shipping envelope and also determines best method for shipment of heavy haul items).

Based upon discussions with some local fabrication shops in Texas, the equipment selected (as described above in the GENERAL section) should be truckable to the New Braunfels site. However, this needs to be validated by the logistics study.

Cement plant is surrounded by residential property, large cement quarries, rail lines and heavy traveled truck route from quarries to cement plant. Cemex has indicated there is truck congestion outside of the plant, particularly in the early mornings, which could impact site access.

2.2.2 ELECTRICAL AND COMMUNICATION OVERHEAD LINES

Overhead high voltage 138kv power lines, bisecting the plant East-West, must be managed. Preliminary discussions with the local utility suggest raising the HV power lines and power and communication lines on Wald Road can be handled to accommodate transportation of equipment to site.

2.2.3 ACCESS TO POTENTIAL LAYDOWN AREA ON EXISTING CEMEX PLANT

The East area of the CEMEX property is a potential laydown area, however, access to the area is sometimes blocked due to loading and staging of rail cars. Develop strategic transport plans for trucks to enter site during off-peak (if possible) and consider all alternate routes.

2.2.4 SOUTH PLOT ACCESS

The plot plan area South of Wald Road can get saturated and can cause vehicles / trucks to get stuck. Consider all routes and have a fallback plan to remove vehicles from mud if necessary.

2.2.5 CONSIDER RAIL FOR SHIPMENT OF LARGER EQUIPMENT

CEMEX New Braunfels site has existing rail for feed and product loadout. CEMEX mentioned this rail may have limitations regarding size and especially width of cargo. This aspect of rail limitations should be addressed in the logistics study to confirm load/sizing limitations, if any.

2.3 LAYDOWN AREAS

2.3.1 LAYDOWN AREA: PLOT PLAN SITE CONSTRAINTS ON OPTIMUM LAYDOWN AREA

The plot area as currently envisioned does not provide what may be considered the “ideal” laydown space (relative to a “factor” of total plot area). Considering the large area of the air coolers and utilizing some of the corners of adjacent facility designated space; the strategy of ‘just-in-time’ deliveries was considered one key approach to maintain maximum laydown areas during peak construction activities.

The following equipment was identified as candidates for ‘just-in-time’ delivery.

- Air coolers
- Flue Gas duct sections

- Tray and packing installation and storage

2.3.2 TEMPORARY CONSTRUCTION FACILITIES

Laydown areas shall also consider temporary construction facilities, which could be up to 2.0 times the total build area, depending on the project. This is to allow for the following temporary facilities need to support construction:

- CM Office, Supervisor's offices, Safety facility, Quality office, Permit office, Warehouse (including Warehousing of temperature control sensitive equipment), Welfare tents (Break tents), Area for stockpiling re-usable and non-reusable soil

2.4 SEQUENCING OF CONSTRUCTION

2.4.1 LIFTING PLANS

The development of lifting plans/procedures should be completed early. Due to the constraints mentioned above, this will be critical to orchestrate crane usage, costs, and safety.

2.4.2 SEQUENCING OF EQUIPMENT

Development of proper sequencing of key equipment deliveries and installation such as Absorber Column, DCC, Boilers, Air coolers.

The optimum path of construction and schedule will need to reflect a staging of key erection and lift and setting plans for the critical pieces of equipment identified in Section 2.1.2

Engage an EPC for final path of construction and develop appropriate Advanced Work Packages (AWP). The following can be packaged by the project EP team:

EWP – Engineering work package

PWP – Procurement work package

CWP – Construction work package

IWP – Installation work package (The IWP process is typically a function of the construction execution contractor)

2.4.3 TIE-IN SEQUENCING OF CEMENT PYRO PROCESS

Develop the sequence for shutdown / cooldown of the cement pyro process system for tie-in of CC Plant equipment. Tie-ins must be planned during schedule outages. Ensure PHA review addresses tie-in logic and cut over in design.

Consider a complete field survey of each tie-in point, irrespective of discipline. Then provide a tie-in package for each tie-in which can include a location drawing, P&ID, data sheets, photographs and description and purpose of the tie-in.

2.4.4 TIE-IN SEQUENCING OF ELECTRIC POWER SOURCES

Investigate electric power sources and eventual tie-ins. In support of commissioning activities, identify power sources and early tie-in strategy if needed. It is recommended to consider whether alternative power sources are needed.

2.4.5 CONSTRUCTION SEQUENCING PATH

The path should set up at a minimum the following objectives:

- A construction execution schedule
- High level Construction Organization
- HSSE Strategy
- QA Strategy
- QC Strategy
- Path of construction (Plot plan, CWA)
- HHR and HHL Plans
- TCF Layout and work sequence
- HSSE
- Logistics (project freight)
- Logistics strategy (Local to plant traffic/workers)
- HHL/HHL Strategy

3. CONSTRUCTABILITY LOG

The Constructability Workshop developed a significant list of items as summarized in Table 3-1 – Constructability Table 3-1. The Construction Access, Laydown Areas, and Construction Work Sequencing tabs of the Constructability Log were extracted and are shown on the following pages. The complete Constructability VIP Log, DE-FE0032220-KBR-00-CM-G-CP-002, is provided as a separate document.

TABLE 3-1 – CONSTRUCTABILITY LOG FOCUS AREAS SUMMARY

KBR NAS FEED Project

Constructability Summary

	c	f	g	h	i	j	k
		Evaluation Criteria Selected					
Focus Areas	Potentially Applicable	HSSE	Cost	Schedule	Integrity	Operability	Accept Item?
General Design	75	46	58	52	10	26	73
General Construction	67	39	59	65	3	1	66
Site Improvements	18	15	14	15	1	2	18
Underground Utilities	37	10	27	29	6	8	34
Civil	95	7	85	90	5	4	95
Fireproofing	8	8	0	6	4	6	7
Architectural & Equipment	87	61	60	77	17	22	87
Piping	160	71	101	104	68	38	157
Electrical	87	37	47	71	25	19	87
Instrumentation	47	7	45	46	2	0	46
Steam Tracing & Paint	19	2	18	18	1	9	19
Insulation	16	8	12	13	1	2	14
Structural Steel	73	19	68	69	0	0	72
Construction Access	8	1	8	8	0	0	8
Lay-Down Areas	8	8	8	8	0	0	8
Construction Work Sequencing	7	0	7	7	0	1	7
CEMEX	28	3	26	26	0	4	28
Extra Worksheet	0	0	0	0	0	0	0
	840	342	643	704	143	142	826

Project Name: KBR NAS FEED Project

Constructability **Construction Access**

Ref. #	Potentially Applicable Y=Yes N=No	Description of Constructability Idea/Item	Evaluation Criteria : Use þ or ý					Accept Item? Y=Yes N=No	Workshop / Specific Notes / Concerns	Non-Specific Guidelines for Consideration
			HSSE	Cost	Schedule	Integrity	Operability			
CA1	Yes	Ensure that site road access is wide enough for large heavy vehicle transport vehicles	☑	☑	☑			Yes	Ensure permits are understood and in place establish geometries that allow turning radius, other. Need logistics study to evaluate bridges, roads from receiving points to the site	
CA2	Yes	manage logistics of Stripper column is 26' diameter and 60' long- probably field erected		☑	☑			Yes	need logistic study to transport to site - consider all routes	
CA3	Yes	manage logistics of Package boilers will be large- logistics study will be required		☑	☑			Yes	need logistic study to transport to site - consider all routes	
CA4	Yes	Manage interface with Overhead power lines on south side of Wald rd		☑	☑			Yes	need logistic study to transport to site - consider all routes	
CA5	Yes	Manage interface with Overhead high voltage 138kv power lines bisecting the plant east to west		☑	☑			Yes	need logistic study to transport to site - consider all routes	
CA6	Yes	Laydown area on east end of property has frequent road blockage due to loading and staging of railcars for Cemex product shipments		☑	☑			Yes	need logistic study to transport to site - consider all routes	
CA7	Yes	Area south of Wald rd can get saturated from precipitation and cause vehicles/ truck to get stuck in mud		☑	☑			Yes	need logistic study to transport to site - consider all routes have fall back plan to remove vehicles from mud	
CA8	Yes	Plan for a heavy haul road with-in site		☑	☑			Yes	explore various location near or on site	

Project Name:	**KBR NAS FEED Project**										
Constructability	**Lay-Down Area**										
Ref. #	**Potentially Applicable** Y=Yes N=No	**Description of Constructability Idea/Item**	**Evaluation Criteria : Use þ or ý**					**Accept Item?** Y=Yes N=No	**Workshop / Specific Notes / Concerns**	**Non-Specific Guidelines for Consideration**
			HSSE	Cost	Schedule	Integrity	Operability			
LDA1	**Yes**	**Allocate space to place tank materials/tools, etc. for AP tanks**	☑	☑	☑			**Yes**	need logistics study. Anticipate skid mounted	
LDA2	**Yes**	Laydown needed for API-650 field erected tanks	☑	☑	☑			**Yes**		
LDA3	**Yes**	Laydown needed for large quantity of air cooled HXs (insert #) See comment on sequencing tab	☑	☑	☑			**Yes**		
LDA4	**Yes**	Laydown needed for package boilers	☑	☑	☑			**Yes**		
LDA5	**Yes**	Laydown and crane needed for concrete erection of absorber column field fabrication on site	☑	☑	☑			**Yes**		
LDA6	**Yes**	Laydown and staging for flue gas duct (over 1500 ft)	☑	☑	☑			**Yes**	anticipate significant area will be needed. Preservation will be required. Could stagger deliverable from vendor	
LDA7	**Yes**	Tray/packing installation and storage	☑	☑	☑			**Yes**		
LDA8	**Yes**	Laydown/Staging area for cranes and trailers	☑	☑	☑			**Yes**		

Project Name: **KBR NAS FEED Project**

Constructability **Construction Work Sequencing**

Ref. #	Potentially Applicable Y=Yes N=No	Description of Constructability Idea/Item	Evaluation Criteria : Use þ or ý					Accept Item? Y=Yes N=No	Workshop / Specific Notes / Concerns	Non-Specific Guidelines for Consideration
			HSSE	Cost	Schedule	Integrity	Operability			
CWS1	**Yes**	Development of Lifting Plan/Procedure to be completed early and include thresholds for weights, and who is signing.		☑	☑			**Yes**	Abel - this is a good one	
CWS2	**Yes**	Develop sequencing for flue gas duct, boilers, DCC, and absorber		☑	☑			**Yes**		
CWS3	**Yes**	Develop sequencing for shut down/ cooldown of cement pyro process system for tie in of CCUS equipment		☑	☑			**Yes**	Consider tie-ins during scheduled kiln outages	
CWS4	**Yes**	determine access for trucks with bigger loads		☑	☑			**Yes**	investigate real time deliveries to manage lay down area usage consider contractor to provide AWP protocols bring potential contractor(s) early to capture best sequence processes deliver equipment directly from truck to final location / foundation establish contingency plan for construction interruptions or weather issues	
CWS5	**Yes**	Establish "real time" delivery philosophy using EPC SMEs		☑	☑			**Yes**	reduce lay down area requirements improve logistics efficiency by having better schedules	
CWS6	**Yes**	establish test work sequences for NDT activities. Limit welder waiting time due to inspections		☑	☑			**Yes**		
CWS7	**Yes**	develop a path of construction to confer with EPC that establishes sequences and develop work packages.		☑	☑		☑	**Yes**	decide how to break down work activities - WBS, other determine at what point to engage EPC resources. Could consider engaging during FEED or after the design is relative understood earlier EPC engagement will better align bids, work packages. Technology projects may delay EPC input until the design is framed	

Project Name: KBR NAS FEED Project

Constructability **Construction Work Sequencing**

Ref. #	Potentially Applicable Y=Yes N=No	Description of Constructability Idea/Item	Evaluation Criteria : Use þ or ý					Accept Item? Y=Yes N=No	Workshop / Specific Notes / Concerns	Non-Specific Guidelines for Consideration
			HSSE	Cost	Schedule	Integrity	Operability			
CWS8		Determine permitting required and verify compliance. Has a permit plan with sequences.							list all permits required to perform work with relative sequences example -site permit, bridge permit	
CWS9		investigate alternative electric power sources							could some power be delivered from existing pole	

Appendix H Estimated Project Schedule

Appendix H.1 EPC Schedule

Level 2 EPC Schedule

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	12-Dec-24	IFI – Issued for Information	EN	SRM	JH	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION

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   1.2 **Site Location Plan** 4
   1.3 **Purpose of this document** 5
   1.4 units 6
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1. INTRODUCTION

1.1 PROJECT QUICK SUMMARY

Research Triangle Institute International is developing a non-aqueous Solvent (NAS) CO2 capture process as an advanced, next generation post combustion capture technology for CO2 removal from power generation and industrial flue gas streams. The technology for this project is owned by Research Triangle Institute International.

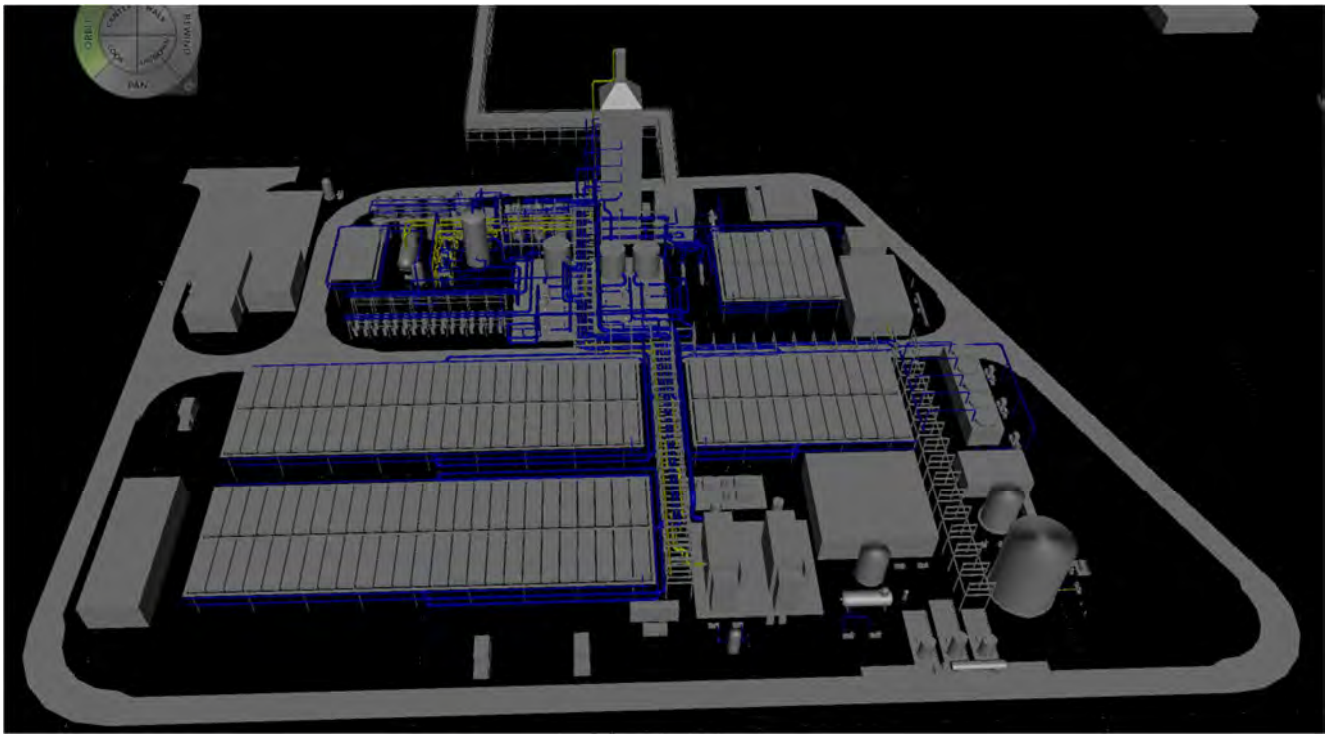
The CO2 capture plant is designed to remove at least 95% of CO2 from the flue-gas from the Balcones cement plant kilns K1 and K2, and the associated natural gas boiler for steam generation. The captured CO2 has a purity of > 95% CO2, and is dried, polished to meet pipeline specifications, and compressed to be made ready for transportation. The capture plant consists of an integrated direct contact cooler (DCC) and SO2 polisher, a flue gas blower, an absorption column with intercoolers, a regeneration column, associated pumps, storage and receiver vessels, and CO2 compression, dehydration, and polishing train.

1.2 SITE LOCATION PLAN

The proposed site is at CEMEX Balcones cement plant in New Braunfels, TX.

Latitude:	North 29.709°
Longitude:	West 98.046°
Plant Area:	South of Wald Rd
Elevation Above Sea Level:	645 ft (196.6 meters)
Total Plot Area:	Approximately 15 acres
Boundary Description:	See plot below highlighted in Red

3D Model Snip



1.3 PURPOSE OF THIS DOCUMENT

As a part of FEED, KBR has developed the Level 2 EPC schedule, and the objective of this document is to narrate the basis and assumptions considered while developing the Schedule. It also documents major Project strategy and decisions that will act as a guideline for project execution to meet the project objectives.

This Basis of Schedule broadly covers the following:

- Key Durations
- Key Milestones
- Basis & Assumptions
- Detailed Design/ Engineering
- Procurement
- Construction

This schedule is developed by KBR to enable the key milestones for the Engineering, Procurement and Construction functions to be established. The project scope is not exhaustively represented in the schedule). The level 2 EPC schedule is developed with the best of available details, feed deliverables and discussion with subject matter experts. Upon contract award a more detailed Level 3 EPC schedule must be developed.

1.4 UNITS

The various units present in this project are

- Unit 01- CO2 Capture
- Unit 02- CO2 Compression, Dehydration, and Polishing
- Utility Systems

Detailed Description of the units

Unit 01 - CO2 CAPTURE

This unit contains the Direct Contact Cooler, the Absorber with integrated water wash and acid wash sections, the Lean/Rich Solvent Exchange, and the Regenerator.

UNIT 02 – CO2 COMPRESSION, DEHYDRATION, AND POLISHING

The CO2 product gas from the Regenerator is sent to the CO2 compression unit. The CO2 stream is compressed and conditioned to meet pipeline specifications for transport.

UNIT 03 – UTILITY SYSTEMS

Unit 11 – Raw, Potable, and Demineralized Water Systems
Unit 12 – Boiler and Steam Systems -
Unit 14 – Solvent and Chemical Storage
Unit 15 – Cooling Water System
Unit 16 – Air/Nitrogen Systems -
Unit 18 – Wastewater Treatment Plant -
Unit 20 – Stack -
Unit 22 – Utility Header -

2. CALENDARS

- The table below lists the number of workdays per week for each Phase of the Project.

Notes 1: For the 5 Day work week

Phase	Workdays
Engineering – Production Design	5 Day Work Week -8 Hours per Day
Procurement Pre-Award	5 Day Work Week -8 Hours per Day
Procurement – Manufacturing & Shipment	7 Day Work Week -8 Hours per Day
Construction & Commissioning	5 Day Work Week -10 Hours per Day

Few Points to be noted

- The start of the project is considered as 2nd March 2026. It has been comminated that the production design will likely start around end of Q1 of 2026. The starting activity is the contract signing and Kickoff meeting.
- It is assumed that the project will commence with the core team after 2 weeks or 10 working days from the contract signing.
- The Duration of the schedule is around 36 months. For production design the duration of the schedule is assumed to be around 24 months and 24 months for the construction duration with 16 months overlap.
- The construction starts 8 months after the commencement of the Production works.
- The duration for commissioning is assumed to be three months. This includes the pre-commissioning works including but not limited to testing, trail run, no load test, load test, continuity check and wet run of the project. It also includes Electrical Substation Commissioning.

3. WBS STRUCTURE

Level 1	Level 2
Project Milestones	Overall Milestones
	Engineering Milestones
	Procurement Milestones
	Construction Milestones
Engineering	Project Engineering
	Process
	Mechanical
	Piping
	Civil
	Electrical
	Instrumentation
Procurement	Mechanical Equipment Ordering
	Electrical Equipment Ordering
	Instrumentation Equipment Ordering
	Piping Ordering
	Post award and Manufacturing
Construction	Early Works
	Underground works
	Above ground works
	Flue Gas Run
	Commissioning and startup

4. ACTIVITY ID NOMENCLATURE

This EPC schedule uses smart activity IDs to enable easy understanding and tracking of the activities.

The table below provides a simple example of the activity ID nomenclature.

Title	Project Number	EPC Phase	Discipline	Activity ID
Example	N429	E	PR	1000

Project Number

N429 Project Code

EPC Phase

E Engineering
P Procurement
C Construction
R Erection
M Commissioning

Discipline

ML Milestone
PR Process
Pi Piping
IC Instrument
EL Electrical
ME Mechanical
CV Civil & Structural & Architecture
PM Project Management
ST Structural Engineering
ER Erection
GE General
PRE Pre-Award
PRO Post Award
CM Commissioning

5. KEY MILESTONES

5.1 OVERALL PROJECT MILESTONES

Overall Project	Milestone Type	Start Date	Finish Date
Contract Signing and Kick off meeting	Start Milestone	02-Mar-26	
Project Complete	Finish Milestone		21-Feb-29

5.2 ENGINEERING MILESTONES

The engineering key milestones are considered as follows.

Engineering	Milestone Type	Start Date	Finish Date
HAZOP Review	Finish Milestone		30-Oct-26
Complete 30% Model Review	Finish Milestone		27-Nov-26
Complete early IFC Packages	Finish Milestone		11-May-27
Complete 60% Model Review	Finish Milestone		06-Jul-27
Complete 90% Model Review	Finish Milestone		16-Nov-27
Issue all IFC Drawings and Documents	Finish Milestone		18-Jan-28
Engineering Complete	Finish Milestone		29-Feb-28

PROCUREMENT MILESTONES

The procurement key milestones are considered as follows.

Procurement	WBS Summary	03-Aug-26	29-Jul-28
Place PO for Major Equipment	Finish Milestone		9-Mar-27
Last Delivery of All Bulks)	Finish Milestone		22-Jul-28
Last Delivery of Mechanical Items	Finish Milestone		29-Jul-28

5.3 CONSTRUCTION MILESTONES

The construction key milestones are considered as follows.

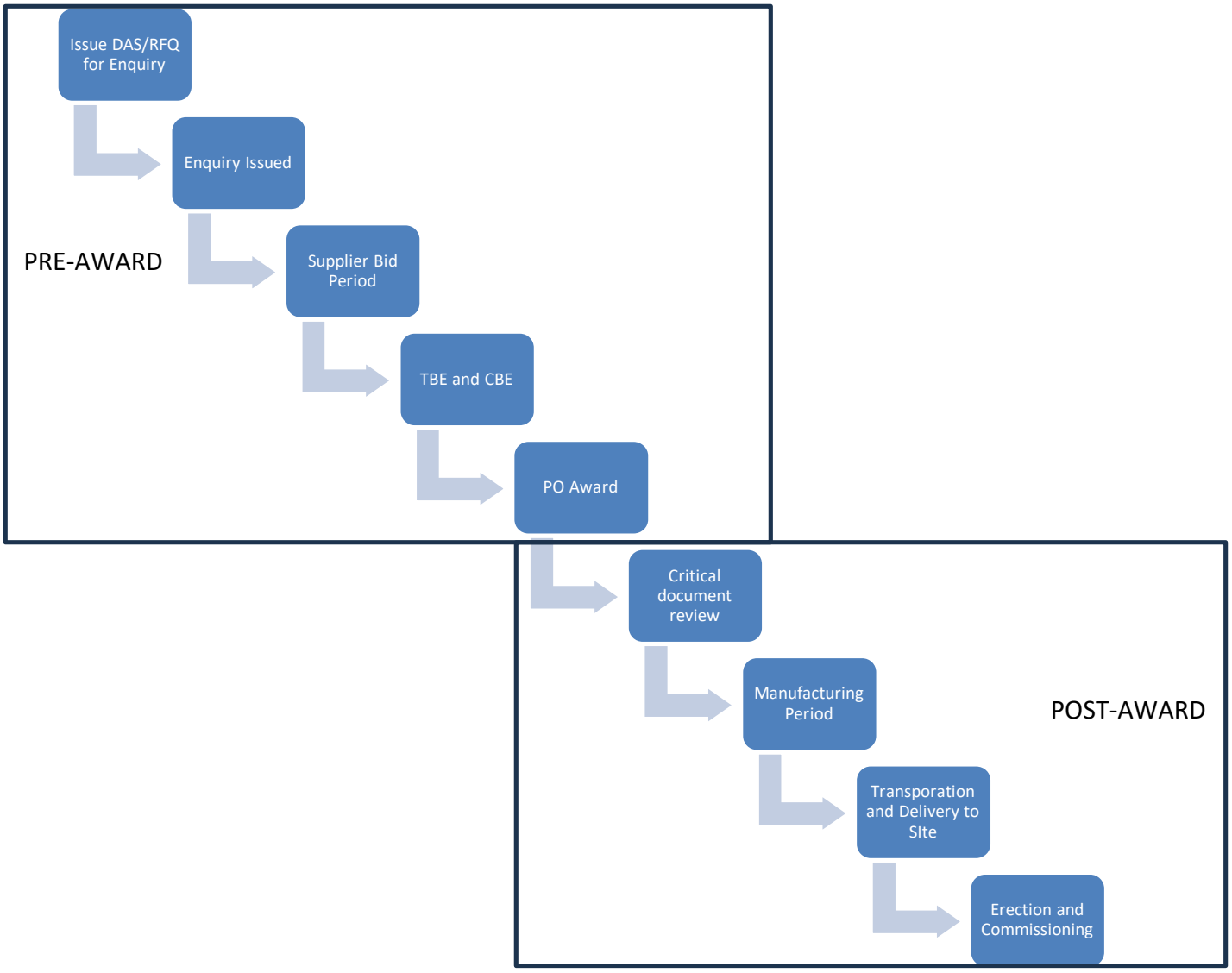
Construction	WBS Summary	12-Oct-26	21-Feb-29
Commence Site Preparation Works	Start Milestone	12-Oct-26	
Underground Works complete	Finish Milestone		22-Sep-27
First Concrete Pouring	Start Milestone	25-Oct-27	
Primary Structural Steel Erection Complete	Finish Milestone		17-Jul-28
Major Equipment Erection Complete	Finish Milestone		23-Aug-28
Substation Erection	Finish Milestone		30-Nov-28
Mechanically Complete	Finish Milestone		08-Jan-29
Commissioning Complete and Project ready for startup	Finish Milestone		21-Feb-29

6. ENGINEERING ASSUMPTIONS

- We have 30%, 60% and 90% model development in this project and all are considered critical.
- These Model reviews are assumed as a 5-day client and contractor combined reviews.
- All Piping, Civil, Electrical, and Instrumentation teams will be available for this review. The Model reviews are considered as key milestone dates for the project.
- The MTO extraction will be based out of the model development stage wise. The preliminary will be around the completion of the 30% model development and the final MTO will be based out of the 90% model completion.
- The preliminary and final MTO have been listed separately in the schedule for Civil, Piping, Electrical and instrumentation along with their procurement cycles.
- Please note that HAZOP is considered as a 5-day workshop and the same will start once the P&IDs are issued for HAZOP. Once HAZOP is completed, the P&IDs will be sent for Design after incorporating the comments.
- Critical vendor data is equipment details like GA, Dimensions and important data which are required for the 60% model development and engineering progress
- Once the Critical vendor document is approved, the vendor can start commencing his equipment manufacturing

7. PROCUREMENT ASSUMPTIONS

The Procurement life cycle is considered as follows



The following Assumptions are made for the procurement timeline

- Produce requisition/ Datasheet for Enquiry – 4 Weeks
- Issue Enquiry 1 Week
- Supplier Bid Period –6 Weeks
- Technical and Commercial Bid Evaluation – 8 Weeks
- PO Award –2 Weeks
- Critical Vendor Data Submission and Review -12 Weeks (max)
- Supplier Manufacturing Period – Please refer the table below
- Transportation to site –60 days

7.1.1 LEAD TIMES

7.1.1.1 MECHANICAL

Equipment	Manufacturing Duration (Months)
Absorber	5
Direct Contact Cooler	5
Pumps	12
Compressor	16
Air Cooler *	8
Site-Fabricated Tanks**	5
Prefabricated Tanks***	8
Heat Exchangers	14
Activated Carbon Bed	14
Regenerator Column	10
Electrolyzer	13
TEG Unit	13
Filters	9
Demin Water Package	11
NG Boiler	14
CW Package	5
Waste Water Treatment	12
N2 Generation Skid	12

Notes:

- *For the Air Coller Package, a maximum of 104 Bays is considered in this project. They will be shipped in several batches. The first supply of the air coolers is assumed to be 8 months after which there will be several batches with a Gap of 4 weeks each.
- **Tanks T-0121, T-0122, T-0141 and T-1102 are site Fabricated, and the plates will be supplied in 5 months and 5 months is considered for site Erection.
- ***Tanks - T-1103, T-1401, T-1402, T-1403 are prefabricated tanks
- All the above lead time are based from the market survey data

7.1.1.2 ELECTRICAL

Equipment	Manufacturing Duration (Months)
Transformer	10
Switchgear	10
UPS	8

7.1.1.3 INSTRUMENTATION

Equipment	Manufacturing Duration (Months)
Control Valve	10
Flowmeter	9
Transmitters	10
Gauge	8
Analyzer	12
DCS	11

- The Electrical and Instrumentation items lead time are based on historical data

8. CONSTRUCTION ASSUMPTIONS

8.1.1 INTRODUCTION

Construction is a crucial stage in project execution and typically follows the design phase.

8.1.2 CONSTRUCTION WBS

The construction part of the schedule is split into 6 as listed as follows

- Early Works
- Underground Works
- Above Ground Works
- Flue Gas Run
- Commissioning and Startup

8.1.3 EARLY WORKS

The construction part of the schedule is considered to start 8 months after the award of contract. The first activities in construction are considered the Early works, The Early works consists of the site clearance if required, contractor mobilization. After this temporary site facilities are set up. During this time period the engineering should be mature enough to provide the required details to site for start of any construction related activities. We have early IFC drawings after the 30% model review.

Once the site is cleared, we have the site preparation activities. Site Survey works, Expansive Soil Removal, Filling and Compaction are considered in this activity.

8.1.4 UNDERGROUND WORKS

The underground work is considered any work that needs to be done below the site level. It includes the following but not limited to excavation, installation of underground tanks, fire water ring mains, collection heads and backfilling followed by compaction.

8.1.5 ABOVE GROUND WORKS

1. The above ground works consists of all the foundation works, steel works, main equipment erection, pipe rack erection, cable tray, cable pulling, substation works, instrument erection, painting and road works
   Foundation / Civil Works
2. Steel works
3. Erection
4. Piping works
5. Electrical & Instrumentation Works
6. Painting, Installation & Finishing works

8.1.5.1 FOUNDATION AND CIVIL WORKS

The Pipe rack foundation consists of foundation required for the pipe racks inside the plant. Then the equipment foundation works is started. During the equipment. The pre-engineered building foundation works are done in parallel to the equipment foundation works. The paving work and road work are also considered under this section. The Roads and paving work run in parallel to the commissioning.

8.1.5.2 STEEL WORKS

The steel works are split into primary steel structure and secondary steel structure. The primary steel structure defined all the structural works required for the main equipment foundation and the secondary steel refers to all the other steel works.

8.1.5.3 ERECTION

Equipment Erection

Upon arrival of the equipment at site, they will be erected directly on the equipment foundations. There is no layover time considered for this. The erection of Absorber and direct contact cooler is around 10 months and the longest erection activity. The air cooler will arrive in batches and be erected. The air cooler erection will commence soon after the first batch is received at site.

Electrical and Instrument Erection

The substation works are also covered under this section which includes but not limited to incoming power supply cable works, substation erection, main equipment erection, DCS erecting, cable tray laying, Cable pulling and then glanding and termination. The instrument erection is also shown under a separate section.

Piping erection

The Piping Works considered are Piping prefabrication work, erection of pipes and flanges and Hydrotesting.

Finish Works

Once all the installation work is complete, we start the finishing activities. This section consists of the following activities. Insulate General Area Instruments, Equipment & Pipework, Paint Area Pipework, Equipment & Pipe racks.

8.1.6 FLUE GAS RUN

There is a separate section shown in the schedule for the duct work to the existing cement plant. It includes excavation, foundation, backfilling, racks and associated duct works.

9. COMMISSIONING AND START UP

Commissioning is the process that confirms all components of a system are designed, installed, tested, and maintained to perform according to the owner's requirements and design intent. The commissioning is a significant step before the trail run to ensure that the plant is ready to start processing the raw materials.

The commissioning starts after the erection of all electrical, mechanical and Instrumentation equipment and components. The commissioning in this schedule also involves the site testing of the equipment (no-load and load test). The loop check is also part of the commissioning activities

In this project commissioning is considered to be 3 months duration

10. REFERENCES

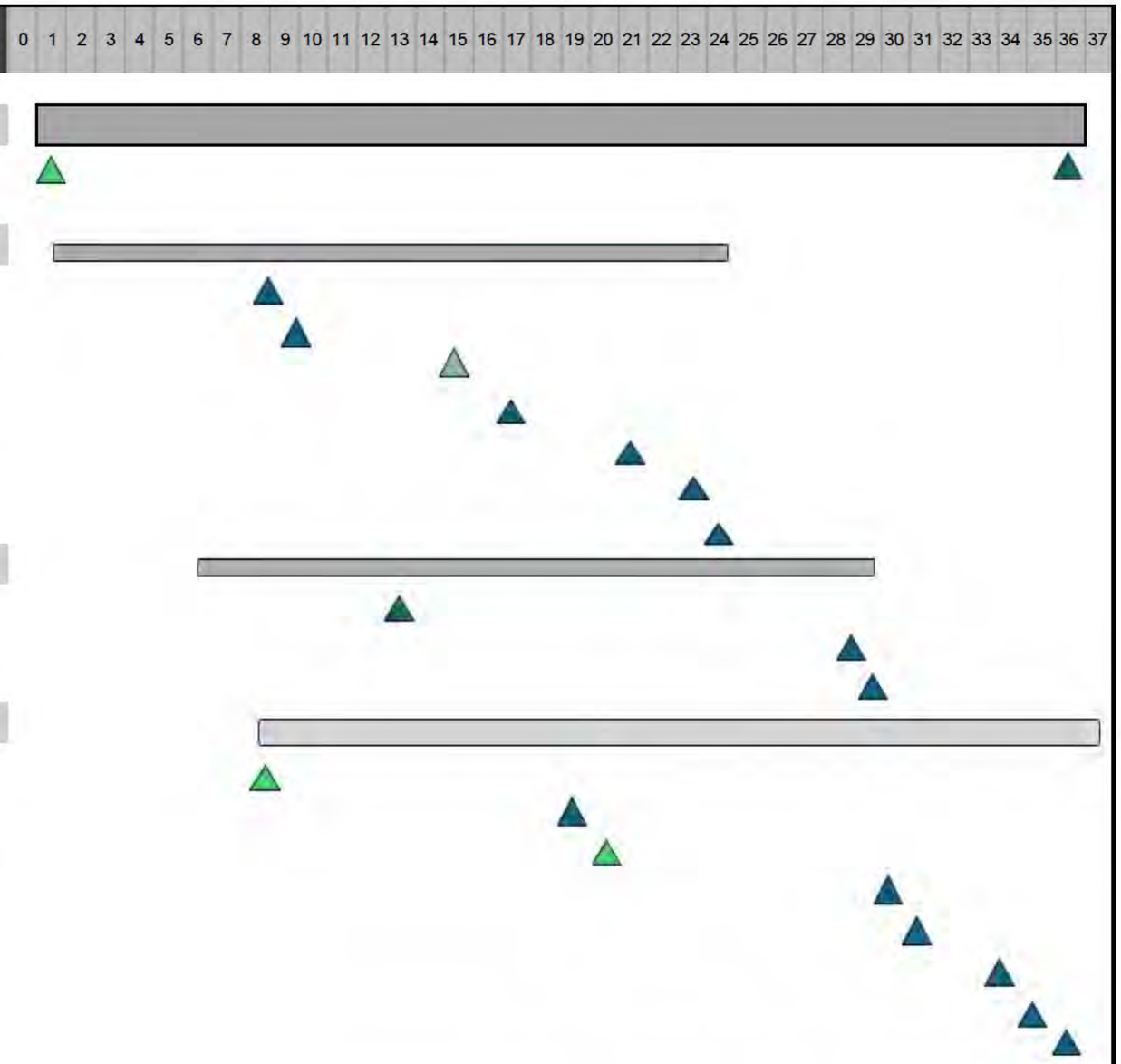
Sl. No	Document Title	Document Number	Revision
1	Process Descriptions	DE-FE0032220-KBR-00-PR-G-PRS-001	E
2	OSBL Sized Equipment List	DE-FE0032220-KBR-00-PR-G-LST-002	E
3	ISBL Sized Equipment List	DE-FE0032220-KBR-00-PR-G-LST-001	E
4	Project Design Basis	DE-FE0032220-KBR-PM-G-PDB-001	B
5	Plant Plans (Sheet 1 and 2)	DE-FE0032220-KBR-00-PI-D-P0A-001	C
6	Single Line Diagram	DE-FE0032220-KBR-00-EL-D-EA0-001	A

11. ANNEXURES

1. Level 1 – EPC Schedule
2. Level 2 – EPC Schedule
3. Level 2 – EPC Schedule – Critical Path
4. Engineering, Construction and Overall project curves

ANNEXURE 1

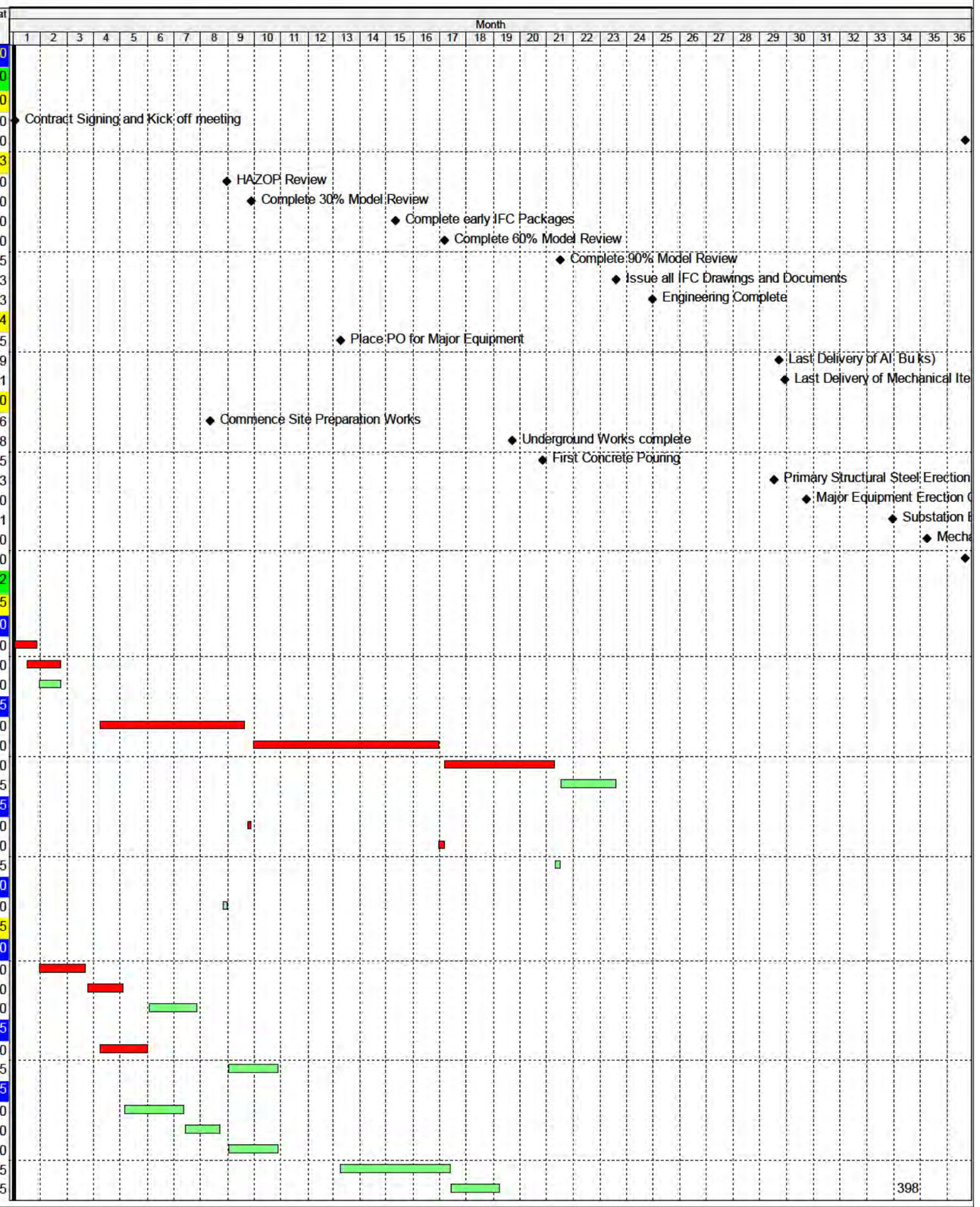
Milestone description	Category	No.of Months	Month Number
Project development			
Overall Project	WBS Summary	36	
Contract Signing and ick off meeting	Milestone		1
Project Complete	Milestone		36
Engineering	WBS Summary	24	
HA OP Review	Milestone		8
Complete 30% Model Review	Milestone		9
Complete early IFC Packages	Milestone		15
Complete 60% Model Review	Milestone		17
Complete 90% Model Review	Milestone		21
Issue all IFC Drawings and Documents	Milestone		23
Engineering Complete	Milestone		24
Procurement	WBS Summary	24	
Place PO for Major Equipment	Milestone		13
Last Delivery of All Bulks)	Milestone		29
Last Delivery of Mechanical Items	Milestone		29
Construction	WBS Summary	29	
Commence Site Preparation Works	Milestone		8
Underground Works complete	Milestone		19
First Concrete Pouring	Milestone		20
Primary Structural Steel Erection Complete	Milestone		30
Major Equipment Erection Complete	Milestone		32
Substation Erection	Milestone		34
Mechanically Complete	Milestone		35
Commissioning Complete and Project ready for startup	Milestone		36



ANNEXURE 2

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

Activity ID	Activity Name	Original Duration	Total Float
RTI-NAS CO2 Capture Plant - EPC Schedule - Level 2		3262	0
Project Milestone		3262	0
Overall Milestones		3262	0
N429-O-ML-1010	Contract Signing and Kick off meeting	0	0
N429-O-ML-1020	Project Complete	0	0
Engineering Milestones		345	23
N429-E-ML-1060	HAZOP Review	0	20
N429-E-ML-1000	Complete 30% Model Review	0	0
N429-E-ML-1010	Complete early IFC Packages	0	40
N429-E-ML-1020	Complete 60% Model Review	0	0
N429-E-ML-1030	Complete 90% Model Review	0	15
N429-E-ML-1040	Issue all IFC Drawings and Documents	0	53
N429-E-ML-1050	Engineering Complete	0	23
Procurement Milestones		1524	74
N429-P-ML-1020	Place PO for Major Equipment	0	15
N429-P-ML-1050	Last Delivery of All Bulks)	0	39
N429-P-ML-1040	Last Delivery of Mechanical Items	0	31
Construction Milestones		766	0
N429-C-ML-1000	Commence Site Preparation Works	0	46
N429-C-ML-1010	Underground Works complete	0	38
N429-C-ML-1100	First Concrete Pouring	0	85
N429-C-ML-1020	Primary Structural Steel Erection Complete	0	133
N429-C-ML-1040	Major Equipment Erection Complete	0	100
N429-C-ML-1090	Substation Erection	0	71
N429-C-ML-1080	Mechanically Complete	0	40
N429-C-ML-1060	Commissioning Complete and Project ready for startup	0	0
Engineering		520	132
Project Engineering		490	15
General		40	20
N429-E-PM-1000	Set Up Project Office / Mobilise Project Team	20	0
N429-E-PM-1020	Review & Verification of FEED Package (ALL Disciplines)	30	0
N429-E-PM-1030	Project Execution Procedure	20	20
Model Development		420	15
N429-E-PM-1130	30% Model Development	120	0
N429-E-PM-1120	60% Model Development	150	0
N429-E-PM-1150	90% Model Development	90	0
N429-E-PM-1160	Model completion and approval	45	15
Model Review		255	15
N429-E-PM-1040	Model Review (30%)	5	0
N429-E-PM-1050	Model Review (60%)	5	0
N429-E-PM-1060	Model Review (90%)	5	15
HAZOP		5	20
N429-E-PM-1100	HAZOP Review	5	20
Process		375	15
Design Basis		130	30
N429-E-PR-1140	Process Design Basis	40	0
N429-E-PR-1130	Process Simulations & H&MB	30	0
N429-E-PR-1110	Process Equipment List	40	30
PFDs		145	45
N429-E-PR-1120	PFDs - Develop/Update & Issue - IFR	40	0
N429-E-PR-1030	PFDs - Finalise & Issue - IFC with out holds	40	45
P&IDs		305	15
N429-E-PR-1090	P&IDs & Line Lists (Preliminary Issue)	50	20
N429-E-PR-1080	P&IDs & Line Lists (Issued for HAZOP)	30	20
N429-E-PR-1060	P&IDs & Line Lists (Issued for Design)	40	20
N429-E-PR-1050	P&IDs & Line Lists (IFC With Holds)	90	15
N429-E-PR-1040	P&IDs & Line Lists (IFC No Holds)	40	15



Actual Work | Remaining Work | Critical Remaining Work | Milestone

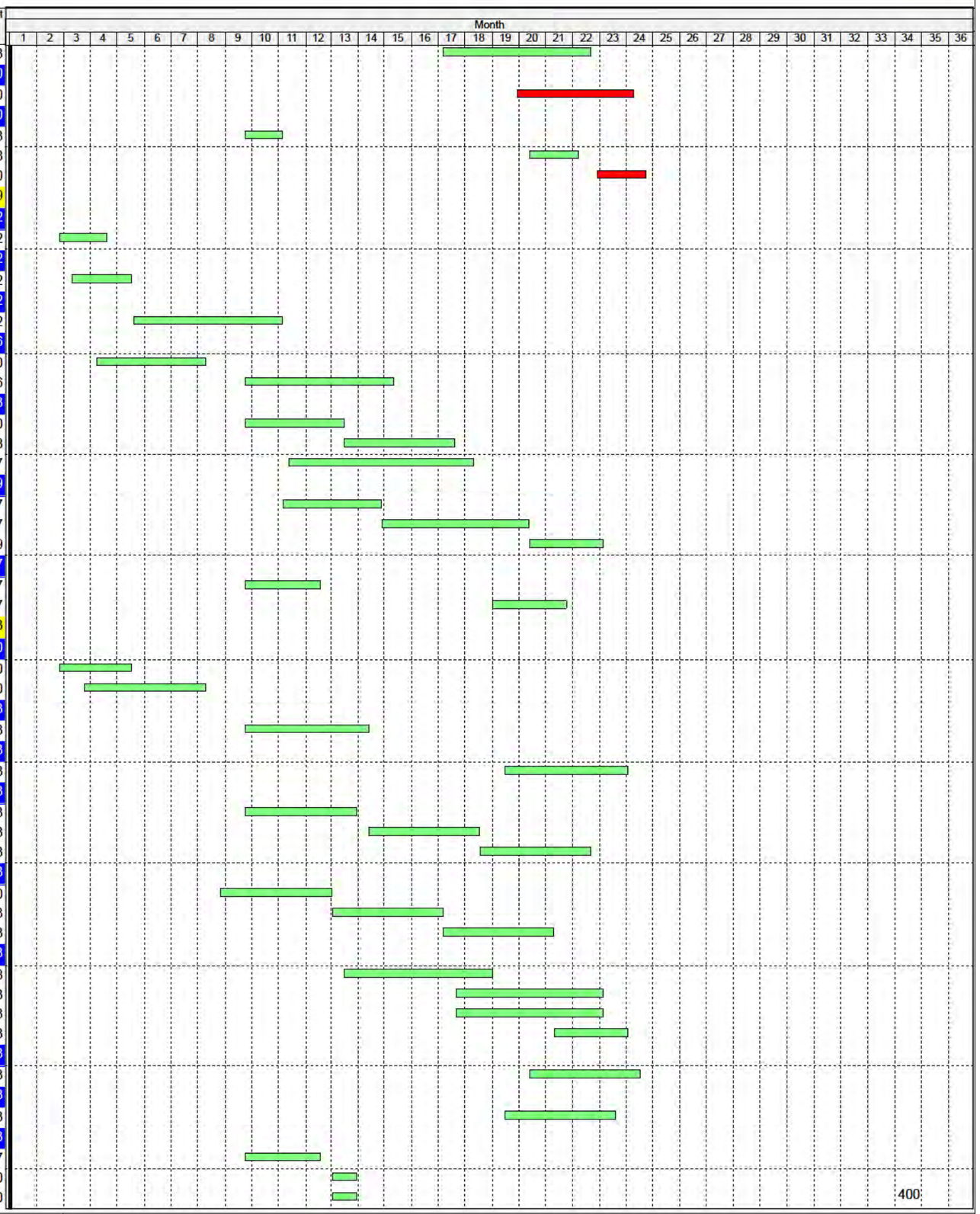
N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

Activity ID	Activity Name	Original Duration	Total Float
General Drawings		25	25
N429-E-PR-1160	Cause and Effect	25	25
Mechanical		320	85
Design Basis		40	35
N429-E-ME-1350	Mechanical Design Basis	40	35
Specifications and Calculations		40	0
N429-E-ME-1340	Specifications and Calculations	40	0
Equipment List		245	85
N429-E-ME-1300	Equipment List (Issued For Comment)	120	10
N429-E-ME-1060	Equipment List (Without Holds)	120	85
Material Requestions		90	15
N429-E-ME-1290	Produce Requisition / Datasheet Issue for enquiry - Compressor	20	0
N429-E-ME-1330	Produce Requisition / Datasheet Issue for enquiry - Absorber Column	20	0
N429-E-ME-1700	Produce Requisition / Datasheet Issue for enquiry - Direct Contact Cooler	20	0
N429-E-ME-1270	Produce Requisition / Datasheet Issue for enquiry - Air Cooler	20	1
N429-E-ME-1280	Produce Requisition / Datasheet Issue for enquiry - Regenerator Column	20	0
N429-E-ME-1740	Produce Requisition / Datasheet Issue for enquiry - Heat Exchangers	40	21
N429-E-ME-1240	Produce Requisition / Datasheet Issue for enquiry - Site Fabricated Tanks	20	1
N429-E-ME-1200	Produce Requisition / Datasheet Issue for enquiry - NG Boiler	20	0
N429-E-ME-1730	Produce Requisition / Datasheet Issue for enquiry - Pre Fabricated Tanks	20	9
N429-E-ME-1230	Produce Requisition / Datasheet Issue for enquiry - TEG Unit	20	8
N429-E-ME-1210	Produce Requisition / Datasheet Issue for enquiry - Demin Water Package	20	10
N429-E-ME-1320	Produce Requisition / Datasheet Issue for enquiry - Pumps	40	1
N429-E-ME-1310	Produce Requisition / Datasheet Issue for enquiry - Activated Carbon Bed	20	10
N429-E-ME-1260	Produce Requisition / Datasheet Issue for enquiry - Electrolyzer	20	8
N429-E-ME-1220	Produce Requisition / Datasheet Issue for enquiry - Filters	20	10
N429-E-ME-1190	Produce Requisition / Datasheet Issue for enquiry - CW Package	20	10
N429-E-ME-1170	Produce Requisition / Datasheet Issue for enquiry - N2 Generation Skid	20	8
N429-E-ME-1180	Produce Requisition / Datasheet Issue for enquiry - Waste Water Treatment	20	15
Post Order Documents Review		130	31
N429-E-ME-1660	Critical Vendor Data Submission and Review - Compressors	60	17
N429-E-ME-1690	Critical Vendor Data Submission and Submission and Review - Absorbers	60	0
N429-E-ME-1720	Critical Vendor Data Submission and Submission and Review - Direct Contact	60	0
N429-E-ME-1640	Critical Vendor Data Submission and Review - Air Coolers	60	16
N429-E-ME-1760	Critical Vendor Data Submission and Review - Heat Exchangers	60	21
N429-E-ME-1620	Critical Vendor Data Submission and Review - Site Fabricated Tanks	60	61
N429-E-ME-1530	Critical Vendor Data Submission and Review - NG Boiler	60	0
N429-E-ME-1750	Critical Vendor Data Submission and Review - Pre Fabricated Tanks	60	9
N429-E-ME-1610	Critical Vendor Data Submission and Review - TEG Unit	60	18
N429-E-ME-1560	Critical Vendor Data Submission and Review - Demin Water Package	60	20
N429-E-ME-1680	Critical Vendor Data Submission and Review - Pumps	60	1
N429-E-ME-1670	Critical Vendor Data Submission and Review - Activated Carbon Bed	60	10
N429-E-ME-1650	Critical Vendor Data Submission and Review - Regenerator Column	60	10
N429-E-ME-1630	Critical Vendor Data Submission and Review - Electrolyzer	60	8
N429-E-ME-1590	Critical Vendor Data Submission and Review - Filters	60	10
N429-E-ME-1500	Critical Vendor Data Submission and Review - CW Package	60	10
N429-E-ME-1450	Critical Vendor Data Submission and Review - N2 Generation Skid	60	10
N429-E-ME-1470	Critical Vendor Data Submission and Review - Waste Water Treatment	60	15
General Drawings		160	20
N429-E-ME-1370	Material Selection Diagrams	80	20
N429-E-ME-1360	Corrosion and Cathodic Protection Drawings	80	20
Piping		475	0
Design Basis		50	105
N429-E-PI-1150	Piping design basis	30	0
N429-E-PI-1140	Piping material Specifications	40	105
Plot Plans		400	43
N429-E-PI-1160	Plot Plans (First issue)	120	2
N429-E-PI-1100	Plot Plans (With Holds)	150	43

Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

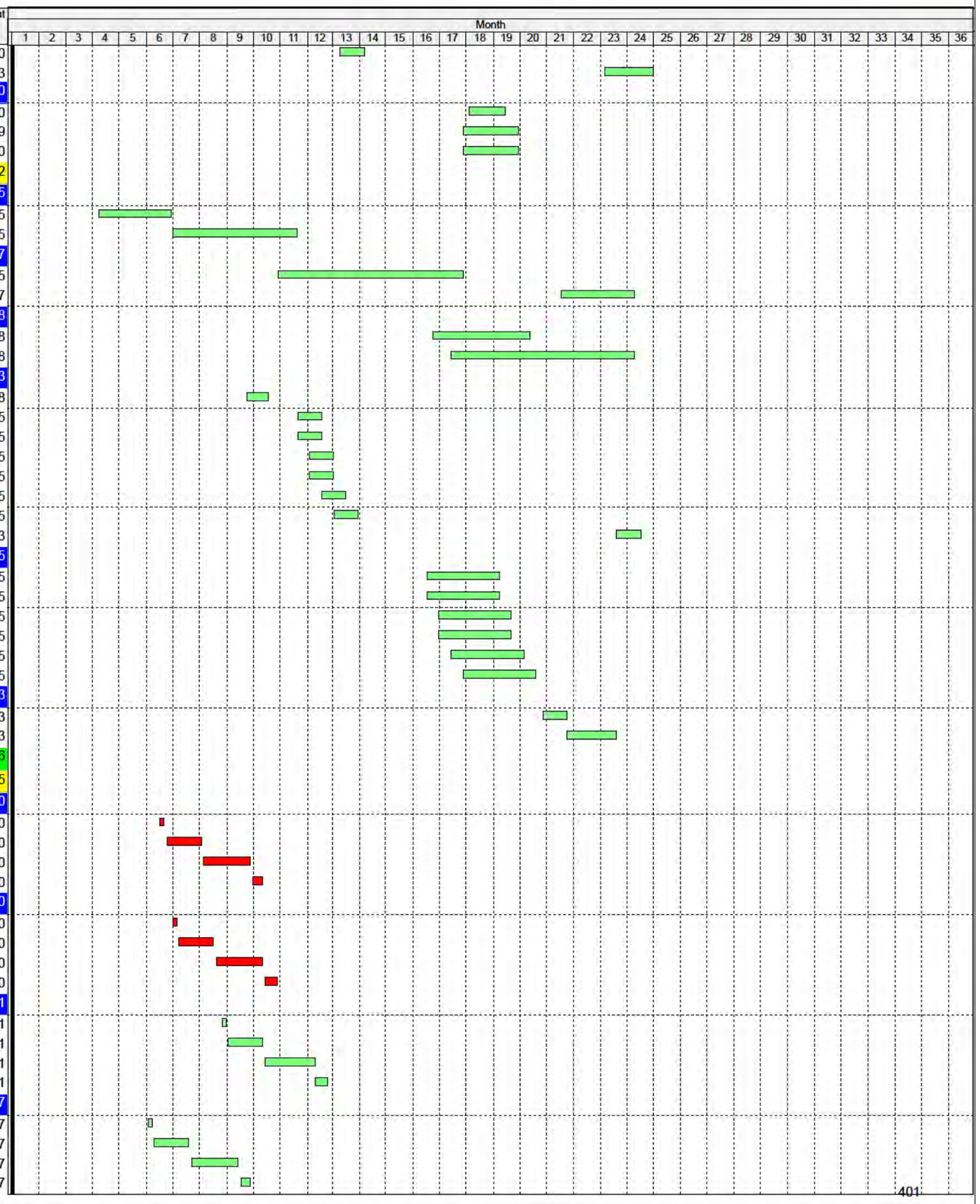
Activity ID	Activity Name	Original Duration	Total Float
N429-E-PI-1040	Plot Plans (Without Holds)	120	43
Isometrics		95	0
N429-E-PI-1070	Stress Analysis and Isometrics Issue	95	0
MTO		325	0
N429-E-PI-1030	Piping Preliminary MTO	30	53
N429-E-PI-1190	Piping Speciality Items	40	48
N429-E-PI-1180	Piping Final MTO	40	0
Civil		440	29
Design basis		40	12
N429-E-CV-1080	Civil and Structural Design basis	40	12
Specifications		50	12
N429-E-CV-1070	Civil and Structural Specs & Standards	50	12
Calculations		120	12
N429-E-CV-1060	Foundation Calculations	120	12
Layouts		240	6
N429-E-CV-1040	Temporary Facilities Drawings	90	20
N429-E-CV-1020	Under Ground Drawings	120	6
Foundation Drawings		185	123
N429-E-CV-1110	Pipe Rack Drawings	80	70
N429-E-CV-1100	Building Foundation Drawings	90	138
N429-E-CV-1090	Equipment Foundation Drawings	150	7
Structural Engineering		260	29
N429-E-CV-1140	Structural GA Piperacks	80	17
N429-E-CV-1130	Structural GA Equipment	120	17
N429-E-CV-1120	Miscellaneous Structural steel drawings	60	29
Civil and Structural MTO		260	17
N429-E-CV-1150	Structural Steel MTO MTO - Preliminary	60	7
N429-E-CV-1160	Structural Steel MTO - Final	60	17
Electrical		480	23
Design Basis		120	20
N429-E-EL-0010	Electrical Design basis	60	20
N429-E-EL-0020	Philosophies, Specification & Calculations	100	20
Studies		100	23
N429-E-EL-1420	Power System Studies	100	23
Diagrams and Drawings		100	43
N429-E-EL-1150	Control & Indication Schedules , Schematic & Wiring Diagrams	100	43
SLD		280	23
N429-E-EL-1400	Single Line Diagrams (Preliminary)	90	23
N429-E-EL-1170	Single Line Diagrams (With Holds)	90	23
N429-E-EL-1120	Single Line Diagrams (No Holds)	90	23
Electrical Load List		270	53
N429-E-EL-1410	Electrical Load List (Preliminary)	90	10
N429-E-EL-1160	Electrical Load List (With Holds)	90	53
N429-E-EL-1110	Electrical Load List (No Holds)	90	53
Layouts		230	43
N429-E-EL-1070	Substation Layouts (No Holds)	120	78
N429-E-EL-1090	Equipment layouts IFC (No Holds)	120	53
N429-E-EL-1030	Cable tray Rack & Support Drawings (No Holds)	120	63
N429-E-EL-1100	Electrical Lighting & Small Power Drawings	60	43
Schedules		90	23
N429-E-EL-1080	Cable Schedule	90	23
Cable Routing		90	43
N429-E-EL-1130	Cable Routing Drawings	90	43
Electrical Requestions		330	23
N429-E-EL-1440	Electrical Preliminary MTO - (Including Incoming Power Supply Cable)	60	77
N429-E-EL-1390	Produce Requisition / Datasheet Issued for enquiry - Transformers	20	10
N429-E-EL-1380	Produce Requisition / Datasheet Issued for enquiry - Switchgear	20	10



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

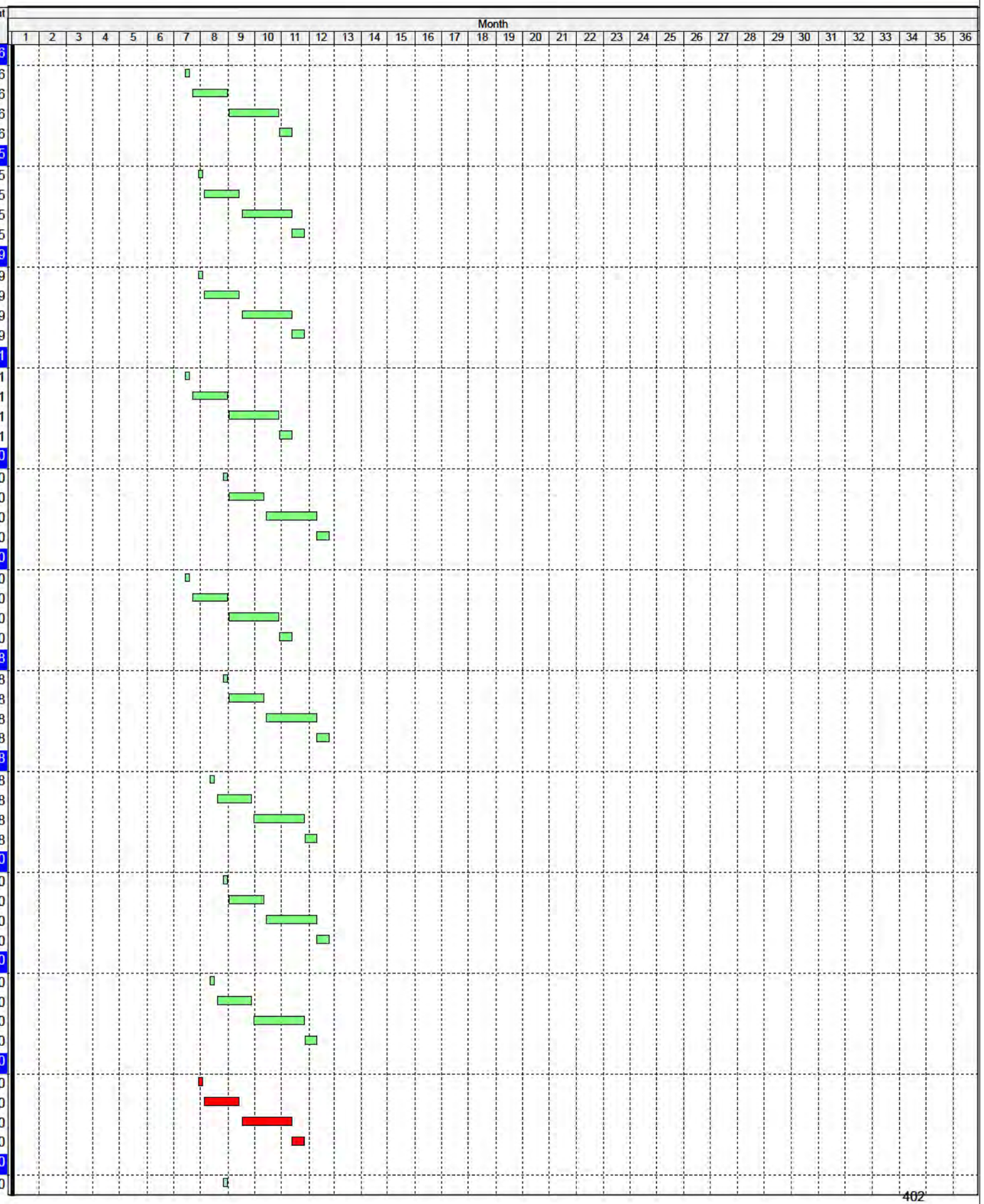
Activity ID	Activity Name	Original Duration	Total Float
N429-E-EL-1370	Produce Requisition / Datasheet Issued for enquiry - UPS	20	30
N429-E-EL-1450	Electrical Final MTO	40	23
Post Order Documents Review		45	20
N429-E-EL-1280	Critical Vendor Data Submission and Review - UPS	30	30
N429-E-EL-1300	Critical Vendor Data Submission and Review - Transformers	45	19
N429-E-EL-1290	Critical Vendor Data Submission and Review - Switchgear	45	10
Instrumentation		440	142
Design basis		160	5
N429-E-IC-1270	Instrument Design Basis	60	5
N429-E-IC-1440	Instrument Specifications and Calculations	100	5
Diagrams and Drawings		290	147
N429-E-IC-1390	Network wiring diagrams	150	75
N429-E-IC-1400	I/O wiring diagrams	60	147
Layouts		165	38
N429-E-IC-1310	Control Room arrangement	80	78
N429-E-IC-1320	Instrument Location Layout drawings	150	38
Instrument DataSheets/ Requestions		320	13
N429-E-IC-1420	Instrumentation Preliminary MTO	20	78
N429-E-IC-1280	Produce Requisition / Datasheet Issued for enquiry Control Valve	20	5
N429-E-IC-1230	Produce Requisition / Datasheet Issued for enquiry Analyzers	20	25
N429-E-IC-1260	Produce Requisition / Datasheet Issued for enquiry Flowmeter	20	5
N429-E-IC-1220	Produce Requisition / Datasheet Issued for enquiry DCS	20	25
N429-E-IC-1250	Produce Requisition / Datasheet Issued for enquiry Transmitters	20	5
N429-E-IC-1240	Produce Requisition / Datasheet Issued for enquiry Gauges	20	5
N429-E-IC-1430	Instrumentation Final MTO	20	13
Post Order Documents Review		90	5
N429-E-IC-1150	Critical Vendor Data Submission and Review - Control Valves	60	35
N429-E-IC-1100	Critical Vendor Data Submission and Review - Analyzers	60	35
N429-E-IC-1130	Critical Vendor Data Submission and Review - Flowmeters	60	25
N429-E-IC-1080	Critical Vendor Data Submission and Review - DCSs	60	25
N429-E-IC-1120	Critical Vendor Data Submission and Review - Transmitters	60	15
N429-E-IC-1110	Critical Vendor Data Submission and Review - Gauges	60	5
Instrument index		60	13
N429-E-IC-1350	Instrument index	20	13
N429-E-IC-1360	Instrument cable schedule	40	13
Procurement		2209	176
Mechanical Equipment Ordering		155	15
Absorber		85	0
N429-P-PRE-1000	Issue Enquiry - Absorber	5	0
N429-P-PRE-1090	Supplier Bid Period - Absorber	30	0
N429-P-PRE-1360	Technical and Commercial Bid Evaluation - Absorber	40	0
N429-P-PRE-1620	PO Award Absorber	10	0
Direct Contact Cooler		85	0
N429-P-PRE-2540	Issue Enquiry - Direct Contact Cooler	5	0
N429-P-PRE-2550	Supplier Bid Period - Direct Contact Cooler	30	0
N429-P-PRE-2560	Technical and Commercial Bid Evaluation - Direct Contact Cooler	40	0
N429-P-PRE-2590	PO Award Direct Contact Cooler	10	0
Pumps		85	1
N429-P-PRE-1010	Issue Enquiry - Pumps	5	1
N429-P-PRE-1120	Supplier Bid Period - Pumps	30	1
N429-P-PRE-1390	Technical and Commercial Bid Evaluation - Pumps	40	1
N429-P-PRE-1640	PO Award Pumps	10	1
Compressor		85	17
N429-P-PRE-1030	Issue Enquiry - Compressor	5	17
N429-P-PRE-1150	Supplier Bid Period - Compressor	30	17
N429-P-PRE-1450	Technical and Commercial Bid Evaluation - Compressor	40	17
N429-P-PRE-1710	PO Award Compressor	10	17



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

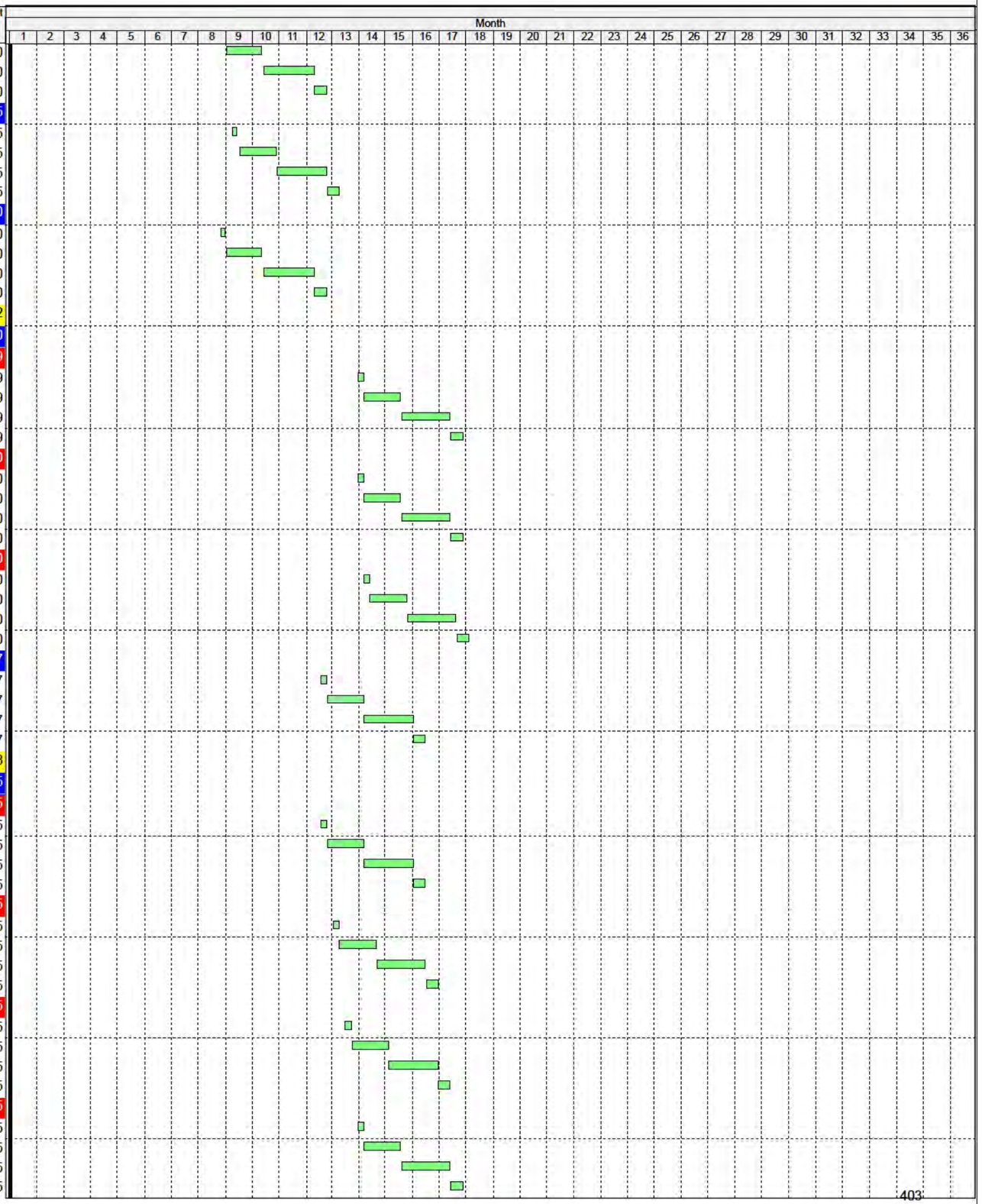
Activity ID	Activity Name	Original Duration	Total Float
Air Cooler		85	16
N429-P-PRE-1060	Issue Enquiry - Air Cooler	5	16
N429-P-PRE-1230	Supplier Bid Period - Air Cooler	30	16
N429-P-PRE-1580	Technical and Commercial Bid Evaluation - Air Cooler	40	16
N429-P-PRE-1840	PO Award Air Cooler	10	16
Site Fabricated Tanks		85	45
N429-P-PRE-1100	Issue Enquiry - Site Fabricated Tanks	5	45
N429-P-PRE-1310	Supplier Bid Period - Site Fabricated Tanks	30	45
N429-P-PRE-1730	Technical and Commercial Bid Evaluation - Site Fabricated Tanks	40	45
N429-P-PRE-1980	PO Award Site Fabricated Tanks	10	45
Pre Fabricated Tanks		85	9
N429-P-PRE-2720	Issue Enquiry - Pre Fabricated Tanks	5	9
N429-P-PRE-2730	Supplier Bid Period - Pre Fabricated Tanks	30	9
N429-P-PRE-2740	Technical and Commercial Bid Evaluation - Pre Fabricated Tanks	40	9
N429-P-PRE-2750	PO Award Pre Fabricated Tanks	10	9
Heat Exchangers		85	21
N429-P-PRE-2760	Issue Enquiry - Heat Exchangers	5	21
N429-P-PRE-2770	Supplier Bid Period - Heat Exchangers	30	21
N429-P-PRE-2780	Technical and Commercial Bid Evaluation - Heat Exchangers	40	21
N429-P-PRE-2790	PO Award Heat Exchangers	10	21
Activated Carbon Bed		85	10
N429-P-PRE-1040	Issue Enquiry - Activated Carbon Bed	5	10
N429-P-PRE-1160	Supplier Bid Period - Activated Carbon Bed	30	10
N429-P-PRE-1470	Technical and Commercial Bid Evaluation - Activated Carbon Bed	40	10
N429-P-PRE-1750	PO Award Activated Carbon Bed	10	10
Regenerator Column		85	40
N429-P-PRE-1070	Issue Enquiry - Regenerator Column	5	40
N429-P-PRE-1240	Supplier Bid Period - Regenerator Column	30	40
N429-P-PRE-1600	Technical and Commercial Bid Evaluation - Regenerator Column	40	40
N429-P-PRE-1870	PO Award Regenerator Column	10	40
Electrolyzer		85	8
N429-P-PRE-1110	Issue Enquiry - Electrolyzer	5	8
N429-P-PRE-1320	Supplier Bid Period - Electrolyzer	30	8
N429-P-PRE-1770	Technical and Commercial Bid Evaluation - Electrolyzer	40	8
N429-P-PRE-2000	PO Award Electrolyzer	10	8
TEG Unit		85	18
N429-P-PRE-1170	Issue Enquiry - TEG Unit	5	18
N429-P-PRE-1370	Supplier Bid Period - TEG Unit	30	18
N429-P-PRE-1890	Technical and Commercial Bid Evaluation - TEG Unit	40	18
N429-P-PRE-2140	PO Award TEG Unit	10	18
Filters		85	10
N429-P-PRE-1180	Issue Enquiry - Filters	5	10
N429-P-PRE-1400	Supplier Bid Period - Filters	30	10
N429-P-PRE-1900	Technical and Commercial Bid Evaluation - Filters	40	10
N429-P-PRE-2200	PO Award Filters	10	10
Demin Water Package		85	20
N429-P-PRE-1250	Issue Enquiry - Demin Water Package	5	20
N429-P-PRE-1480	Supplier Bid Period - Demin Water Package	30	20
N429-P-PRE-2020	Technical and Commercial Bid Evaluation - Demin Water Package	40	20
N429-P-PRE-2290	PO Award Demin Water Package	10	20
NG Boiler		85	0
N429-P-PRE-1280	Issue Enquiry - NG Boiler	5	0
N429-P-PRE-1520	Supplier Bid Period - NG Boiler	30	0
N429-P-PRE-2060	Technical and Commercial Bid Evaluation - NG Boiler	40	0
N429-P-PRE-2370	PO Award NG Boiler	10	0
CW Package		85	10
N429-P-PRE-1330	Issue Enquiry - CW Package	5	10



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

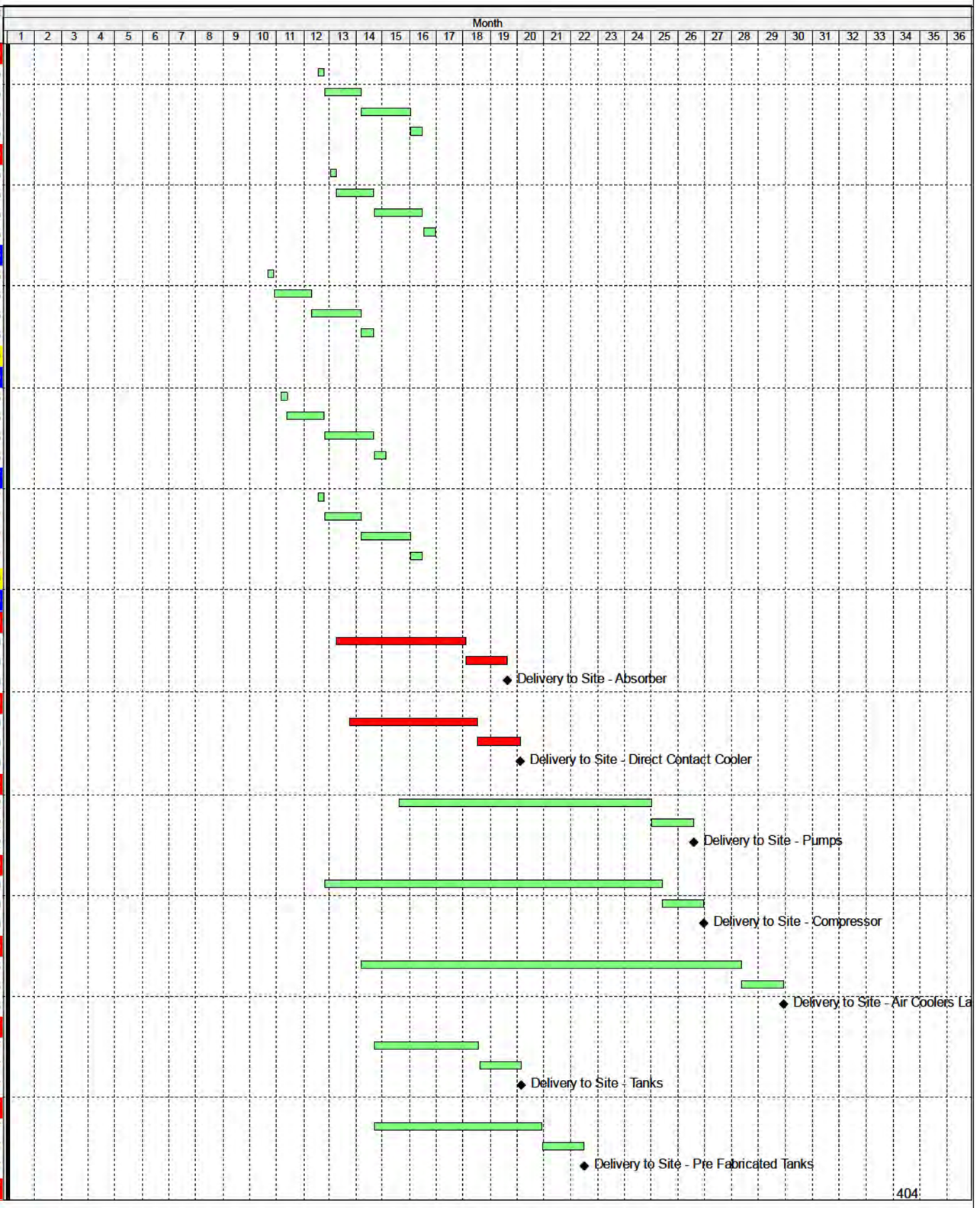
Activity ID	Activity Name	Original Duration	Total Float
N429-P-PRE-1610	Supplier Bid Period - CW Package	30	10
N429-P-PRE-2160	Technical and Commercial Bid Evaluation - CW Package	40	10
N429-P-PRE-2440	PO Award CW Package	10	10
Waste Water Treatment		85	15
N429-P-PRE-1340	Issue Enquiry - Waste Water Treatment	5	15
N429-P-PRE-1650	Supplier Bid Period - Waste Water Treatment	30	15
N429-P-PRE-2220	Technical and Commercial Bid Evaluation - Waste Water Treatment	40	15
N429-P-PRE-2470	PO Award Waste Water Treatment	10	15
N2 Generation Skid		85	10
N429-P-PRE-1380	Issue Enquiry - N2 Generation Skid	5	10
N429-P-PRE-1780	Supplier Bid Period - N2 Generation Skid	30	10
N429-P-PRE-2310	Technical and Commercial Bid Evaluation - N2 Generation Skid	40	10
N429-P-PRE-2490	PO Award N2 Generation Skid	10	10
Electrical Equipment Ordering		120	42
Major Equipment		90	30
Transformers		85	19
N429-P-PRE-1190	Issue Enquiry - Transformer	5	19
N429-P-PRE-1410	Supplier Bid Period - Transformer	30	19
N429-P-PRE-1910	Technical and Commercial Bid Evaluation - Transformer	40	19
N429-P-PRE-2400	PO Award Transformer	10	19
Switchgear		85	10
N429-P-PRE-1200	Issue Enquiry - Switchgear	5	10
N429-P-PRE-1420	Supplier Bid Period - Switchgear	30	10
N429-P-PRE-1920	Technical and Commercial Bid Evaluation - Switchgear	40	10
N429-P-PRE-2240	PO Award Switchgear	10	10
UPS		85	30
N429-P-PRE-1260	Issue Enquiry - UPS	5	30
N429-P-PRE-1490	Supplier Bid Period - UPS	30	30
N429-P-PRE-2030	Technical and Commercial Bid Evaluation - UPS	40	30
N429-P-PRE-2330	PO Award UPS	10	30
Bulk Items		85	77
N429-P-PRE-2600	Issue Enquiry - Bulks	5	77
N429-P-PRE-2610	Supplier Bid Period - Bu ks	30	77
N429-P-PRE-2620	Technical and Commercial Bid Evaluation - Bulks	40	77
N429-P-PRE-2630	PO Award Bulks	10	77
Instrument Equipment Ordering		155	8
Major Equipment		115	5
Control Valve		85	35
N429-P-PRE-1020	Issue Enquiry - Control Valve	5	35
N429-P-PRE-1130	Supplier Bid Period - Control Valve	30	35
N429-P-PRE-1430	Technical and Commercial Bid Evaluation - Control Valve	40	35
N429-P-PRE-1670	PO Award Control Valve	10	35
Flowmeter		85	25
N429-P-PRE-1050	Issue Enquiry - Flowmeter	5	25
N429-P-PRE-1210	Supplier Bid Period - Flowmeter	30	25
N429-P-PRE-1540	Technical and Commercial Bid Evaluation - Flowmeter	40	25
N429-P-PRE-1800	PO Award Flowmeter	10	25
Transmitters		85	15
N429-P-PRE-1080	Issue Enquiry - Transmitters	5	15
N429-P-PRE-1290	Supplier Bid Period - Transmitters	30	15
N429-P-PRE-1690	Technical and Commercial Bid Evaluation - Transmitters	40	15
N429-P-PRE-1940	PO Award Transmitters	10	15
Gauges		85	5
N429-P-PRE-1140	Issue Enquiry - Gauges	5	5
N429-P-PRE-1350	Supplier Bid Period - Gauges	30	5
N429-P-PRE-1820	Technical and Commercial Bid Evaluation - Gauges	40	5
N429-P-PRE-2100	PO Award Gauges	10	5



Actual Work Remaining Work Critical Remaining Work Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

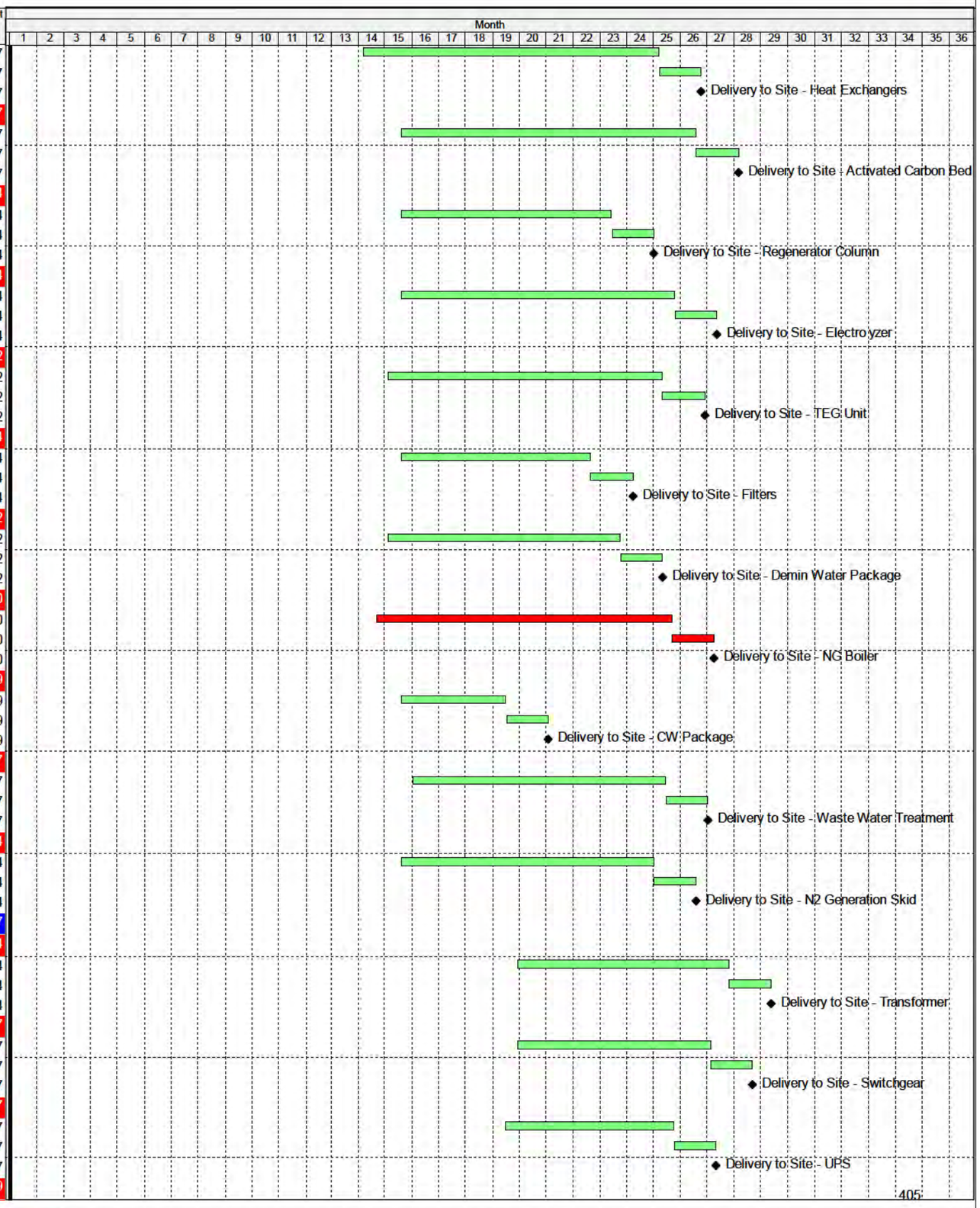
Activity ID	Activity Name	Original Duration	Total Float
Analyzers		85	35
N429-P-PRE-1220	Issue Enquiry - Analyzers	5	35
N429-P-PRE-1440	Supplier Bid Period - Analyzers	30	35
N429-P-PRE-1960	Technical and Commercial Bid Evaluation - Analyzers	40	35
N429-P-PRE-2260	PO Award Analyzers	10	35
DCS		85	25
N429-P-PRE-1300	Issue Enquiry - DCS	5	25
N429-P-PRE-1550	Supplier Bid Period - DCS	30	25
N429-P-PRE-2120	Technical and Commercial Bid Evaluation - DCS	40	25
N429-P-PRE-2420	PO Award DCS	10	25
Bulk Items		85	78
N429-P-PRE-2640	Issue Enquiry - Bulks	5	78
N429-P-PRE-2650	Supplier Bid Period - Bu ks	30	78
N429-P-PRE-2660	Technical and Commercial Bid Evaluation - Bulks	40	78
N429-P-PRE-2670	PO Award Bulks	10	78
Piping Ordering		115	23
Bulk Items		85	53
N429-P-PRE-2680	Issue Enquiry - Bulks	5	53
N429-P-PRE-2690	Supplier Bid Period - Bu ks	30	53
N429-P-PRE-2700	Technical and Commercial Bid Evaluation - Bulks	40	53
N429-P-PRE-2710	PO Award Bulks	10	53
Civil and Structural		85	7
N429-P-PRE-2840	Issue Enquiry - Primary Structural Steel MTO	5	7
N429-P-PRE-2850	Supplier Bid Period - Primary Structural Steel MTO	30	7
N429-P-PRE-2860	Technical and Commercial Bid Evaluation - Primary Structural Steel MTO	40	7
N429-P-PRE-2870	PO Award Primary Structural Steel MTO	10	7
Post Award and Manufacturing		665	73
Mechanical Equipment		653	28
Absorber		243	0
N429-P-POS-1730	Supplier Manufacturing Completion & Documentation - Absorber	183	0
N429-P-POS-1760	Transportation to Site - Absorber	60	0
N429-P-POS-1770	Delivery to Site - Absorber	0	0
Direct Contact Cooler		243	0
N429-P-POS-1780	Supplier Manufacturing Period - Direct Contact Cooler	183	0
N429-P-POS-1790	Transportation to Site - Direct Contact Cooler	60	0
N429-P-POS-1800	Delivery to Site - Direct Contact Cooler	0	0
Pumps		420	2
N429-P-POS-1300	Supplier Manufacturing Period - Pumps	360	2
N429-P-POS-1470	Transportation to Site - Pumps	60	2
N429-P-POS-1480	Delivery to Site - Pumps	0	2
Compressor		540	29
N429-P-POS-1570	Supplier Manufacturing Period - Compressor	480	29
N429-P-POS-1640	Transportation to Site - Compressor	60	29
N429-P-POS-1650	Delivery to Site - Compressor	0	29
Air Cooler		600	28
N429-P-POS-1180	Supplier Manufacturing Period - Air Cooler	540	28
N429-P-POS-1310	Transportation and Delivery to Site - Air Coolers	60	28
N429-P-POS-1320	Delivery to Site - Air Coolers Last Batch	0	28
Site Fabricated Tanks		210	107
N429-P-POS-1000	Tanks Plates Supply for Fabrication	150	107
N429-P-POS-1010	Transportation to Site - Tanks	60	107
N429-P-POS-1020	Delivery to Site - Tanks	0	107
Pre Fabricated Tanks		300	17
N429-P-POS-1840	Supplier Manufacturing Period - Pre Fabricated Tanks	240	17
N429-P-POS-1850	Transportation to Site - Pre Fabricated Tanks	60	17
N429-P-POS-1860	Delivery to Site - Pre Fabricated Tanks	0	17
Heat Exchangers		480	37



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

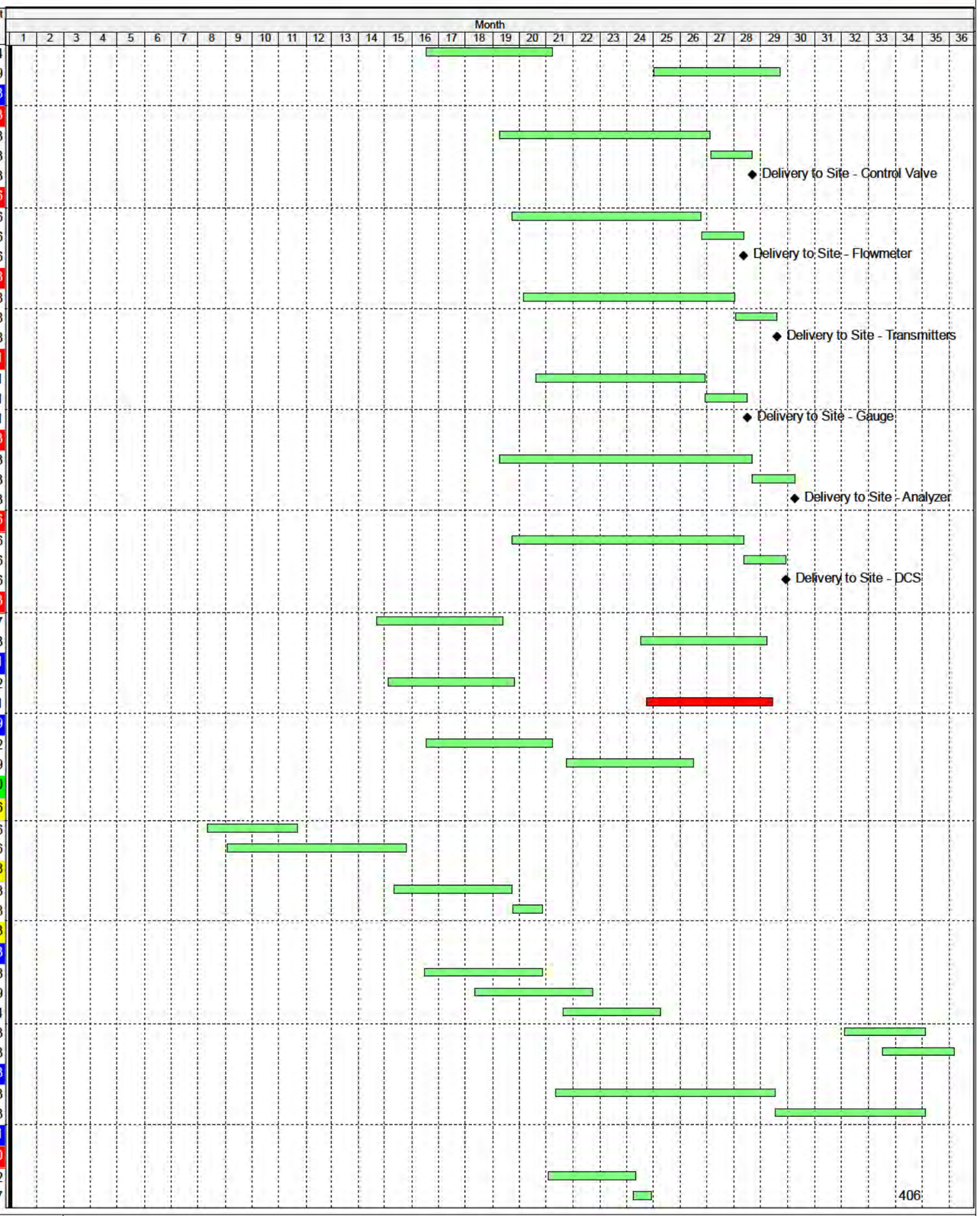
Activity ID	Activity Name	Original Duration	Total Float
N429-P-POS-1870	Supplier Manufacturing Period - Heat Exchangers	420	37
N429-P-POS-1880	Transportation to Site - Heat Exchangers	60	37
N429-P-POS-1890	Delivery to Site - Heat Exchangers	0	37
Activated Carbon Bed		480	27
N429-P-POS-1690	Supplier Manufacturing Period - Activated Carbon Bed	420	27
N429-P-POS-1710	Transportation to Site - Activated Carbon Bed	60	27
N429-P-POS-1720	Delivery to Site - Activated Carbon Bed	0	27
Regenerator Column		360	104
N429-P-POS-1190	Supplier Manufacturing Period - Regenerator Column	300	104
N429-P-POS-1330	Transportation to Site - Regenerator Column	60	104
N429-P-POS-1340	Delivery to Site - Regenerator Column	0	104
Electrolyzer		450	14
N429-P-POS-1490	Supplier Manufacturing Period - Electrolyzer	390	14
N429-P-POS-1590	Transportation to Site - Electrolyzer	60	14
N429-P-POS-1600	Delivery to Site - Electrolyzer	0	14
TEG Unit		450	32
N429-P-POS-1560	Supplier Manufacturing Period - TEG Unit	390	32
N429-P-POS-1620	Transportation to Site - TEG Unit	60	32
N429-P-POS-1630	Delivery to Site - TEG Unit	0	32
Filters		330	134
N429-P-POS-1040	Supplier Manufacturing Period - Filters	270	134
N429-P-POS-1100	Transportation to Site - Filters	60	134
N429-P-POS-1110	Delivery to Site - Filters	0	134
Demin Water Package		390	92
N429-P-POS-1270	Supplier Manufacturing Period - Demin Water Package	330	92
N429-P-POS-1440	Transportation to Site - Demin Water Package	60	92
N429-P-POS-1450	Delivery to Site - Demin Water Package	0	92
NG Boiler		481	0
N429-P-POS-1700	Supplier Manufacturing Period - NG Boiler	421	0
N429-P-POS-1740	Transportation to Site - NG Boiler	60	0
N429-P-POS-1750	Delivery to Site - NG Boiler	0	0
CW Package		210	59
N429-P-POS-1050	Supplier Manufacturing Period - CW Package	150	59
N429-P-POS-1120	Transportation to Site - CW Package	60	59
N429-P-POS-1130	Delivery to Site - CW Package	0	59
Waste Water Treatment		420	27
N429-P-POS-1390	Supplier Manufacturing Period - Waste Water Treatment	360	27
N429-P-POS-1540	Transportation to Site - Waste Water Treatment	60	27
N429-P-POS-1550	Delivery to Site - Waste Water Treatment	0	27
N2 Generation Skid		420	44
N429-P-POS-1610	Supplier Manufacturing Period - N2 Generation Skid	360	44
N429-P-POS-1660	Transportation to Site - N2 Generation Skid	60	44
N429-P-POS-1670	Delivery to Site - N2 Generation Skid	0	44
Electrical Equipment		504	67
Transformers		360	34
N429-P-POS-1350	Supplier Manufacturing Period - Transformer	300	34
N429-P-POS-1500	Transportation to Site - Transformer	60	34
N429-P-POS-1510	Delivery to Site - Transformer	0	34
Switchgear		334	17
N429-P-POS-1250	Supplier Manufacturing Period - Switchgear	274	17
N429-P-POS-1400	Transportation to Site - Switchgear	60	17
N429-P-POS-1410	Delivery to Site - Switchgear	0	17
UPS		300	157
N429-P-POS-1140	Supplier Manufacturing Period - UPS	240	157
N429-P-POS-1230	Transportation to Site - UPS	60	157
N429-P-POS-1240	Delivery to Site - UPS	0	157
Bulks		504	39



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

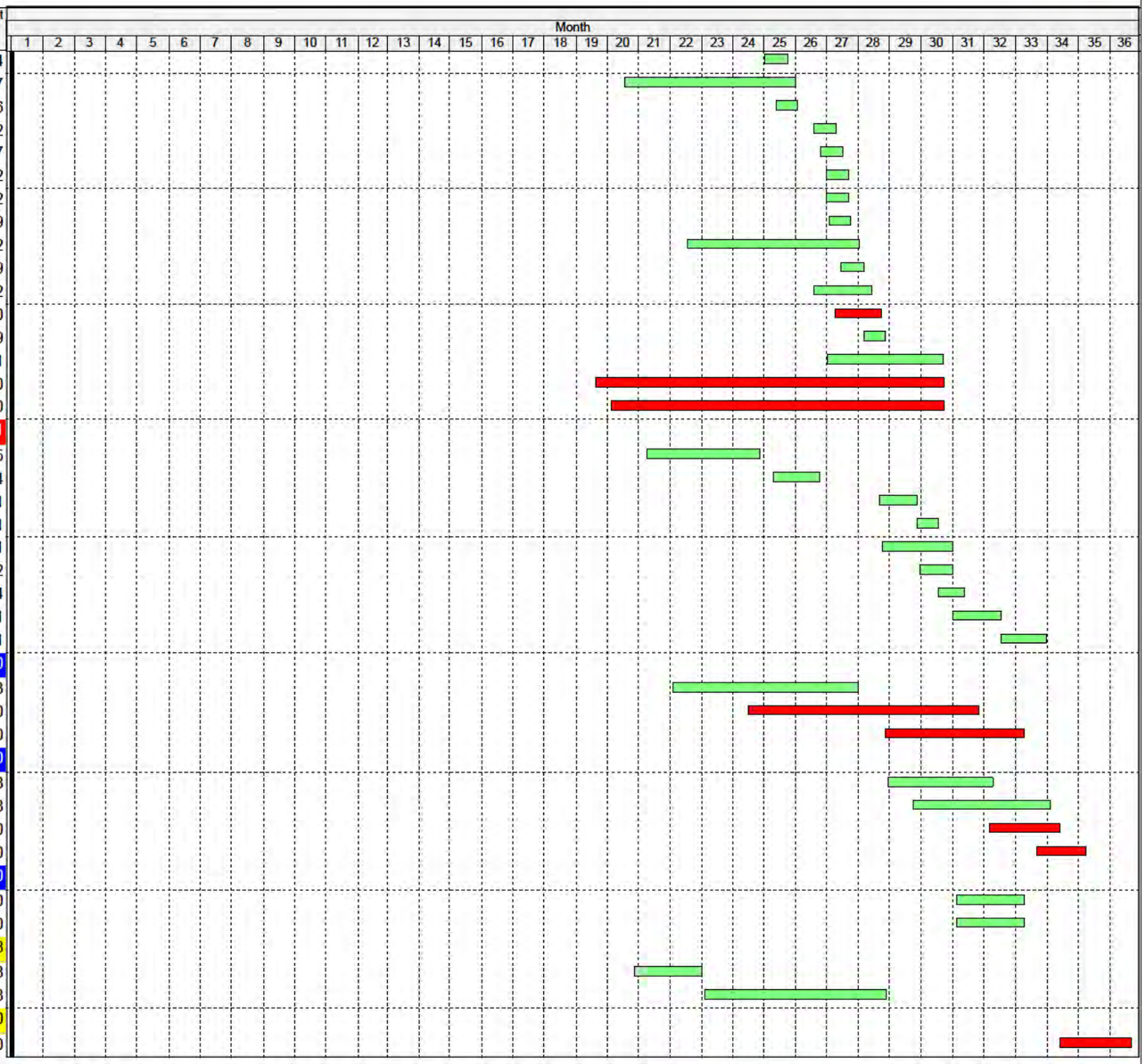
Activity ID	Activity Name	Original Duration	Total Float
N429-P-POS-1460	Preliminary Electrical Bulks Purchase and Delivery to Site	180	134
N429-P-POS-1820	Final Electrical Bulks Purchase and Delivery to Site	180	39
Instrument Equipment		595	73
Control Valve		360	133
N429-P-POS-1060	Supplier Manufacturing Period - Control Valve	300	133
N429-P-POS-1160	Transportation to Site - Control Valve	60	133
N429-P-POS-1170	Delivery to Site - Control Valve	0	133
Flowmeter		330	146
N429-P-POS-1090	Supplier Manufacturing Period - Flowmeter	270	146
N429-P-POS-1210	Transportation to Site - Flowmeter	60	146
N429-P-POS-1220	Delivery to Site - Flowmeter	0	146
Transmitters		360	98
N429-P-POS-1150	Supplier Manufacturing Period - Transmitters	300	98
N429-P-POS-1280	Transportation to Site - Transmitters	60	98
N429-P-POS-1290	Delivery to Site - Transmitters	0	98
Gauges		300	141
N429-P-POS-1200	Supplier Manufacturing Period - Gauge	240	141
N429-P-POS-1370	Transportation to Site - Gauge	60	141
N429-P-POS-1380	Delivery to Site - Gauge	0	141
Analyzer		420	73
N429-P-POS-1260	Supplier Manufacturing Period - Analyzer	360	73
N429-P-POS-1420	Transportation to Site - Analyzer	60	73
N429-P-POS-1430	Delivery to Site - Analyzer	0	73
DCS		390	46
N429-P-POS-1360	Supplier Manufacturing Period - DCS	330	46
N429-P-POS-1520	Transportation to Site - DCS	60	46
N429-P-POS-1530	Delivery to Site - DCS	0	46
Bulks		556	23
N429-P-POS-1580	Preliminary Instrumentation Bulks Delivery to Site	180	137
N429-P-POS-1830	Final Instrumentation Bulks Delivery to Site	180	23
Piping		548	1
N429-P-POS-1680	Preliminary Piping Bu ks - Delivery to Site	180	92
N429-P-POS-1810	Final Piping Bulks - Delivery to Site	180	1
Civil and Structural		381	29
N429-P-POS-1910	Preliminary Structural Steel MTO - Delivery to Site	180	12
N429-P-POS-1920	Final Primary Structural Steel MTO - Delivery to Site	180	29
Construction		766	0
Early Works		200	26
N429-C-GE-1000	Site Clearance , Contractor Mobilization & Temporary Facility Set-up	90	26
N429-C-GE-1010	Site Preparation Works (Site Survey works, Expansive Soil Removal, Filling ar	180	26
Underground Works		150	8
N429-C-GE-1030	Installation of underground tank vault, Fire Water main & associated works	120	8
N429-C-GE-1050	Hydrotest of Firewater ring header, Tank vault & Backfilling	30	8
Above Ground Works		535	13
Foundation / Civil Works		535	13
N429-C-GE-1080	Piperack Foundations	120	8
N429-C-GE-1130	Equipment Foundations	120	9
N429-C-GE-1110	Pre Engineered Buildings	100	64
N429-C-GE-1150	Area Paving & Civil Finishing	80	13
N429-C-GE-1140	Development of Road works	70	13
Steel Works		370	13
N429-C-GE-1100	Erect Primary Steel Structure	220	3
N429-C-GE-1120	Erect Secondary Steel Structure	150	13
Erection		390	11
Mechancial Erection		302	20
N429-C-ER-1040	Mechanical Erection - CW Package	90	42
N429-C-ER-1030	Mechanical Erection - Filters	20	97



Actual Work | Remaining Work | Critical Remaining Work | Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

Activity ID	Activity Name	Original Duration	Total Float
N429-C-ER-1070	Mechanical Erection - Regenerator Column	20	74
N429-C-ER-1020	Mechanical Erection - Site Fabricated Tanks (Discuss)	150	67
N429-C-ER-1120	Mechanical Erection - Demin Water Package	20	66
N429-C-ER-1230	Mechanical Erection - N2 Generation Skid	20	32
N429-C-ER-1310	Mechanical Erection - Heat Exchangers	20	27
N429-C-ER-1220	Mechanical Erection - Compressor	20	22
N429-C-ER-1210	Mechanical Erection - TEG Unit	20	22
N429-C-ER-1160	Mechanical Erection - Waste Water Treatment	20	19
N429-C-ER-1300	Mechanical Erection - Pre Fabricated Tanks	150	12
N429-C-ER-1190	Mechanical Erection - Electrolyzer	20	9
N429-C-ER-1150	Mechanical Erection - Pumps	50	2
N429-C-ER-1260	Mechanical Erection - NG Boiler	40	0
N429-C-ER-1250	Mechanical Erection - Activated Carbon Bed	20	19
N429-C-ER-1080	Mechanical Erection - Air Cooler	100	21
N429-C-ER-1270	Mechanical Erection - Absorber	301	0
N429-C-ER-1280	Mechanical Erection - Direct Contact Cooler	289	0
Electrical / Instrumentation Control Room		347	11
N429-C-ER-1320	Incoming Power Supply Cable and Associated works	100	95
N429-C-ER-1290	Installation of Electrical Substation	40	64
N429-C-ER-1140	Erection at Site - Switchgear	30	11
N429-C-ER-1170	Erection at Site - Transformer	20	11
N429-C-GE-1300	Substation Cable Tray Laying & Cable pulling	60	11
N429-C-ER-1240	Erection at Site - DCS	30	32
N429-C-ER-1090	Erection at Site - UPS	20	24
N429-C-GE-1310	Substation Glanding & Termination works	41	11
N429-C-GE-1330	Precommissioning and ready for Energization	40	11
Piping works		304	0
N429-C-GE-1190	Piping Pre-Fabrication Work	160	3
N429-C-GE-1200	Erect/weld/support Area Pipework	200	0
N429-C-GE-1230	Piping Hydrotest Work	120	0
Electrical & Instrumentation Works		168	0
N429-C-GE-1220	Erect Cable Trays & Junction Box	90	8
N429-C-GE-1320	E & I Cable Pulling	120	8
N429-C-ER-1050	Erection at Site - Inline Instruments	60	0
N429-C-GE-1250	Gland & Termination works	40	0
Painting, Installation & Finishing works		60	90
N429-C-GE-1260	Insulate General Area Instruments, Equipment & Pipework	60	90
N429-C-GE-1270	Paint Area Pipework, Equipment & Piperacks	60	30
Flue Gas Run		220	8
N429-C-GE-1060	Flue Gas Run Foundation works	60	8
N429-C-GE-1070	Flue Gas Run Racks Installation and associated duct works	160	8
Commissioning and Start Up		60	0
N429-C-CM-1280	Commissioning and Start Up	60	0



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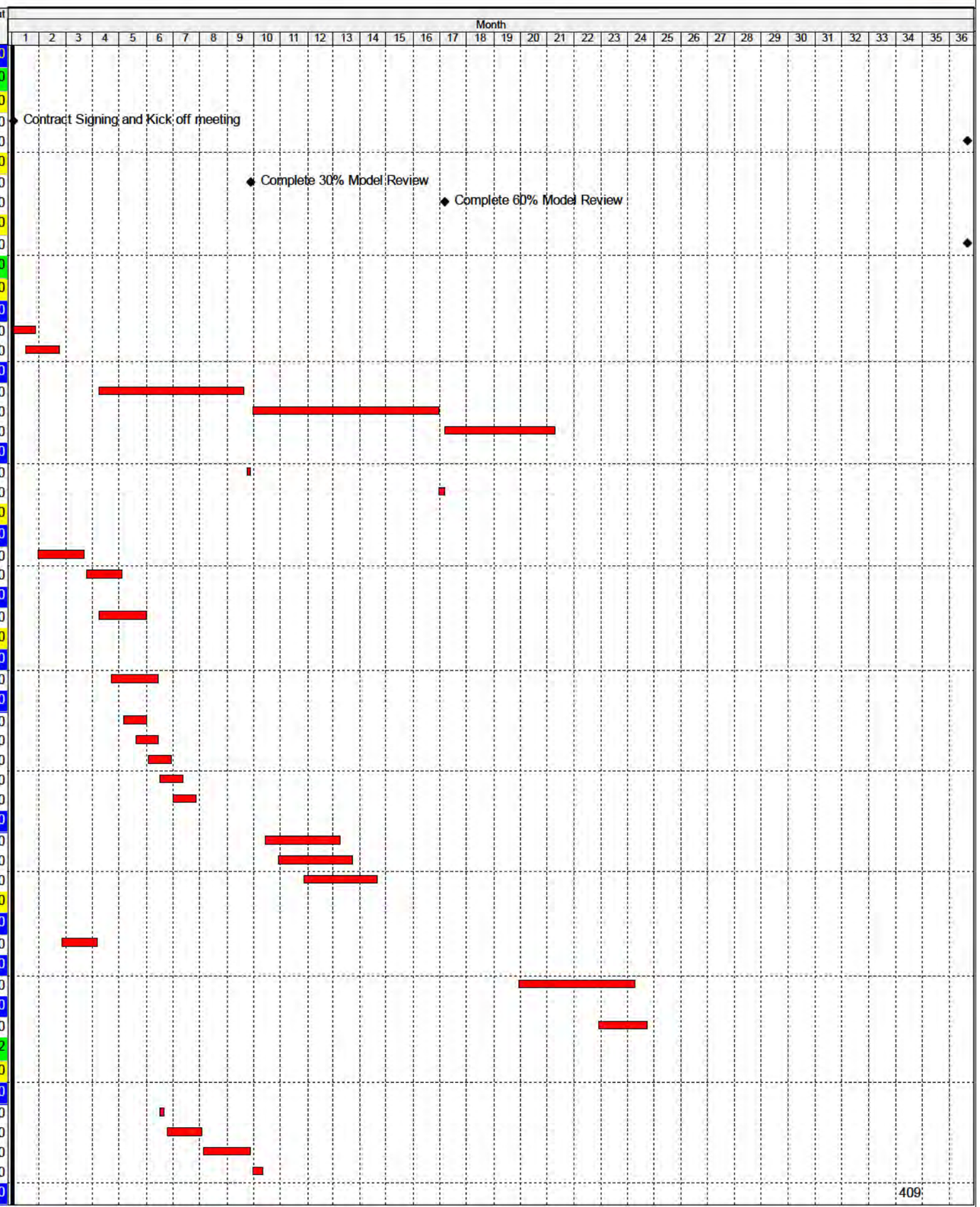
Actual Work Remaining Work Critical Remaining Work Milestone

ANNEXURE 3

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

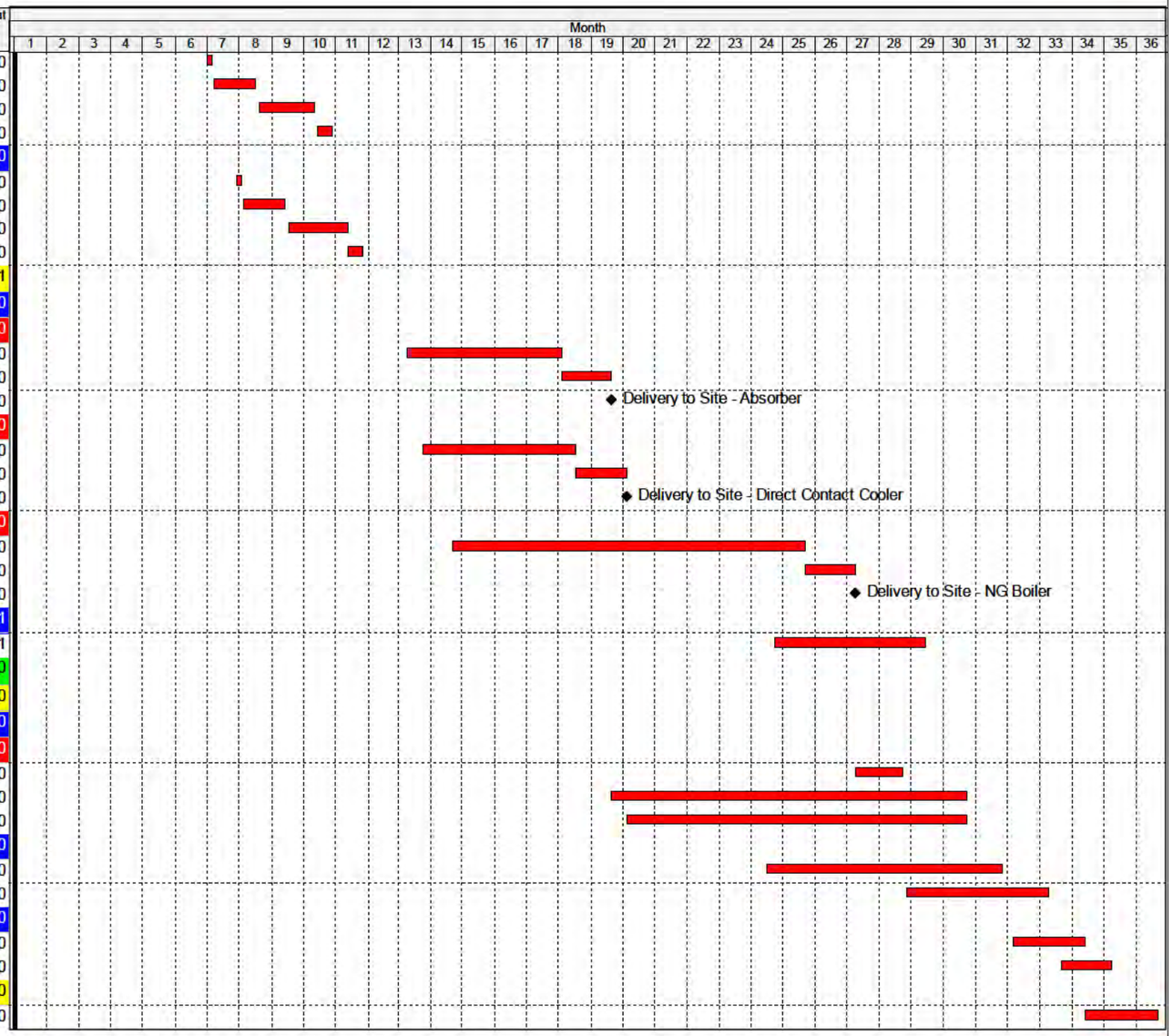
Activity ID	Activity Name	Original Duration	Total Float
RTI-NAS CO2 Capture Plant - EPC Schedule - Level 2		3262	0
Project Milestone		3262	0
Overall Milestones		3262	0
N429-O-ML-1010	Contract Signing and Kick off meeting	0	0
N429-O-ML-1020	Project Complete	0	0
Engineering Milestones		155	0
N429-E-ML-1000	Complete 30% Model Review	0	0
N429-E-ML-1020	Complete 60% Model Review	0	0
Construction Milestones		0	0
N429-C-ML-1060	Commissioning Complete and Project ready for startup	0	0
Engineering		515	0
Project Engineering		440	0
General		40	0
N429-E-PM-1000	Set Up Project Office / Mobilise Project Team	20	0
N429-E-PM-1020	Review & Verification of FEED Package (ALL Disciplines)	30	0
Model Development		370	0
N429-E-PM-1130	30% Model Development	120	0
N429-E-PM-1120	60% Model Development	150	0
N429-E-PM-1150	90% Model Development	90	0
Model Review		160	0
N429-E-PM-1040	Model Review (30%)	5	0
N429-E-PM-1050	Model Review (60%)	5	0
Process		90	0
Design Basis		70	0
N429-E-PR-1140	Process Design Basis	40	0
N429-E-PR-1130	Process Simulations & H&MB	30	0
PFDs		40	0
N429-E-PR-1120	PFDs - Develop/Update & Issue - IFR	40	0
Mechanical		215	0
Specifications and Calculations		40	0
N429-E-ME-1340	Specifications and Calculations	40	0
Material Requestions		60	0
N429-E-ME-1290	Produce Requisition / Datasheet Issue for enquiry - Compressor	20	0
N429-E-ME-1330	Produce Requisition / Datasheet Issue for enquiry - Absorber Column	20	0
N429-E-ME-1700	Produce Requisition / Datasheet Issue for enquiry - Direct Contact Cooler	20	0
N429-E-ME-1280	Produce Requisition / Datasheet Issue for enquiry - Regenerator Column	20	0
N429-E-ME-1200	Produce Requisition / Datasheet Issue for enquiry - NG Boiler	20	0
Post Order Documents Review		90	0
N429-E-ME-1690	Critical Vendor Data Submission and Submission and Review - Absorbers	60	0
N429-E-ME-1720	Critical Vendor Data Submission and Submission and Review - Direct Contact	60	0
N429-E-ME-1530	Critical Vendor Data Submission and Review - NG Boiler	60	0
Piping		475	0
Design Basis		30	0
N429-E-PI-1150	Piping design basis	30	0
Isometrics		95	0
N429-E-PI-1070	Stress Analysis and Isometrics Issue	95	0
MTO		40	0
N429-E-PI-1180	Piping Final MTO	40	0
Procurement		2095	2
Mechanical Equipment Ordering		115	0
Absorber		85	0
N429-P-PRE-1000	Issue Enquiry - Absorber	5	0
N429-P-PRE-1090	Supplier Bid Period - Absorber	30	0
N429-P-PRE-1360	Technical and Commercial Bid Evaluation - Absorber	40	0
N429-P-PRE-1620	PO Award Absorber	10	0
Direct Contact Cooler		85	0



Actual Work | Remaining Work | Critical Remaining Work | ◆ Milestone

N429 CEMEX-RTI CARBON CAPTURE PLANT
LEVEL 2 EPC SCHEDULE

Activity ID	Activity Name	Original Duration	Total Float
N429-P-PRE-2540	Issue Enquiry - Direct Contact Cooler	5	0
N429-P-PRE-2550	Supplier Bid Period - Direct Contact Cooler	30	0
N429-P-PRE-2560	Technical and Commercial Bid Evaluation - Direct Contact Cooler	40	0
N429-P-PRE-2590	PO Award Direct Contact Cooler	10	0
NG Boiler		85	0
N429-P-PRE-1280	Issue Enquiry - NG Boiler	5	0
N429-P-PRE-1520	Supplier Bid Period - NG Boiler	30	0
N429-P-PRE-2060	Technical and Commercial Bid Evaluation - NG Boiler	40	0
N429-P-PRE-2370	PO Award NG Boiler	10	0
Post Award and Manufacturing		618	1
Mechanical Equipment		534	0
Absorber		243	0
N429-P-POS-1730	Supplier Manufacturing Completion & Documentation - Absorber	183	0
N429-P-POS-1760	Transportation to Site - Absorber	60	0
N429-P-POS-1770	Delivery to Site - Absorber	0	0
Direct Contact Cooler		243	0
N429-P-POS-1780	Supplier Manufacturing Period - Direct Contact Cooler	183	0
N429-P-POS-1790	Transportation to Site - Direct Contact Cooler	60	0
N429-P-POS-1800	Delivery to Site - Direct Contact Cooler	0	0
NG Boiler		481	0
N429-P-POS-1700	Supplier Manufacturing Period - NG Boiler	421	0
N429-P-POS-1740	Transportation to Site - NG Boiler	60	0
N429-P-POS-1750	Delivery to Site - NG Boiler	0	0
Piping		180	1
N429-P-POS-1810	Final Piping Bulks - Delivery to Site	180	1
Construction		462	0
Above Ground Works		422	0
Erection		302	0
Mechancial Erection		302	0
N429-C-ER-1260	Mechanical Erection - NG Boiler	40	0
N429-C-ER-1270	Mechanical Erection - Absorber	301	0
N429-C-ER-1280	Mechanical Erection - Direct Contact Cooler	289	0
Piping works		240	0
N429-C-GE-1200	Erect/weld/support Area Pipework	200	0
N429-C-GE-1230	Piping Hydrotest Work	120	0
Electrical & Instrumentation Works		80	0
N429-C-ER-1050	Erection at Site - Inline Instruments	60	0
N429-C-GE-1250	Gland & Termination works	40	0
Commissioning and Start Up		60	0
N429-C-CM-1280	Commissioning and Start Up	60	0



410

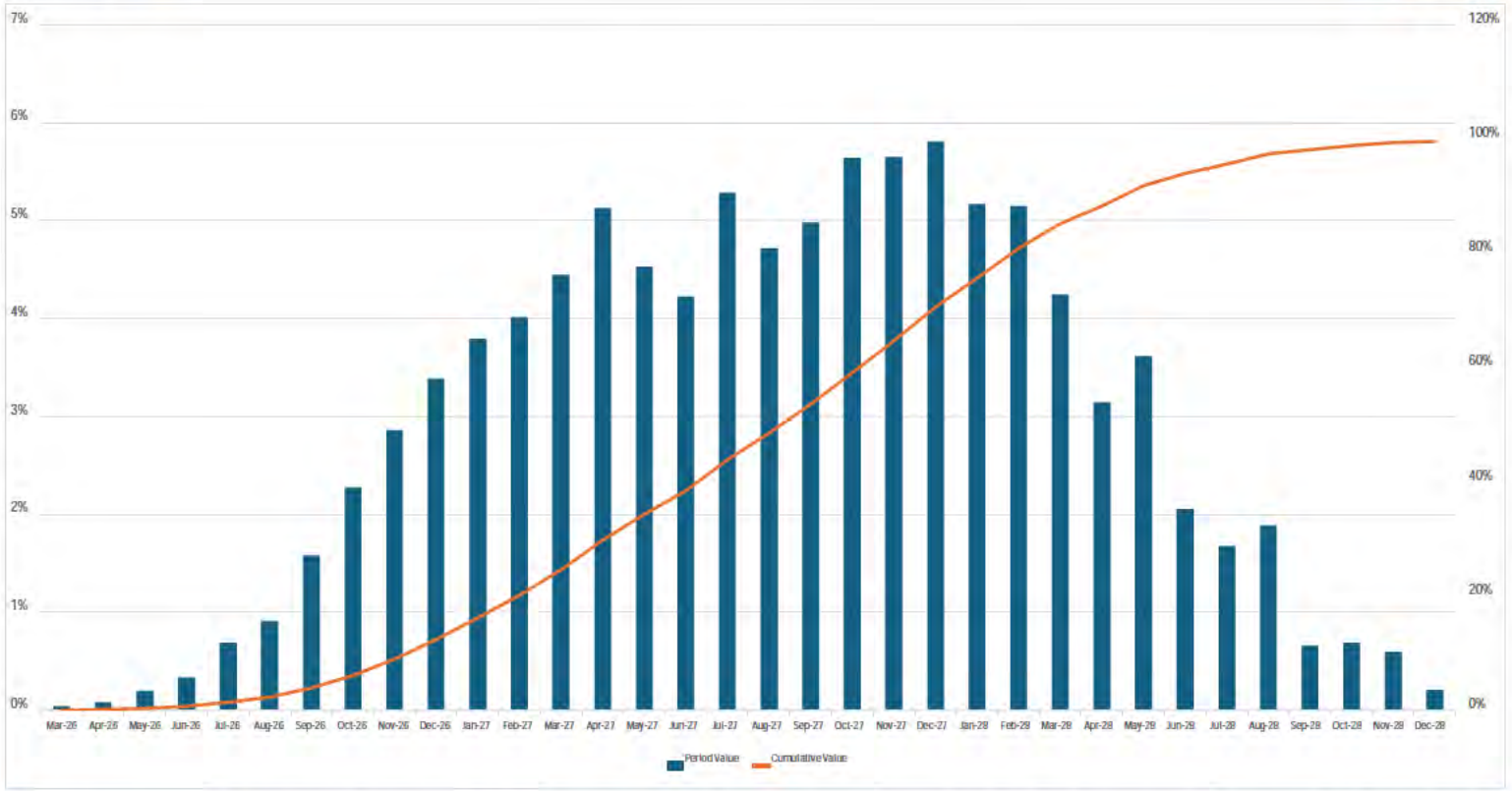
Actual Work | Remaining Work | Critical Remaining Work | ◆ Milestone

ANNEXURE 4

RTI INTERNATIONAL

RTI -NAS ENGINEERING AND CONSTRUCTION CURVE

KBR

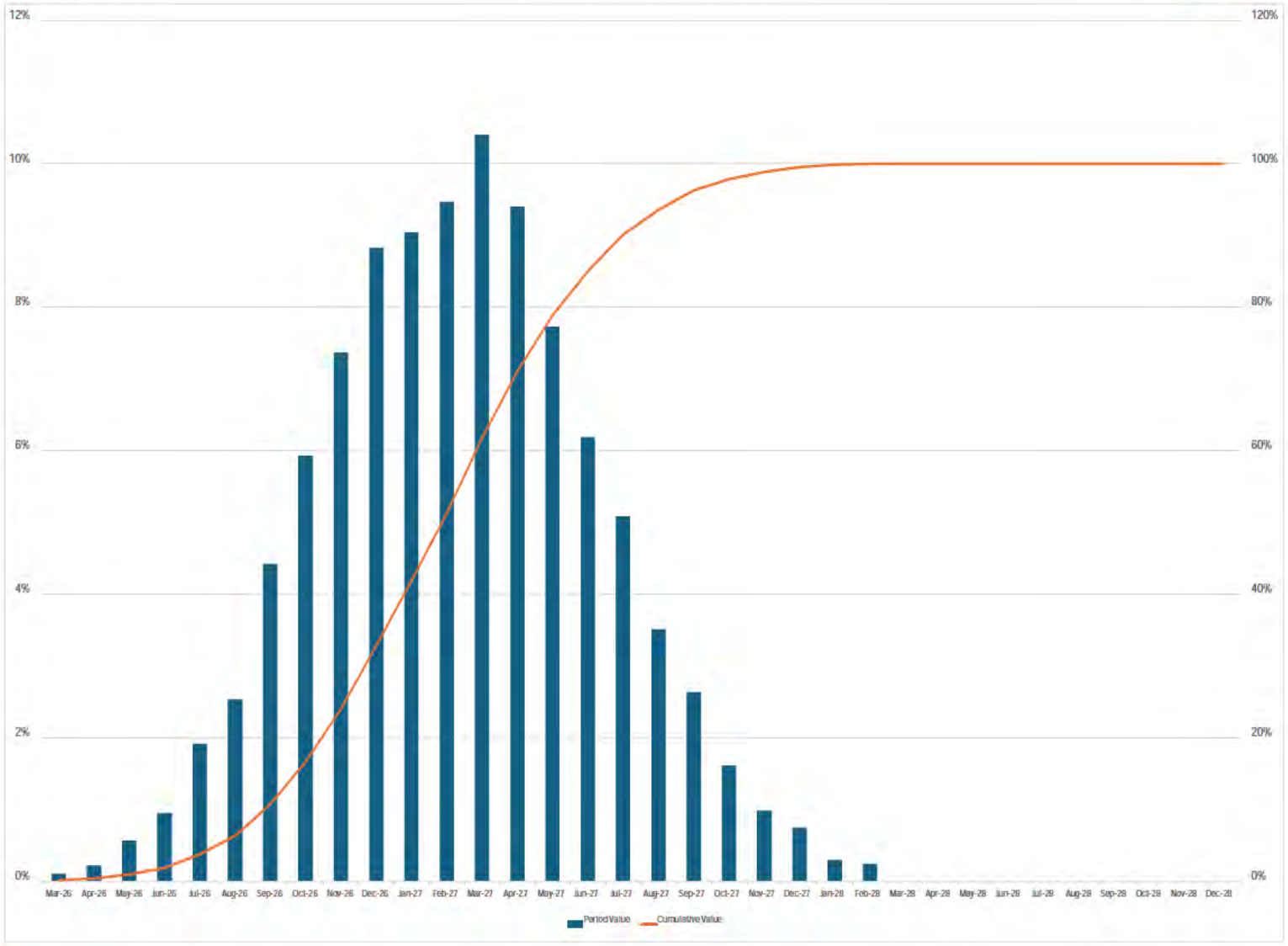


Month	Mar 26	Apr 26	May 26	Jun 26	Jul 26	Aug 26	Sep 26	Oct 26	Nov 26	Dec 26	Jan 27	Feb 27	Mar 27	Apr 27	May 27	Jun 27	Jul 27	Aug 27	Sep 27	Oct 27	Nov 27	Dec 27	Jan 28	Feb 28	Mar 28	Apr 28	May 28	Jun 28	Jul 28	Aug 28	Sep 28	Oct 28	Nov 28	Dec 28
Period Value	0%	0%	0%	0%	1%	1%	2%	2%	3%	3%	4%	4%	4%	5%	5%	4%	5%	5%	5%	6%	6%	6%	5%	5%	4%	3%	4%	2%	2%	2%	1%	1%	1%	0%
Cumulative Value	0%	0%	0%	1%	1%	2%	4%	6%	9%	12%	16%	20%	25%	30%	34%	38%	44%	48%	53%	59%	65%	71%	76%	81%	85%	88%	92%	94%	96%	97%	98%	99%	99%	100%

RTI INTERNATIONAL

RTI -NAS PROJECT ENGINEERING CURVE

KBR



Month	Mar 26	Apr 26	May 26	Jun 26	Jul 26	Aug 26	Sep 26	Oct 26	Nov 26	Dec 26	Jan 27	Feb 27	Mar 27	Apr 27	May 27	Jun 27	Jul 27	Aug 27	Sep 27	Oct 27	Nov 27	Dec 27	Jan 28	Feb 28	Mar 28	Apr 28	May 28	Jun 28	Jul 28	Aug 28	Sep 28	Oct 28	Nov 28	Dec 28
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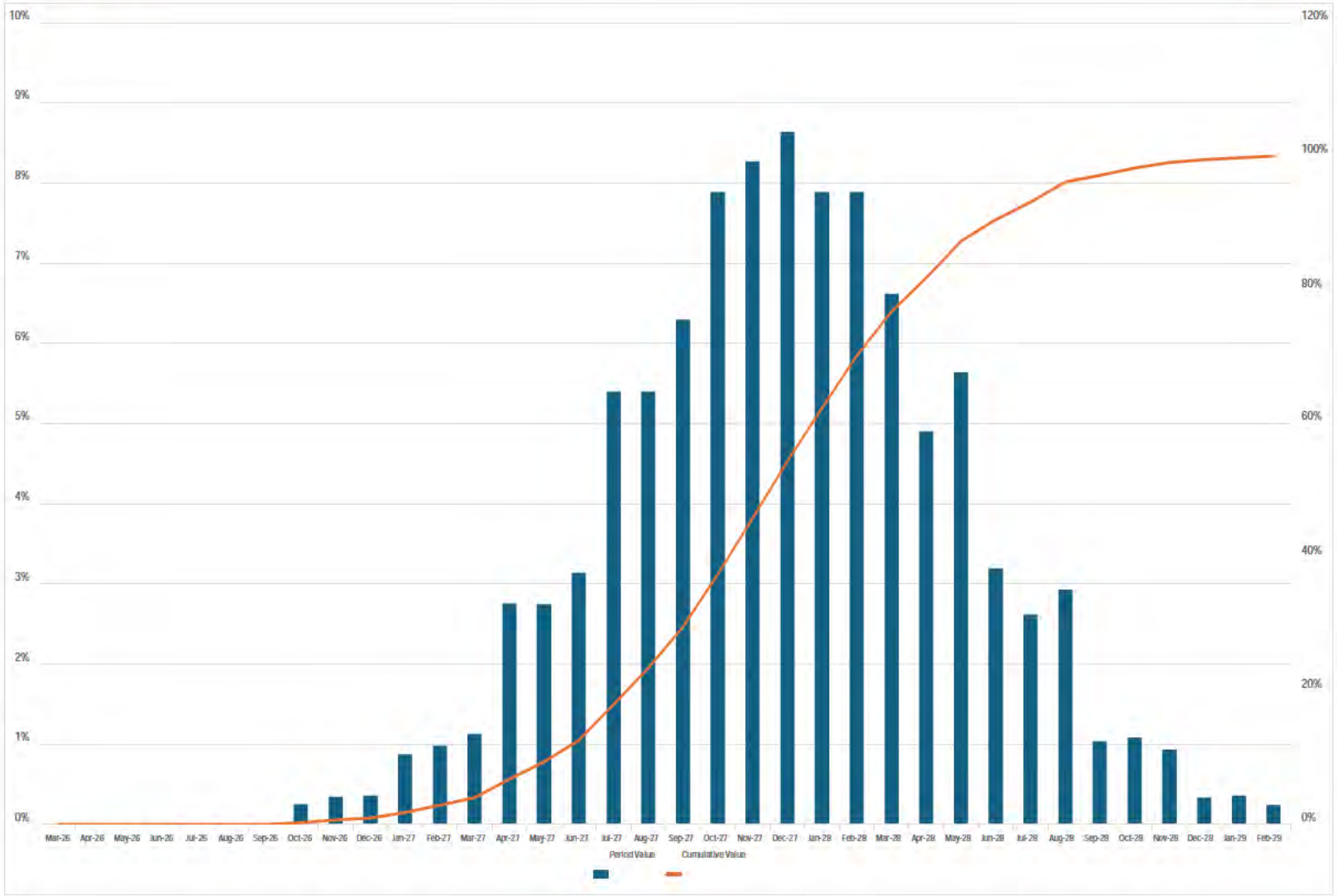
Cumulative Value	0%	0%	1%	2%	4%	6%	11%	17%	24%	33%	42%	51%	62%	71%	79%	85%	90%	94%	96%	98%	99%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

RTI INTERNATIONAL

RTI - NAS PROJECT CONSTRUCTION CURVE

KBR



Month	Mar 26	Apr 26	May 26	Jun 26	Jul 26	Aug 26	Sep 26	Oct 26	Nov 26	Dec 26	Jan 27	Feb 27	Mar 27	Apr 27	May 27	Jun 27	Jul 27	Aug 27	Sep 27	Oct 27	Nov 27	Dec 27	Jan 28	Feb 28	Mar 28	Apr 28	May 28	Jun 28	Jul 28	Aug 28	Sep 28	Oct 28	Nov 28	Dec 28	Jan 29	Feb 29
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Cumulative Value	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	3%	4%	7%	9%	13%	18%	23%	30%	37%	44%	50%	56%	62%	70%	77%	82%	87%	91%	93%	96%	97%	98%	99%	99%	100%	100%

Appendix H.2 Construction Execution Plan

Construction Execution Plan

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REV.	DATE	KBR ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	12/03/2024	IFI	Thomas Jones	John Hughes		

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION

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1. PROJECT REVIEW:

1.1 Project Information:

The Research Triangle Institute (RTI) International requested a Front-End Engineering & Design (FEED) study to build a greenfield capture facility at the CEMEX Balcones Plant in New Braunfels, Texas USA. The facility removes carbon dioxide (CO_2) from either power generation or industrial flue gas streams.

The CO2 capture plant is designed to remove at least 95% of CO2 from the flue gas from the Balcones Cement Plant kilns K1 and K2, which collectively produce CO2 emissions of 1.6 MM metric tonnes per year, and the associated natural gas boiler for steam generation. The captured CO2 has a purity of > 95% CO2, and is dried, polished to meet pipeline specifications, and compressed to 2215 psia (152.7 bara) to be made ready for sequestration. The CO2 capture plant consists of an integrated direct contact cooler (DCC) and SO2 polisher, a flue gas blower, an absorption column with intercoolers, a regeneration column, associated pumps, storage and receiver vessels, and a CO2 compression, dehydration, and polishing train. CO2 product end use (sequestration, EOR, etc.) will be determined in future phases.

1.2 Construction Introduction:

The goal of KBR's CM team (CMT) is to provide critical management and logistical contributions to the construction phase. This includes instilling cohesion in communication and purpose, cultivating a culture of safety, adhering to standards of quality, and meeting schedule and cost requirements. KBR CMT will draw on the unique advantage of working with a general contractor (GC) as well as subcontractors, whichever is the best for the success of the project.

1.3 Construction Execution Overview

The project area south of Wald Road and the length of the low duct supports area needs to be over-excavated by 9' since the soil is not suitable for structural backfill. This excavated soil will need to be relocated to an approved landfill off-site. Once the areas are excavated Imported non-expansive soil fill will to be brought into the site and compacted as needed to

meet the elevations for the new foundations and or pilings. During early site prep work preparation for the laydown and parking areas will begin at the site. The duct work inside the Cemex facility will be treated as a separate construction activity based on the information we have at this time. The path of construction will be based on the WBS information used during the FEED using the below list.

- Unit 01 – CO_2 Capture System
- Unit 02 – CO_2 Compression, Dehydration, and Polishing
- Unit 11 – Raw, Potable, and Demineralized Water System
- Unit 12 – Boiler & Steam System
- Unit 14 – Solvent & Chemical Storage Utilities
- Unit 15 – Cooling Water System
- Unit 16 – Air / Nitrogen System
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack
- Unit 22 – Utility Headers
- Unit 23 – Power Generation

2. ACRONYMNS

	Definition
A&D	Alcohol & Drug
AWP	Advanced Work Packaging
BOP	Balance of Plan
CEMP	Construction Environmental Management Plan
CM	Construction Manager
CMT	Construction Management Team
AWP	Advanced Work Packaging
EMP	Environmental Management Plan
EPCC	Engineering, Procurement, Construction & Commissioning
FEED	Front End Engineering Design
HSSE	Health, Safety, Security & Environment
IM	Interface Management

	Definition
IPMS	Integrated Project Management System
IQ	Interface Query
ISBL	Inside Battery Limits
ITP	Inspection Test Plan
IWP	Installation Work Package
JSA	Job Safety Analysis
KBR	Kellogg Brown & Root
RTI	RTI International
LOTO	Lock Out, Tag Out
NCR	Non-Conformance Request
OSBL	Outside Battery Limits
P&ID	Piping & Instrumentation Diagram
PDN	Project Deviation Notice
QC	Quality Control
RFI	Request for Information
RFSU	Ready for Start-Up
RTI	RTI International
TSTI	Total Safety Task Instructions
UPS	Uninterruptible Power Supply

3. CMT ROLES & RESPONSIBILITIES

3.1 Construction Management Responsibilities

The Construction Management Team (CMT) delivers several essential functions necessary for the operation of projects. These functions include:

- Supervisory

- Quality Control
- HSSE Management (including field safety professionals)
- Project Controls
- Scheduling
- Material Management
- Administrative
- Document Control

The CMT is responsible for day-to-day construction operations, material warehousing, direct work progress reporting, scheduling and cost reporting and field engineering support. The objective of this group is to detail and refine the path of construction, develop the Level 2-4 schedules and the weekly work plan, establish construction control tools, and coordinate the sourcing and processing of materials.

3.2 Construction Management Roles

3.2.1 Construction Manager

The construction manager (CM) reports to the project manager. The CM will be responsible for the development of a construction team that will be integrated with engineering and procurement. The CM will assist with the development of an integrated EPC schedule. As the project mobilizes, the CM will be the senior construction representative onsite and, through his staff, be responsible for all site activities. The CM will be the KBR designated representative to CEMEX on site for any communications concerning management and coordination of the work. The CM provides formal direction to the project team members to ensure that the project is executed in accordance with the Project Execution Plan and safety, quality, cost and schedule goals are successfully met.

3.2.2 Field Superintendent

The field superintendent (Supt.) reports to the Construction Manager. Each Supt. is responsible for the day-to-day coordination, supervision, and field administration of the construction work activities in their respective disciplines. The Supt. will work closely to improve productivity and provide efficient project completion activities. The Supt. will ensure that activities between the various crafts are closely coordinated,

construction equipment utilization is managed, and project procedures related to safety and quality standards are upheld. This project will utilize field Supt. with respective knowledge in mechanical, electrical and instrumentation (E&I), and civil/structural/architectural (CSA) disciplines.

3.2.3 HSEE Manager

The HSSE Manager functionally reports to the CM and administratively to KBR's corporate HSSE manager. The HSSE Manager is responsible for coordinating the Project HSSE Program with RTI, and all Subcontractors on the project. During Stage 2 design, HSE Manager will develop the Project HSE Site Specific Plan and supporting project safety procedures. The HSE Plan is a comprehensive safety and health program encompassing a system for total loss prevention and control. This system is based upon the principles:

- People are the Company's most important asset
- All accidents and injuries are preventable
- Health Safety and environmental protection is a line management responsibility
- Management has the responsibility to train employees to work safely and to develop a "Zero Harm" culture.

The HSSE Manager will monitor the overall safety performance of the project, identifying unsafe conditions and procedures, and recommending and insuring the implementation of corrective actions. The HSSE Manager ensures safety observations are tabulated and analyzed for trends and opportunities to reinforce safe behaviors. The HSSE Manager has a thorough knowledge of the federal, state, safety, fire, and health regulations and a working knowledge of hazardous gases and chemicals as well as the appropriate detection devices. The HSEE Manger will provide safety information and guidance to the project team on proper safety procedures, current and potential hazards and employee training requirements. This role will act as a "coach" to all subcontractors and direct hire supervision to make certain that safe work practices are the top priority for all personnel. The HSSE Manager is responsible for the establishment and maintenance of all HSSE record keeping systems.

3.2.4 Quality Manager

Quality Manager (QM) is responsible for the establishment of the QC programs in the field and for providing the technical direction during implementation at the site. The

QM will develop a construction quality plan during Stage 2 design and will incorporate CEMEX site QA/QC requirements.

The QM leads the selection and assignment of QC personnel and is responsible for their indoctrination, training, and certification.

3.2.5 Materials Manager

The Materials Manager will report directly to the CM. They will be responsible for field coordination of receiving all project furnished materials and plant equipment for construction and for transferring care, custody and control to the crafts and subcontractors. They will also be responsible for the field purchased materials and will approve all material and plant equipment invoices for payment. Material Manager supports project procurement and materials personnel and their associated activities to execute the work in a manner that achieves the objectives of the Project Materials Plan.

3.3 Interfacing Parties

The Carbon Capture project pulls together many integral engineering and construction teams. KBR will be responsible for overall stewardship of the interface management (IM process) at RTI's direction. Details of construction interface communication are discussed in Section 8. Major project interfacing parties affecting construction are:

- RTI
- KBR
- CEMEX
- Contractors

4. EXECUTION STRATEGY

4.1 EPC Pre-Planning

The construction manager will be an integral part of the project management staff during FEL and pre-construction phase of the project. The construction manager will provide input to engineering and materials management and review construction execution plans.

In addition to providing input to the project controls procedures, the construction team will also help identify construction control areas (work breakdown structure). These control areas will be referenced on all engineering design drawings.

CMT will develop and implement a comprehensive and proactive constructability program that will involve timely input to detailed engineering and materials management. Timely inputs will be provided during the development of plot plans, specifications, drawings, and where applicable, vendor data. The constructability program will be fully integrated with all project entities and will strive to provide cost effective and timely input into the project work processes.

4.2 Site Preparation

4.2.1 Site preparations will be divided up into early and advanced stage scope.

- Grading
- Foundation for Secondary Transformer
- Stormwater/Drainage
- Temporary Roadways
- Temporary Parking
- Ready Heavy Construction Laydown Area

4.2.2 KBR will work with the contractors to complete advanced-stage site preparation, which includes:

- Piles
- Pour Pile Caps/Backfill Up to Cap
- Underground Piping/Utilities
- Prepare Trenches for Trenway Cable Boxes
- Building, Equipment, & Tank Foundations

4.3 Access Control

- Access control measures will be implemented immediately following mobilization and remain through the course of construction. Initial access control measures until fence is completed will be 24-hour security personnel controlling access to

the site and will include signage and physical barriers to protect the public, construction workforce, and project property.

- All visitors will be required to sign into the gate log and will be escorted while on site.
- Project personnel will only use employer provided vehicles for use at the site and those vehicles may be subject to search, when entering or exiting the construction project area.
- All contractor vehicles are to have company placards displayed on both sides of the vehicle at all times.
- Employees, contractors, and visitors may park only in designated parking areas.
- Unauthorized vehicles, equipment and individuals will be immediately removed from the site.

4.4 Modularization & Pre-Assembly

Based on the technology capacity, design, large size erect in place columns, tanks, and very large sized equipment, there is minor potential for modularization for the Carbon Capture Plant during the FEED activities. Piperacks, Piping, Ductwork, may be preassembled at a local fabrication shop or at the project site. Pre-engineered Buildings, Large Tanks, Absorber Column, and the Direct Contact Cooler will be assembled on site.

Steel for air-coolers will be site erected and in place prior to the coolers arriving at site. Cranes will be used to set modules. Hook-up interface locations will be made at deck level to minimize the amount of scaffolding required.

4.5 Construction Milestones

The following are the Key Construction Milestones:

- Complete site prep
- Temporary Power Available
- Start Piling
- Underground Piping & Utilities
- Start Foundations
- Receipt of Bulk and Ship Loose materials
- Equipment/Skid Installation
- Stick-build construction
- Above Ground Piping

- Electrical and Instrumentation Installation
- Touch up Painting, Insulation, and Heat Tracing
- Permanent perimeter fencing (where applicable)
- Final permanent roads and drainage
- Permanent power available
- Start and complete electrical and instrumentation checkout
- Completion and handover of the plant. Buildings ready for occupancy.

4.6 Construction Completion

The CMT will manage project completion including inspection and testing, with complete quality control documentation. The project will be systematically turned over to a Commissioning Team to commence commissioning.
Prior to testing and turnover, Construction will coordinate with commissioning to jointly inspect system. This is to ensure no changes are needed for safety or operability before final construction testing. When a system is declared construction complete and turned over for commissioning, the care and custody become the responsibility of the Commissioning Team thus bringing the complete system.

4.6.1 Turnover System

If a Turnover system is needed for a project, KBR uses TurnOver System Tracking and Reporting (TOSTR). TOSTR is designed to monitor and inform the status of gradual transfer of care, custody, and control of the project to the owner by means of organizing and monitoring the status of the documentation required to certify the construction completeness of pre-designated portions of the job known as “Turnover Systems”. The program can utilize Tablet PCs to capture electronic Quality Control sign-off forms.
The program utilizes information generated by the Project Engineering Design teams, including Equipment Mechanical and Electrical Lists, Pipeline Line List, Tie-Ins and Isometrics Lists, Instrument Index, and Relief Valve List to organize and cross-reference all components and items by "Turnover System."

Some status reports generated by TOSTR include:

- Equipment Status
- Electrical Status

- Packaged Equipment Status
- Piping Testpack Status
- Instrument Local Status
- Instrument Loop Status
- Painting and Insulation Status
- Miscellaneous Status
- Punch List Status

4.6.2 Pre-Commissioning

Pre-commissioning will be conducted by Construction with the support of Commissioning and will commence once the system, or subsystem, is complete and safe to place under pressure for the purpose of blowing, flushing, or energizing for electrical and instrument testing.
Pre-commissioning consists of the following primary activities:

- Line cleaning - All system pipe and static equipment will be cleaned by air blowing or flushing as required.
- Reinstatement of all system equipment- Following the cleaning of all breakouts, valves, instrumentation, etc. will be reassembled using permanent specification gaskets.
- Vessel Inspection and final closure - The cleaning and inspection of internals installation will be witnessed and signed off by Commissioning.
- Instrument full loop checking - Loop checking will be witnessed and signed off by Commissioning.
- Bump the motor – Confirm terminations are correct on equipment.
- Cold alignment checks and coupling installation of rotating equipment
- Installation of temporary and permanent strainers and filters- witnessed by Commissioning.
- Function testing of electrical equipment - UPS, emergency and instrument power systems, switchgear, grounding, lighting, etc. - Lockout Tag out (LOTO) procedure will apply.

Pre-commissioning is complete when the relevant QC documentation and construction completion checklist items are signed off. Further details regarding commissioning will be provided in the future by the Commissioning Execution Plan.

5.0 CONSTRUCTION LABOR

5.1 Hiring Overview

The construction of this project will be executed by labor hired by local contractors. KBR will act as an agent for RTI/ CEMEX and will manage any subcontract work on-site.

5.2 Recognition & Reward Program

KBR will implement an employee recognition and reward program which is designed to have a positive impact on safety, quality, absenteeism and turnover, productivity, morale, and community relations. The program's key features are communication, appreciation and recognition. These basic elements provide for employee/contractor communication, appreciation, recognition, project participation/involvement. Subcontractor personnel will be involved in these programs through subcontract requirements.

5.3 Parking

A traffic simulation study will be conducted to optimize the incoming and outgoing traffic on the project site. At the peak of construction effort, it is estimated there will be 600+ people at the site during peak of construction.

5.4 Alcohol and Drug Policy Administration and Development

KBR implements an alcohol and drug program that prescribes an alcohol and drug free work environment as per KBR's Drug, Alcohol and Substance Abuse Policy (P-GL-KBR-HSSE-0602) and Drugs of Abuse and Alcohol Program Global Testing Guidelines (GD-GL-KBR-HSE-0618).

5.5 Training

KBR personnel will receive site specific training to perform assigned work safely and efficiently. Areas of special or essential training to include but not limited to the following:

- Expectations and Orientations
- Health and Safety
- Environmental
- CEMEX site specific training for work inside the CEMEX facility

6. HEALTH, SAFETY, SECURITY AND ENVIRONMENTAL

Commitment to HSSE performance is foremost of all considerations in planning and execution of work. The primary focus for the project is to execute with Zero Harm. Zero Harm is based on the understanding that all incidents and injuries can be prevented and that the behavior of all personnel on the project will demonstrate this belief.

6.1 Health and Safety

The CMT is committed to achieving the highest standards of HSSE performance on the project and in order to achieve this will apply the following:

- Develop a Project Specific HSSE Management System that incorporates all project requirements.
- Assign an experienced and dedicated Health, Safety, Security and Environmental Manager who will assist management with the administration and implementation of the HSSE program.
- Create a culture where individuals understand and take responsibility for their health and safety as well as the health and safety of co-workers.

Commitment will be demonstrated through visibility and communication by participation in safety program activities such as orientations, training sessions, meetings, jobsite safety walks and group safety talks.
To further everyone's understanding of their responsibilities, as well as understanding how to work safely, the HSSE program includes requirements for preparation of field level risk analyses and pre-task safety planning. The KBR Total Safe Task Instruction program (TSTI) will be implemented for this pre-task review. Each contractor's supervisor is required to review their work activities and conduct a pre-task safety meeting to address hazards, required protective equipment, safe work methods and work area inspections.

Jobsite and work area safety walks administered by the HSSE group will be scheduled under the direction of KBR management and will include subcontractors and area supervision. Unsafe acts and conditions will be recorded, and corrective actions taken immediately. If a condition cannot be corrected immediately, correction will be completed within the required or agreed time frame with a follow up inspection performed to confirm the condition is made safe.

6.2 Security

The project will use physical security measures and access control processes to protect personnel, facilities, and equipment. KBR will apply protective procedures and enforce

regulations within the project area. A KBR Security Execution Plan will be developed during the EPCC phase and will contain full details of the security policies and procedures to be implemented.

All personnel entering and exiting the project site will comply with the site security plan. Managers have a responsibility to ensure that all personnel, contractors, and subcontractors under their supervision adhere to and comply with security procedures.

All breaches of security procedures or road traffic incidents will be investigated to identify the cause to prevent recurrence. When appropriate, disciplinary proceedings or contractual requirements will be used to ensure compliance. KBR's HSSE Manager has the overall responsibility for the construction site security program. This includes development and maintenance of the security plan; approval of detailed security procedures; and overseeing of the guard force. For the guard force PCT plans to engage professional security services with a local security company.

6.3 Environmental

As part of project execution, KBR will undertake a program of environmental monitoring to assess the environmental impacts of activities during the construction phase as required by local, state, and federal regulations.

KBR's environmental monitoring program will be designed and staffed to ensure sufficient observation and reporting is performed to satisfy all applicable regulatory requirements, and project policies.

During the EPCC phase KBR will develop and implement a site-specific Construction Environmental Management Plan (CEMP) to minimize impacts to the environment. The plan will outline the processes, procedures, and administrative arrangements necessary to maintain compliance with all relevant project requirements, and Federal, State, and local regulations. The document will also include management approaches for coordinating with suppliers and subcontractors, as well as auditing, reporting and review processes, which are applicable to all aspects of environmental management. The CEMP will be a living document and will be periodically evaluated and improved, based on lessons learned, potential regulatory changes, changing operations, input from users and KBRs commitment to continuous improvement.

The plan will address:

- Roles and responsibilities for KBR staff, contractors and third-party environmental monitors
- Environmental risk management, compliance and monitoring
- Waste & Wastewater management
- Spill prevention and clean-up
- Incident management, reporting and investigation

- Environmental performance indicators & Auditing

KBR will implement an environmental monitoring program to confirm that all activities related to the construction effort are compliant with the standards outlined in the CEMP. KBR will obtain assurance from contractors, other third parties and their personnel that they commit to the CEMP and all its environmental plans and procedures.
The CEMP will outline the field practices and procedures in place to maintain compliance with the requirements for construction emissions, noise, water quality, sewage and waste disposal as outlined in the scope. Audits of the KBR CEMP and the construction works will be undertaken at regular intervals throughout the EPCC phases.

6.3.1 Air Emissions

Air emissions during the construction phase primarily consist of exhaust emissions from construction equipment, vehicles and dust emissions due to site preparation activities (clearing of vegetation and topsoil, excavation, placement and transport of soil, etc.) plus vehicle traffic on unpaved surfaces. Construction phase air emissions will be mitigated by a combination of site policies and conventional practices. For example, measures that may be employed are: a no idling policy for vehicles; the use of dust suppressants on active worksites and unpaved roads (either plain water or water with commercially available additives); and the use of sediment controls on exposed soil faces.

6.3.2 Liquid Effluents

Liquid effluents associated with the construction phase of the Project include:

- Sanitary wastes,
- Surface runoff,
- Concrete wash water and leachate,
- Hydrostatic test water,
- Spills from temporary generators, re-fueling stations and other construction equipment utilized on the Project.

Disposition of all these liquid effluents will be governed by federal, state, and local regulations, along with various construction permits also required.

6.3.3 Sanitary Waste

Waste from the job site toilet and washroom facilities will be collected and transported via tanker trucks to offsite facilities for proper disposal.

6.3.4 Spill Prevention & Response

The CEMP will detail the methods for preventing and responding to spills that may occur during construction. These procedures will be consistent with the information developed for the Local Emergency Response Plan.
Preventative measures include:

- Pre-trip equipment inspections,
- Regularly scheduled compliance audits
- Maintenance of an incident database and trend analysis
- Periodic worker education and awareness campaigns
- Toolbox talks and sharing of lessons learned.
- Project spill reporting thresholds will be established in consideration of KBR policies and regulatory requirements. Minor spills to land will be cleaned up by Gulfspan or Subcontractor staff.

6.3.5 Waste Management

KBR will work together to meet waste management requirements during all phases of the project. These requirements are applicable to all personnel generating waste, including subcontractors. Gulfspan will rely on licensed third-party specialty subcontractors for the disposal of waste generated during construction, municipal solid waste, and hazardous materials. A central waste management facility will be constructed early in the project to support the work activity. Where appropriate, accumulated wastes will be covered, bonded, or otherwise protected to maintain a neat orderly site that is safe, sanitary, and protected from vectors and wildlife. Subcontractors will be responsible for maintaining their work areas in compliance with the project policies. Upon commencement of the advanced-stage site preparation work, Gulfspan will provide roll-off containers in the active work areas for collection of bulk construction debris such as metal, wood waste, and concrete. Subcontractors will be responsible for transferring their accumulated waste to the central waste management area where it will be logged with the necessary paperwork and manifests.
Hazardous materials will be stored in a separate area and incompatible or reactive materials will be segregated. All hazardous materials will be handled and disposed of in compliance with applicable local, state, and federal regulations. Waste manifests and 'cradle to grave' documentation will be generated for all hazardous wastes.
Recyclable materials will be segregated at the source, collected separately, forwarded for further processing, and returned to beneficial use where feasible.
KBR's waste management procedures for the project will be detailed in the CEMP.

The Project waste management practices will be based on XXXX policies and Federal, State, and local laws and regulations.
KBR will track the waste production by category to determine the quantities generated and recycled.

7. QUALITY CONTROL AND QUALITY ASSURANCE

7.1 QC Plan

The KBR Quality Plan defines the activities to assure that civil, buildings, structural, pipe, mechanical, electrical, and instrumentation, equipment and materials are assembled, installed, erected, inspected, and tested in accordance with the applicable engineering drawings, specifications, codes, proven practices, local regulations and project specific requirements; that conforms to ISO 9001(2008) standards. Site specific Construction QC Procedures will be developed for the Project and included in the Construction QC Procedures Manual.
The KBR Quality Manager and associated staff are responsible for administration of the Quality Program and will oversee and coordinate with the Construction Team members who have the day-to-day responsibilities for installation. KBR field QC inspectors, under the direction of the Quality Manager will perform inspections and surveillances to confirm that the installation activities meet project requirements including verification of testing equipment.
The KBR quality overview is implemented via a range of activities including:

- Routine meetings that provide problem and performance comments as well as status/progress information
- Close overview of work performance
- Observance of inspections and tests per the Inspection and Test Plans (ITP)
- Conducting independent inspections and tests at random points/events
- Conducting audits of quality program implementation and documentation
- Include project specific training and quality workshops

The basis of quality control is the Inspection and Test Plan (ITP). The ITP lists specific witnesses and hold points and QC documentation for a particular work process. The management of the QC documentation is crucial to the smooth handover of the completed work by system and eventually the entire facility. The KBR Turnover Systems Tracking Report (TOSTR) will be used to track the status of the quality control documentation by discipline and by system. TOSTR tracks the completion of QC documentation at each milestone by discipline including exceptions and/or punch list items.

8.PROJECT COMMUNICATIONS

The CMT will execute Request for Information (RFI) to clarify drawings and design specifications back to engineering team, issue Non-conformance Request (NCR) for any discrepancies by supplier or subcontractor and identify scope changes which could potentially require a Project Deviation Notice (PDN) to report any costs related to a deviation.

The RFI/NCR/PDN process will be utilized to provide a uniform communication process, tracking system, and documentation between KBR, vendors, and RTI/CEMEX. This process satisfies the requirements and necessary approvals for construction, engineering, subcontractors, and vendors to request information, resolve non-conformances and to track rework and back charge costs. An RFI/NCR/PDN form will be used to request information on any construction question or problem, potential non-conformance, supplier deficiency, potential scope change, possible material substitution and requests for KBR engineering information or clarification. The form will be prepared and processed by CM or Supt., assigned a log number and kept in an active log showing all RFIs/NCRs, including need/response dates, resolution, associated drawings, associated equipment, etc. If the RFI results in action deviating from original scope, a unique PDN number is maintained with the RFI Number referenced.

The RFI process will be used by the field to modify all IFC documents (P&IDs, data sheets, vendor drawings, etc.) All red-line mark-ups incorporating as-built data will be tracked and closed via the RFI process with distribution to document control group for incorporation into the Turnover and Completion Package.

A document control program will be put in place to ensure that current engineering drawings and documents are available and maintained for craft, subcontractors, and vendors. KBR will perform audits to ensure consistency and accuracy of data and quality assurance compliance to procedures and project requirements.

9.0 CONSTRUCTION INTERFACES

KBR CMT is responsible for the coordination and management of the CEMEX Carbon Capture Project interfaces during the construction phase. CEMEX will be responsible for the decision making when interface conflicts arise based on cost and schedule considerations. The Interface Management plan referenced in appendix is intended to establish a framework for management of interfaces between multiple contractors during design and installation phases.

10. PROJECT CONTROLS

10.1 Work Breakdown Structure

Construction schedules, progress, and cost will follow the defined Work Breakdown Structure (WBS) for the project planning and scheduling. Working with Engineering and Procurement, the Construction Team will provide input to the project schedule to ensure drawings, material and equipment deliverables support construction need dates. CEMEX and KBR CMT will work together on a path of construction to define the most optimum sequence in progressing through the work areas. Material and equipment delivery requirements will be scheduled to support the path. The schedule will be tied to deliverables and will include all activities through construction completion to support pre-commissioning. This schedule will be in accordance with the agreed WBS and will be resource loaded once quantities and work hour estimates are complete.

The primary tool to be used for the schedules is Primavera. The following are the construction schedules that will be prepared and included in the project schedule:

- Level II Summary Schedule – The Summary Schedule is based on the Project Master Schedule and is the road map for the Level III Schedule. This schedule shows major milestones, activities per area, discipline, and work phase.
- Level III Detailed Schedule – The Detailed Schedule is the management level control tool for monitoring and reporting the overall construction status. This schedule further details the activities in the Level II schedule and identifies critical paths and sets priorities for the execution of the work. The Detailed Schedule is precedence based, critical path method network. The network is tied to engineering and procurement deliverables for early identification of any delay or change that requires corrective action.
- Level IV and Level V Working Schedule – based on the Level III schedule, the Working Schedule details activities to be performed daily and weekly.

10.2 Work Hours and Progress

Construction progress is milestone and quantity based and will be measured by direct work activity, by discipline within the WBS. The quantities of work, by activity, will be assigned unit work hours for installation. The total of the work hours by discipline as derived from the quantities will establish budget hours for each discipline. The total of all budget work hours for all disciplines will be the total direct construction work hours budgeted for the Project. The progress and productivity data derived from the progress measurement system will be the basis for workforce planning and forecasting.

11 LOGISTICS AND SITE MATERIAL CONTROL

11.1 Logistics

In KBR material control system, IPMS, each line item has an associated WBS designation, and that designation determines where that material will be dispatched to on-the-job site. Material shipments to the site will arrive at either the laydown yard or warehouse. The material management team will receive shipment and determine if material needs to be dispatched directly to the jobsite or to laydown area.

11.2 Material Management

The construction warehouse and storage areas will be established at the on the project site. Material control at site will be managed by the construction material control group, headed by the material control manager. The KBR material control group will manage the receipt, storage, and movement of material.
All materials arriving at site will be inspected and recorded by the site material control group along with the respective construction quality control representative.
The material control system that will be used is KBR IPMS. IPMS entries are initiated by home office procurement where all requisitions and purchase orders are entered. At site, IPMS is used to record receipts, record materials issued and maintain an inventory of materials onsite against purchase orders and requisitions. The system provides material status of undelivered material, material requirements by drawing, onsite storage location, and installation planning tools.

The material control group will prepare all receiving documentation, inspect materials for compliance to the requisition specifications and quantities, prepare overage, shortage and damage reports, record site storage location, and send reports to and follow up with home office procurement on exceptions.
The construction warehouse and lay down yard will accommodate required indoor storage as well as an area for materials which require climate-controlled storage. The warehouse and lay down yard are within fenced area of plant site.
Material preservation measures will be implemented on all materials and equipment beginning with arrival onsite, during storage, during installation and through pre-commissioning and start up. Material preservation maintenance records will be maintained to verify measures taken.

12. TEMPORARY FACILITIES

TBD Contractors will be responsible for mobilizing, installing, commissioning, operating,

managing, decommissioning, and demobilizing temporary facilities.
The temporary facilities include, amongst others:

- Buildings, including modular buildings, that will serve as administration offices, field offices, lunchrooms, toilets, medical facility, training center
- The construction and installation of the utilities required for the operation of the buildings.
- Facilities required to support the construction execution, such as waste handling, and fuel storage
- Temporary warehousing, laydown and storage.
- Temporary roadway, parking lots, and stormwater basins will be part of site preparation work.
- Temporary power for offices and buildings will be supplied from temporary substation and will meet the demands for construction power of the project.

12.1 Temporary Construction Facilities

Temporary construction facilities will be available and will be maintained by the KBR CMT.to include but not limited to the following.

- Construction, Subcontract, & Client Site Offices.
- Warehouses
- General Services Subcontracts Area
- Medical Area
- Training Center
- Parking
- Waste Management
- Fuel Storage
- Material Laydown Areas
- Heavy Equipment yard

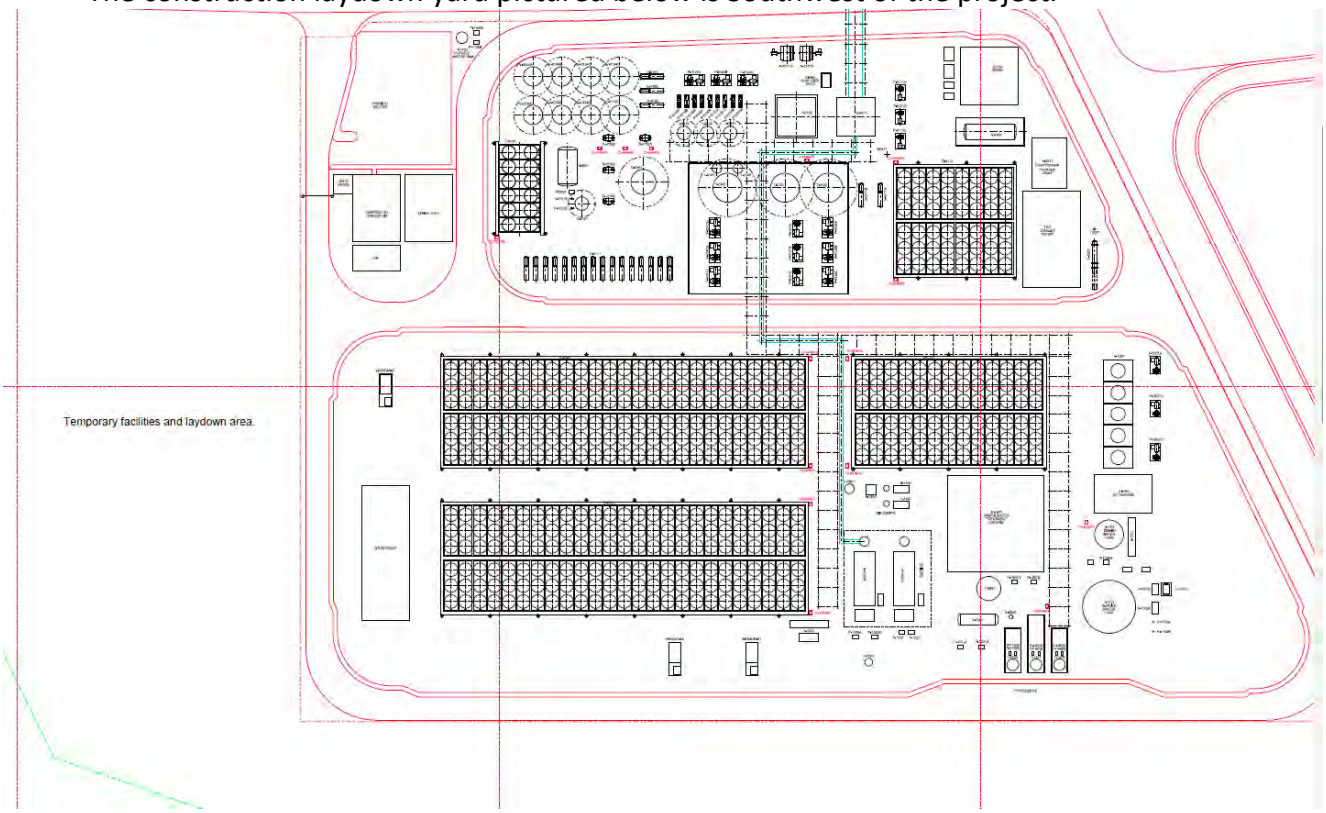
12.2 Subcontractor Areas

Areas will be designated for each Subcontractor's use to support the performance of its work.
Subcontractor supplied temporary facilities including offices, workshops, and other support infrastructure may
be placed in these areas. Subcontractors are responsible for permitting, supply, installation,

and removal of all facilities in its designated area, including connection to any utilities made available.

12.3 Construction Laydown Yard

The construction laydown yard pictured below is Southwest of the project.



Appendix I Project Cost Estimate

Appendix I.1 Capital Cost Estimate Basis

AACE Class 3 Basis of Estimate

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PROJECT NO.: N429	**DOCUMENT NO.:** DE-FE0032220-KBR-00-ES-G-RPT-001

REV.	DATE	ISSUE QUALITY	PREPARED BY	REVIEWED BY	KBR APPROVED	CLIENT APPROVED
A	11/25/24	Issue for Client Review	NW	RG	JH	
B	12/11/24	Updated for Client Comments	NW	RG	JH	

SUMMARY OF DOCUMENT REVISIONS

REV.	DATE REVISED	SECTION REVISED	REVISION DESCRIPTION
A	11/25/24	All	Original draft
B	12/11/24	2, 4, 7, 11	Maximum Unit Capacity, Capital Spares in Direct Construction Costs Section, Ocean Freight in Exclusion Section

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1. PURPOSE

This Basis of Estimate describes the methodology used to prepare the non-binding Class 3 estimate (target +15%/-15% accuracy) of the Carbon Capture Plant for cement manufacturing. This estimate was developed during Front End Loading (FEL-3) engineering and targeted as a Class 3 estimate based on the Association for the Advancement of Cost Engineering (AACE) International practice from the published Cost Estimate Classification System (18R-97, page 3, Rev. 8/7/20). KBR Estimating used the Aspen Economic Evaluation tools to organize, extend, compile, and sort the estimate data according to the agreed cost breakdowns. Specifically, Aspen Capital Cost Estimator (ACCE) V14.2 was used for this project.

2. PROJECT INFORMATION

The Research Triangle Institute (RTI) International requested a Front-End Engineering & Design (FEED) study to build a carbon capture facility at the CEMEX Balcones Plant in New Braunfels, Texas USA. The facility removes carbon dioxide (CO_2) from industrial flue gas streams.

The RTI technology uses a non-aqueous solvent and an absorber tower to capture CO_2 from cooled flue gas streams. The flue gas is washed to remove solvent and may be further treated to remove emissions (particulates, sulfur, NO_x, etc.). The stripped CO_2 is then treated and compressed for export. The study basis is to use the RTI CO_2 capture system on a design feed rate of 2.4 MM metric tons (tonne) of CO_2 per year with an average capture of 1.6 MM metric tons (tonne) of CO_2 per year at a lower capacity. This includes the exhaust gas from two cement kilns with 1.4 MM metric tons (tonne) of CO_2 per year, along with the exhaust gas from the natural gas boiler of 0.2 MM metric tons (tonne) of CO_2 per year installed for the RTI process. Total CO_2 capture is expected to be 95% or greater.

3. GENERAL ESTIMATE INFORMATION

The main tool utilized to compile the estimate was the Aspen Economic Evaluation Capital Cost Estimator, V14.2 version (ACCE). The tool relies on quantities and sizing information to generate costs and field labor hours from its own database of costs. The estimate is made up of a combination of sources of cost. The estimate was generated with the ACCE tool using regional cost conditions, KBR historical costs information, and vendor budgetary quotes.

3.1 CURRENCY

The estimate was provided in U.S. Dollars since the project is in the United States.

3.2 UNITS OF MEASURE

The estimate was generated using the Imperial system of units.

3.3 PROJECT WORK BREAKDOWN STRUCTURE (WBS)

At this stage there is not a formal Work Breakdown Structure (WBS) for the project. The cost estimate lists items by unit number, tag number, description, and discipline as applicable. The unit numbers are listed below:

- Unit 01 – CO_2 Capture System
- Unit 02 – CO_2 Compression, Dehydration, and Polishing
- Unit 11 – Raw, Potable, and Demineralized Water System
- Unit 12 – Boiler & Steam System
- Unit 14 – Solvent & Chemical Storage Utilities
- Unit 15 – Cooling Water System
- Unit 16 – Air / Nitrogen System
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack
- Unit 22 – Utility Headers
- Unit 23 – Power Generation

The unit numbers on the P&IDs were the basis for splitting the piping lines by unit number.

3.4 COST BASIS

The estimate was generated in U.S. dollars ($) with a 4th Quarter 2024 cost basis. The ACCE base escalation indices were adjusted based on current market conditions in order to bring the system generated costs to "today's" cost. Equipment quotes or costs provided by vendors, licensors, and contractors were brought up to the same overall cost basis. Forward-looking escalation was included in the estimate. The escalation is further explained in Section 9.

3.5 CONSTRUCTION BASIS

The construction basis for the estimate was based on stick-built methods (non-modular). A Construction Execution Plan (CEP) was generated by the KBR Construction Management group where a preliminary contracting strategy was mentioned. Specific contractors will not be identified at this time, so the specific construction sequence will not be part of the CEP or the estimate. The field labor productivity was adjusted to local conditions based on information specific to the project along with experience from past KBR projects in the region. The construction work week was based on 5 days x 10 hours a day for 40 regular hours and 10 overtime hours with a 50% pay premium. The plan was for a single mobilization of the construction contractor, since multiple mobilizations of the same contractor would have higher costs and increase the time required to complete the project. There is expected to be constraints in the workspace, which may require multiple crafts to work at the same time. The contractors fabricating the large towers on-site like the absorber mentioned that a certain distance has to be maintained

around these towers, which could possibly reduce the area available for other contractors to work on other tasks.

The project execution basis is an EPCM approach, where all procurement is on client's paper. An EPC type arrangement has not been considered in the costs or in the risk profiles that such arrangement may signify.

3.6 LABOR RATE AND PRODUCTIVITY

The construction worker field labor productivity in the estimate is 70% (x1.43 hours relative to a baseline project), using local greenfield labor productivity for the work week duration, some work at heights, worker skill level, site congestion, worker turnover, rigging requirements, and potential weather delays. Even though the project is near San Antonio, there is expected to be some difficulty hiring craft workers based on current labor surveys published from Alpha Resources (10/4/24) considering the size of the job. A craft per diem (50% of workers x $96/day) is expected to attract some of the workers who live outside of the region. Delays or increased costs due to future pandemics like COVID are not considered in the productivity or in the estimate. These are force majeure events that are beyond the scope of the estimate.

A contractor "All-in Wage Rate" (AIWR) for all construction disciplines was determined based labor surveys for the region. The breakdown of what was included in the AIWR is shown:

- Partial All-In Field Wage Rate (AIWR) – The expected non-union / open shop partial all-in wage rate (AIWR) was determined based on information provided by construction. The wages in the estimate vary by craft type. The average all-in wage rate (AIWR) is $105.80/hr and broken down as follows:
    - Direct Labor Wage Rate – Base take home pay to construction worker. (30%)
    - Fringe Benefits & Burdens – Includes taxes, unemployment insurance, health benefits, vacation, holidays, sick pay, etc. (11%).
    - Overtime / Premium Time – Covers the 50% premium paid for the 10 overtime hours each week (3%).
    - Craft Supervision– Foreman and overhead excluding construction management (15%).
    - Small Tools & Consumables – For items like drills, wrenches, welding electrodes, fuel used by workers (3%).
    - Field Services – G&A overhead and home office support (13%).
    - Construction Equipment Rental – For equipment rental (manlifts, small cranes, specialty equipment, etc.), mobilization/demobilization & maintenance (8%).

- Temporary Facilities – Trailers, utilities, furniture, toilets, internet, etc. for the construction workers (7%). Construction Management (CM) temporary facilities is included in the Construction Management costs explained in Section 6.
- Business Expenses – Covers office supplies and office equipment (1%).
- Contractor Profit / Fee – Applied to the costs listed above for the construction firm (9%).

*Scaffolding, Construction Management, Vendor Representatives, Start-up, Commissioning, and Per Diem are accounted for outside of the AIWR, and explained in Sections 6 and 7 of this Basis of estimate.

3.7 PIPE EXECUTION STRATEGY

The estimate assumed that typical process piping is fabricated in a local pipe fabrication facility and shipped to the site. Any small bore (<0.5" diameter) piping or specialty piping is fabricated in the field.

3.8 STEEL EXECUTION STRATEGY

The estimate assumed most steel installed in the field will be fabricated in a local steel fabrication facility and shipped to the site. The estimate is based on a fabricated cost/ton of steel, whether shop or field fabricated. Percentages of field vs shop will not be defined in the Basis of Estimate.

4. ISBL AND OSBL PLANT COSTS

4.1 ENGINEERING DELIVERABLES

The engineering deliverables were reviewed by estimating and included the key information listed below.

- Equipment List – Number, type, capacity, size, design pressure, design temperature, etc.
- Electrical Equipment List / Datasheets – Number, type, capacity, size, power, etc.
- Electrical Material Take-Offs – Number, type, material, diameter, length, etc.
- Lighting Plans – Number, type, mounting type, etc.
- Control Systems Material Take-Offs – Number, type, location, capacity, material, diameter, length, etc.
- Piping & Instrument Diagrams (P&ID's) – To determine pipe fittings, valves, and associated instruments.
- Piping Material Take-Offs – Number, material, length, diameter, thickness, fittings, valves, insulation, tracing, etc.

- Piping Tie-in List – Location, number, material, diameter, etc.
- Civil, Structural, Architectural Material Take-Offs – Number, location, materials, dimensions, volumes, strength, etc.
- Heating, Ventilation, and Air Conditioning (HVAC) Scope – Type, capacity, size, energy output, design pressure, design temperature, etc.
- Fire Protection Scope – Number, equipment type, piping type, location, capacity, size, design pressure, design temperature, etc.
- Project Schedule

4.2 VENDOR BUDGETARY QUOTES & CONTRACTOR ESTIMATES

KBR provided the relevant information like the technical datasheets, requisition package, specifications, etc., to obtain vendor budgetary quotes. The budgetary quotes were checked against the associated design specifications to see what is included and excluded. Any items excluded from the quote were estimated with allowances. Equipment quotes were obtained on all critical mechanical equipment, which make up 94% of the total mechanical equipment costs in the estimate. In addition, quotes were obtained on most electrical equipment and instruments. In general, the lowest technically viable quotes were considered for the estimate, but averages were used in a few cases due to uncertainty in the accuracy of the quote and items included by the vendor.

Contractor quotes were also included for Power Overhead Feeder, Gatehouse, Warehouse, ECR Building, Control Room & Change Room Building, Maintenance Building, Lab, and Compressor Sheds.

- The combined value of the vendor budgetary quotes and contractor estimates make up 66% of the total project equipment & material costs. The remaining bulk materials and equipment were estimated by Aspen Capital Cost Estimator (ACCE) indexed based on KBR experience.

4.3 CAPITAL SPARES

The capital spares are included in the estimate as estimated by KBR ($5.6 MM). All other spares are excluded and should be determined by the client in the Owner's costs.

4.4 SITE SOIL FILL & DISPOSAL

The project area south of Wald Road and the length of the low duct supports area will need to be over-excavated by 9' since the soil (expansive soils) is not suitable for structural backfill, as per the CEMEX new Geotechnical Report. This excavated soil will

need to be disposed of at an approved landfill off-site. Imported non-expansive soil fill will need to be brought into the site and compacted to replace the over-excavated expansive soil. The costs for the imported fill, soil transportation, and soil disposal cost were estimated by KBR based on previous projects in the area. The soil fill purchase price used in the estimate is $20.98/CY. The soil transportation and disposal costs used in the estimate are $42.17/CY assuming non-contaminated soil.

5. DETAILED DESIGN

Engineering & Home Office costs ($50.6 MM) for detailed design were included in the estimate based on the typical factors employed by KBR for this type of scope accounting for the expected scope split between the KBR USA offices, and other high value engineering centers such as the Chennai office (India). Detailed Design cost includes Procurement. The detailed design cost was based on factors for standard detailed design work and does not include any costs outside of the design work. Equipment Quality (QA) assurance is excluded (explained in Section 8).

6. CONSTRUCTION MANAGEMENT

The Construction Management Team (CMT) costs are based on the project schedule, field hours, expected staffing plan, and per-diems ($9 MM). It includes Construction Quality Assurance (QA) for the supervision of general construction activities with a materials management representative, and a Health, Environment, and Safety (HSE) representative. The temporary facilities, vehicles, and indirect supplies associated with the CMT were included. Construction Management costs include support during Start-up/Commissioning.

7. OTHER INDIRECT COSTS

The following is a list of other costs that are included in the estimate:

- Scaffolding –Estimated by KBR based on a percentage of the field direct hours times the scaffolding rates for labor & materials (11% of direct construction labor costs).
- Vendor Representatives – Costs are an allowance (1% of equipment costs) based on previous projects.
- Freight – Was added when not covered by the vendor budgetary quotes. For large equipment like the absorber, regenerator, and direct cooler that has to be shipped on the largest truckable freight sizes, it was estimated at 5% of equipment costs. For other items freight was estimated at 3% of equipment and field material costs. There was no ocean freight or air freight considered.
- Heavy Haul / Heavy Lift – Assumed heavy haul/lift applies to a few large equipment that could be 150 tons or more with a cost $4,000 / ton based on previous projects.

- Fire / Hole Watch – Assumed at 1% of direct labor costs to cover an extra construction person to monitor crews doing welding, trench work, etc.
- Start-Up & Commissioning –Used an allowance (2.5% of the Total Installed Costs) based on previous KBR projects.

8. OWNER'S ESTIMATED COSTS

The Owner might be better able to estimate these. In most cases these costs are excluded from the capital estimate:

- Owner's Staff (Excluded)
- Equipment Quality Assurance (Excluded beyond what is already covered in the vendor quotes)
- Permits (Excluded)
- Financing and Interest Charges (Excluded)
- Land Purchase Cost (Excluded)
- Initial Stores Stock, Feedstock Costs, and Process Waste Costs (Excluded)
- Catalyst and Chemicals – Excluded except for the 1st fill of activated carbon.
- Capital Contributions to Utility Infrastructure or 3rd Party Facilities (Included) – The estimate includes the New NBU Utility Transformers / Substation Costs and Feeder Line Costs allocation to CEMEX.
- Owner's Contingency (Excluded) – Estimate includes only the P50 value of the CRA (reference section 10).
- Road Improvements (Excluded) – If required outside of plant boundaries to facilitate shipping.
- Other Spare Parts (Excluded) – For equipment and bulk materials classified for commissioning & start-up, warehouse, operating, etc.

9. ESCALATION

An allowance of forward escalation was applied based on the expected purchase of items like equipment, materials, labor, etc. from the project schedule. This accounts for the expected increase in costs from today's date to when the expenditure is made on the project. Currently, the project construction schedule has not been finalized. The current escalation forecasts from KBR for this project are 2.5%/year. RTI & CEMEX has advised using a projected EPC Start Date of the 1st quarter of 2026, the escalation applied to the project costs are shown below based on the predicted timing of expenditures:

- Absorber, Regenerator, Direct Contact Cooler (2.9%) – Purchased 20 months ahead (March 2026) of the midpoint of construction (November 2027).
- Long Lead Equipment (4.6%) – Other specialty equipment that requires more extensive fabrication is purchased 12 months ahead (November 2026) of the midpoint of construction (November 2027).
- Other Equipment, Materials, Construction Labor, & Staffing (7.5%) – Purchased around the midpoint of construction (November 2027).

10. CONTINGENCY

A Cost Risk Analysis has been performed for this project through a Monte Carlo simulation with the results of this analysis provided as one of the tabs in the estimate reports. The analysis included conversations with the engineering disciplines and other KBR departments involved in the development of the estimate to assign proper expected variability ranges to quantities and costs. The P50 value of the results was included as the contingency cost in the estimate summary but the final selection of the appropriate P value is dependent on multiple factors including the client's/owner's affinity to risk. Clients all differ in their opinions on which P value they are willing to contemplate for their capital investments, hence why the entire distribution of results was provided. Note that at this time, a schedule risk analysis has not been performed and discrete risks have not been identified. These risks normally generate their own components of contingency that are not currently included in the analysis performed for this project.

11. ESTIMATE EXCLUSIONS

Below is a list of additional excluded costs in addition to the Owner's costs mentioned in section 8:

- Davis Bacon Act/Prevailing Wage Rates
- Early and Front-End Engineering & Design (FEED)
- Subcontractor Claims Allowances
- Removal, Remediation, and Disposal of hazardous material
- Removal of underground obstructions
- All-Risk Insurance
- Camps for field labor support and bussing/transportation of field labor
- Air freight
- Ocean Freight
- All taxes and permits

- Import Duties and Special Fees
- Warranties
- Operating Costs
- Decommissioning and Demolition Costs
- EPC execution or EPC costs related to profit/risk

Appendix I.2 Capital Cost Estimate, AACE Class 3

Class 3 Cost Estimate (DE-FE0032220-KBR-00-ES-C-EST-001) - Rev B 12/11/24

Project Cost Summary

Project Title: CO2 Capture in Cement Manufacturing

Project Name: CO2 Capture in Cement Manufacturing ***Scenario Name:*** Base Case

Proj. Location: New Braunfels,TX ***Job No:*** N429 ***Prep. By:*** NW

Estimate Date: 11DEC24 16:43:38 ***Est. Class:*** 3 ***Currency:*** DOLLARS USD

Account	MH	Wage Rate	Labor Cost	Matl Cost	Total Cost	Percentages
(2) Equipment	145,062	120.19	17,435,052	230,284,642	247,719,694	44.4% of TDC
(3) Piping	432,036	118.12	51,030,880	59,283,342	110,314,223	19.8% of TDC
(4) Civil	449,555	87.78	39,461,054	49,711,474	89,172,528	16.0% of TDC
(5) Steel	151,411	113.18	17,137,379	19,705,834	36,843,213	6.6% of TDC
(6) Instruments	73,205	109.32	8,002,938	8,890,445	16,893,383	3.0% of TDC
(7) Electrical	113,730	105.88	12,041,383	39,592,539	51,633,922	9.3% of TDC
(8) Insulation	44,793	81.90	3,668,418	970,143	4,638,561	0.8% of TDC
(9) Paint	4,313	78.36	337,947	57,114	395,061	0.1% of TDC
Total Direct Field Costs	**1,414,104**	**105.45**	**149,115,051**	**408,495,533**	**557,610,585**	100.0% of TDC
	(TDMH)		(TDL)	(TDM)	(TDC)	
Indirect Field Costs					**54,328,759**	36.4% of TDL
	(IFMH)				(IFC)	
Owner's Indirect Costs					**12,075,800**	8.1% of TDL
					(OFC)	
Direct + Indirect Costs					**624,015,144**	82.2% of TIC
	(TFMH)				(TFC)	
Freight					13,324,866	3.3% of TDM
Heavy Lift / Haul					4,704,200	1.2% of TDM
Taxes (VAT), Import Duties, Permits						
Engineering & Home Office					50,600,000	6.7% of TIC
Total Non-Field Costs	(HOMH)				**68,629,066**	9.0% of TIC
Project Costs					**692,644,210**	124.2% of TDC
Escalation					41,522,844	5.5% of TIC
Contingency					24,741,430	3.3% of TIC
Project Costs (with Escalation & Contingency)					**758,908,484**	136.1% of TDC
					(TIC)	

Notes:

1. Field Labor based on Local Wage Rates, Labor Productivity (70% 30 productive min/hr), and work week is 5x10 hrs/day including overtime. A craft per diem was included for 50% of workers at $96/day.
2. Prevailing Wage, normally required for government funded projects, has not been considered in this estimate.
3. 1st fill of activated carbon is included in the capital costs.
4. 1st fill of lean amine solvent is not included in the capital costs.
5. Contingency amount is the P50 value determined through a Monte Carlo CRA.
6. The CRA/Monte Carlo simulation does not account for schedule risk or for discrete risks (normally identified in a Risk Register). Both of these risks should have a contribution to the final contingency required for the project.

Aspen Capital Cost Estimator

Indirect Field Cost Summary

Code	Description	Notes	Ind Cost
	CONSTRUCTION MANAGEMENT	Includes Staff & Temp Facilities	9,037,056
	START-UP, COMMISSIONING	2.5% of Total Installed Costs (TIC)	18,972,500
	Field Office Staff		**28,009,556**

Code	Description	Notes	Ind Cost
	SCAFFOLDING, PLATFORMS	11% of Direct Labor Costs including Equipment	15,737,509
	FIRE WATCH / HOLE WATCH	1% of Direct Labor Costs	1,491,151
	E UIPMENT RENTAL	Small Cranes, Manlifts, etc.	In Direct Field Costs
	VENDOR REPRESENTATIVES		2,302,846
	FRINGE BENEFITS		In Direct Field Costs
	PA ROLL TAXES & INSURANCE		In Direct Field Costs
	SMALL TOOLS & CONSUMABLES		In Direct Field Costs
	CRAFT SUPERVISION		In Direct Field Costs
	CRAFT PER DIEM (NOTE 1)	$96/day for 50% of Crafts	6,787,697
	BUSINESS EXPENSES		In Direct Field Costs
	FIELD SERVICES		In Direct Field Costs
	TEMP. CONST., UTILITIES		In Direct Field Costs
	OVERTIME PREMIUM (NOTE 1)	40 regular + 10 overtime hours x 50% premium	In Direct Field Costs
	PREVAILING WAGE RATE (NOTE 2)		Excluded
	OVERHEAD		In Direct Field Costs
	PROFIT		In Direct Field Costs
	Construction Indirects Total		**26,319,203**

Code	Description	Notes	Ind Cost
	CEMEX NEW POWER SUBSTATION		12,075,800
	Owner's Indirects Total		**12,075,800**

Aspen Capital Cost Estimator

Non - Field Cost Summary

Code	Description	Notes	Ind Cost
	FREIGHT	5% for large equipment, 3% of small equipment & materials	13,324,866
	HEAV HAUL / LIFT	$4000/ton for 150 ton	4,704,200
	Freight Total		**18,029,066**

Code	Description	Notes	Ind Cost
	TAXES / VAT		Excluded
	IMPORT DUTIES		Excluded
	PERMITS	To be determined from client.	Excluded
	Taxes and Permits Total		

Code	Description	Notes	Ind Cost
	DETAIL ENGINEERING	6.7% of TIC based on expected hours and average rate with HVEC content	50,600,000
	PMT & OWNERS COSTS	To be determined from client.	Excluded
	Engineering & HO Total		**50,600,000**

Code	Description	Notes	Ind Cost
	ESCALATION	@ 2.5%/yr for the Absorber/Regenerator/Direct Cooler 2.9% (March 2026),	41,522,844
	Other Project Costs Total	Long Leads 4.6% (Nov 2026), Rest 7.5% (Nov 2027-Construction Midpoint)	**41,522,844**

Code	Description	Notes	Ind Cost
	CONTINGENC (NOTE 5 & 6)	3.37% of Net Costs (P50 value from Monte Carlo results).	24,741,430
	Contingency Total		**24,741,430**

Aspen Capital Cost Estimator

Wage Rate Summary

Average Wage Rate Build-up (All-In Rate)		
FIELD HOURS	1,414,104	hr
WAGE RATE	$105.45	per MH
CONSTRUCTION MANAGEMENT	$6.39	per MH
E UIPMENT RENTAL	Included	per MH
BUSINESS EXPENSES	Included	per MH
PA ROLL TAXES & INSURANCE	Included	per MH
SMALL TOOLS & CONSUMABLES	Included	per MH
CRAFT SUPERVISION	Included	per MH
CRAFT PER DIEM (NOTE 1)	$4.80	per MH
FIELD SERVICES	Included	per MH
TEMP. CONST., UTILITIES	Included	per MH
OVERTIME PREMIUM (NOTE 1)	Included	per MH
PREVAILING WAGE RATE (NOTE	Excluded	per MH
OVERHEAD	Included	per MH
FIRE WATCH / HOLE WATCH	$1.05	per MH
PROFIT	Included	per MH
***All Inclusive Wage Rate**	**$117.69**	per MH

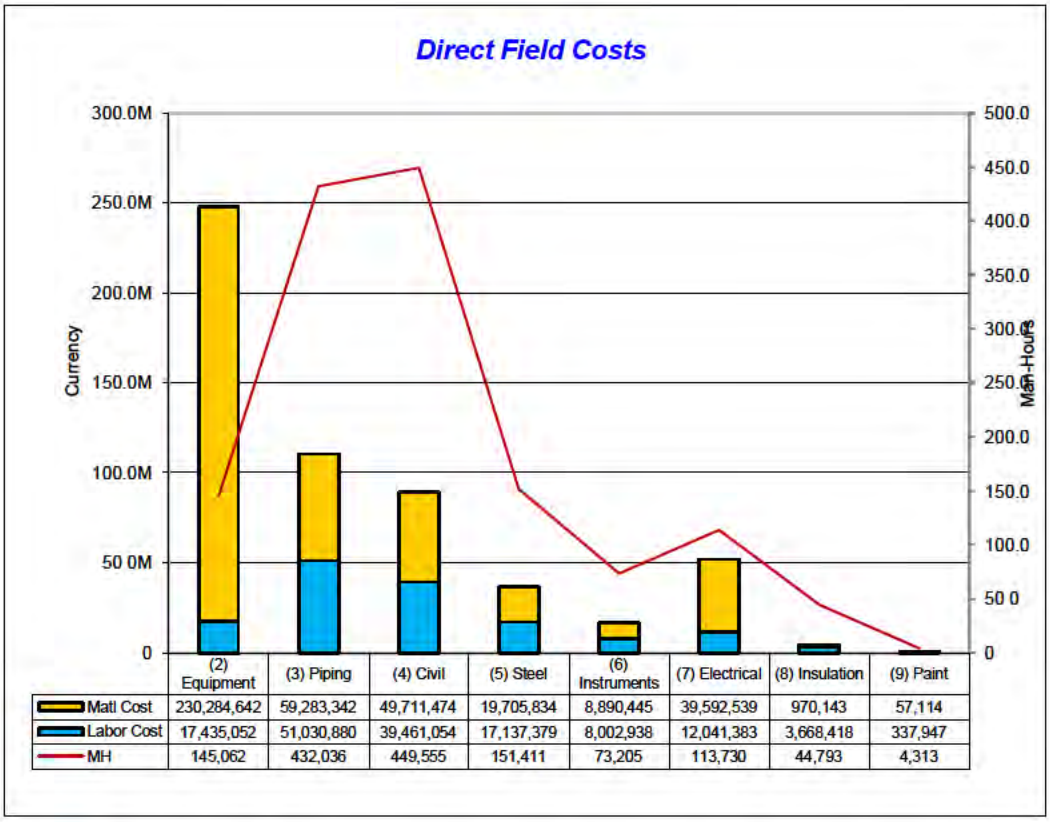
(Excludes Escalation)

Direct Account Totals

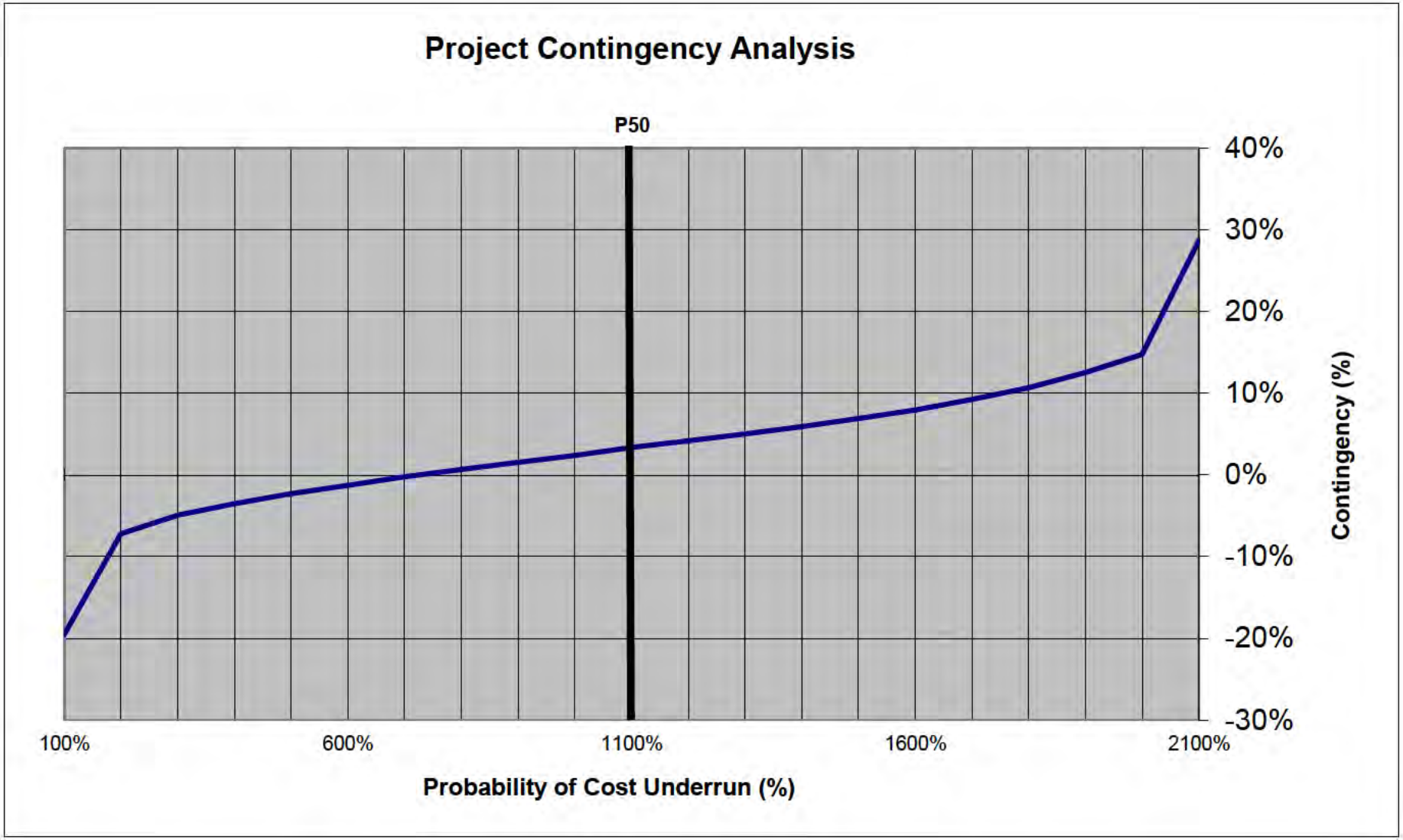
Key Quantity Summary

Project Title:	CO2 Capture in Cement Manufacturing							**Prep. By:**	NW
Project Name:	CO2 Capture in Cement Manufac	**Scenario Name:**	Base Case			**Proj. Location:**	New Braunfels,TX		
Estimate Date:	11DEC24 16:43:38	**Est. Class:**	3			**Job No:**	N429	**Currency:**	DOLLARS USD

Account	ey ty	ey Units	Unit MH	MH	Wage Rate	Labor	Unit Matl	Matl	Total
(2) Equipment	185.0	ITEM(S)	784.12	145,062	120.19	17,435,052	1,244,781 85	230,284,642	247,719,694
(3) AG Pipe	76,387.2	FEET	5.13	391,882	118.78	46,546,486	737.15	56,308,973	102,855,459
(3) UG Pipe	19,755.0	FEET	2.03	40,154	111.68	4,484,394	150.56	2,974,369	7,458,763
(4) Concrete	29,234.6	C	13.20	385,909	87 94	33,936,114	501.64	14,665,337	48,601,452
(4) Earthwork	12.0	LS		39,401	77.67	3,060,370		28,760,378	31,820,747
(4) Other Civil	2.0	LS		28	90.12	2,523		3,017,500	3,020,023
(4) Other Sitework	5.0	LS		4,052	87 85	356,010		163,586	519,596
(4) Paving	563.7	C	17.71	9,982	103 28	1,030,952	2,083.52	1,174,561	2,205,513
(4) Piling	623.0	EACH	15.46	9,633	106 95	1,030,247	3,032.00	1,888,935	2,919,182
(4) Roads / RR	9.0	LS		549	81.63	44,838		41,176	86,014
(5) Steel	2,819.7	TONS	53.70	151,411	113.18	17,137,379	6,988.58	19,705,834	36,843,213
(6) Instrumentation	590.0	EACH	124.08	73,205	109 32	8,002,938	15,068.55	8,890,445	16,893,383
(7) AG Electrical	324,811.1	FEET	0.32	104,705	107 38	11,243,680	120.45	39,124,735	50,368,415
(7) UG Electrical	30,061.0	FEET	0.30	9,025	88 39	797,703	15.56	467,804	1,265,507
(8) Equip Insula ion	31,910.3	SF	0.54	17,233	85.71	1,476,959	7.12	227,275	1,704,234
(8) Pipe Insula ion	28,238.7	FEET	0.98	27,560	79 52	2,191,459	26.31	742,868	2,934,327
(9) Paint	88,382.0	SF	0.05	4,313	78 36	337,947	0.65	57,114	395,061
Totals:				**1,414,104**		**149,115,051**		**408,495,533**	**557,610,585**



	(2) Equipment	(3) Piping	(4) Civil	(5) Steel	(6) Instruments	(7) Electrical	(8) Insulation	(9) Paint
Matl Cost	230,284,642	59,283,342	49,711,474	19,705,834	8,890,445	39,592,539	970,143	57,114
Labor Cost	17,435,052	51,030,880	39,461,054	17,137,379	8,002,938	12,041,383	3,668,418	337,947
MH	145,062	432,036	449,555	151,411	73,205	113,730	44,793	4,313


Project Contingency Analysis
P50
40%
30%
20%
10%
0%
-10%
-20%
-30%
Contingency (%)
100%
600%
1100%
1600%
2100%
Probability of Cost Underrun (%)

Appendix J EH&S Topical Report

Carbon Capture Plant FEED Study for Cement Manufacturing

Topical Report:

Environmental, Health and Safety (EH&S) Analysis

Contributors: Jak Tanthana, Vijay Gupta , Paul Mobley, Marty Lail, atherine Fuller (RTI, Senior Environmental & Occupation Safety Specialist) and Eric Chen (RTI, Senior Industrial Hygienist)

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DE-FE0032220

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LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH: American Conference of Industrial Hygienists

ASME: American Society of Mechanical Engineers

BACT: Best Available Control Technology

CAA: Clean Air Act

CARC: Carcinogens

CERCLA: Comprehensive Environmental Response and Liability Act of 1980

CWA: Clean Water Act

DCC: Direct Contact Cooler

DHS: Department of Homeland Security

DL: Detection Limit

DNEL: Derived No Effective Level

DOE: U.S. Department of Energy

ECT: Emission Control Technology

EH&S: Environmental, Health, and Safety

EPA: Environmental Protection Agency

FEED: Front-end Engineering Design

FOA: Funding Opportunity Announcement

GHGT: Greenhouse Gas Control Technology Conference

HMIS: Hazardous Materials Identification System

IARC: International Agency for Research on Cancer

ICPMS: Inductively Coupled Plasma Mass Spectrometry

IDLH: Immediately Dangerous to Life or Health

JSA: Job Safety Analysis

K_{oc}: Organic Carbon-Water Partition Coefficient, a measure of organic material soli mobility

LC50: "Lethal Concentration, 50%" or LCt50 (lethal concentration and time) of a toxin, radiation, or pathogen is the dose required to kill 50% of the members of a tested population after a specified test duration.

LD50: "Lethal Dose, 50%" or median lethal dose. It is the amount of the substance required (usually per body weight) to kill 50% of the test population.

LEPC: Local Emergency Planning Committee(s)

MEA: Monoethanolamine

NAS: Non-aqueous Solvent

NCCC: National Carbon Capture Center

NDEA: N-nitrosodiethylamine

NMOR: 4-nitrosomorpholine

NDMA: N-nitrosodimethylamine

NETL: National Energy Technology Laboratory

ng: Nano-gram $=10^{-9}$ gram

NIOSH: National Institute for Occupational Safety and Health

NPDES: National Pollutant Discharge Elimination System

NSPS: New Source Performance Standards

NTP: National Toxicology Program

OECD: Organization for Economic Cooperation and Development

OEHHA: Office of Environmental Health Hazard Assessment

OSHA: Occupational, Safety and Health Administration (U.S. Government Agency)

PI: Principal Investigator

POTW: Public Owned Treatment Works

PM: Particulate Matter

PPE: Personal Protection Equipment

ppm: parts per million

PSV: Pressure Safety Valve

REPR: Reproductive Toxins

RTI: Research Triangle Institute

SARA: Superfund Amendments and Reauthorization Act

SCBA: Self-Contained breathing Apparatus

SAR: Supplied-Air Respirator

SERC: State Emergency Response Commission

SDS: Safety Data Sheet

SSTU: Slip-steam Test Unit

TCM: Technology Centre, Mongstad

TEG: Triethylene Glycol

TLV: Threshold Limit Value

TSCA: Toxic Substances Control Act

USEPA: U.S. Environmental Protection Agency

VOC: Volatile Organic Carbon

WWTF: Waste Water Treatment Facility

wt%: weight percent

EXECUTIVE SUMMARY

This topical report presents the environmental, health and safety (EH&S) analysis for the project under DE-FE0032220 involving the front-end engineering design (FEED) study of RTI's Non aqueous solvent (NAS) CO_2 capture technology for Cemex's cement manufacturing plant in Balcones, TX. This EH&S risk analysis is conducted to assess the risks associated using the NAS for post-combustion CO_2 capture at commercial scale. The technical data for the NAS are drawn from multiple DOE projects with the most notable ones being the Emission and Effluent Summary report produced in this project (ref. DE-FE0032220-KBR-00-EV-C-EV2-001) and recently completed engineering-scale testing campaign conducted at Technology Centre Mongstad (TCM) (DE-FE0031590). The FEED study has quantitatively determined the air emissions, liquid and solid waste streams that would be produced as a result of installing the NAS CO_2 capture technology at Balcones along with potential fugitive emissions that would be generated by the auxiliary units such as TEG dehydration unit, natural gas boiler, etc. Under the TCM project, the solvent was tested for > 2800 hours under a realistic flue gas and operating condition. The secondary emissions, degradation products, and formation of the by-products, corrosivity data from the TCM test campaign serve as basis for determination of the secondary emissions generated from the NAS capture plant at Balcones site.

This assessment summarizes the key CO_2 capture plant EH&S concepts and approach. Key EH&S risk factors assessed and addressed as part of the overall approach are provided in tabular form including the risk mitigation factors. The assessment describes the technology as applied to carbon capture from flue gas in response to the six specific topics from the Append H of FOA DE-FOA0002515.

This EH&S analysis also evaluates the potential risks along with their impacts and mitigation actions to increase the technology viability from the safety and environmental standpoints. It is to be noted that some of these risks are perceived risks at the current stage of development of our technology at engineering-scale level. There could be other site-specific risks that will be identified as we continue the effort in development to a commercial scale of the NAS technology. Nonetheless, the conventional liquid absorption process and well-established operational understanding of this process would make it unlikely to discover major safety roadblocks or identify large risks that were unaccounted before.

Furthermore, this analysis details and quantifies waste streams that will be generated during the normal operation of a cement plant with 2,400,000 TPY CO_2 capture unit. Process modifications and suggestions that could potentially reduce or recycle the waste generated from these points of discharge will be discussed. Finally, the compliance and regulatory implications in reference to applicable U.S. EH&S laws and associated standards of RTI's NAS technology will be evaluated. It is to be noted that the compliance evaluations are not fully-conducted at the current stage of the technology development and certainly require further considerations that are more local and site-specific that involve stakeholders and EH&S authorities. The cross-reference and comparison between federal requirements and state regulations need to be conducted to ensure the operating compliances for emissions, waste generation and treatment, and proper emergency responses.

Both the NAS-amine and the organic diluent used in NAS formulation are commercially available materials, and the associated risks outlined in the document draws from the Safety Data Sheets (SDS) of these chemicals. The SDS of the formulated NAS will be made available to the end user as a controlled document.

Key findings of the preliminary EH&S assessment process are:

- No significant EH&S risks to plant operators, other employees, and surrounding area environment were identified that would adversely affect the implementation of NAS technology.
- The NAS CO_2 capture plant will increase the VOC emissions from the baseline by 6X-7X at the site due to the presence of amine and secondary emissions of the organic compounds from NAS solvent. However, the PM2.5 and SO_x emissions will be eliminated compared to the baseline emissions. NO_2 emission will also be reduced but overall NOx emission remains essentially the same due to the large presence of NO.
- The toxicological issues related to the NAS amine, as per the SDS, shows that the NAS is low in toxicity and highly biodegradable and is, therefore, not expected to bio-accumulate.
- The NAS flash point has been tested using the Pensky Martin Closed Cup method (ASTM D93) by multiple third-party labs and was determined to have no measurable flash point. It is stable under normal conditions without possible hazardous polymerization reaction, has a relatively low volatility and low corrosivity.
- The SDS sheet lists hazards associated with the NAS and the recommended precautions: Avoid contact with eyes. Avoid inhalation of vapor. Wear protective clothing as necessary to minimize contact. The primary employee health hazard is contact exposure to NAS during material handling. Appropriate personal protective equipment (PPE) is required to reduce/eliminate direct exposure. Provide local exhaust ventilation to control vapors/mists. Wear respiratory protection if ventilation is inadequate, such as a NIOSH-certified (or equivalent) organic vapor respirator.

PROCESS DESCRIPTION

The NAS CO_2 capture process is designed similar to an aqueous amine absorption process. The process is installed downstream of the flue gas desulfurization unit and upstream of the stack (Figure 1). The process uses low-pressure steam from the power plant's steam cycle to provide the thermal energy needed to regenerate the NAS.

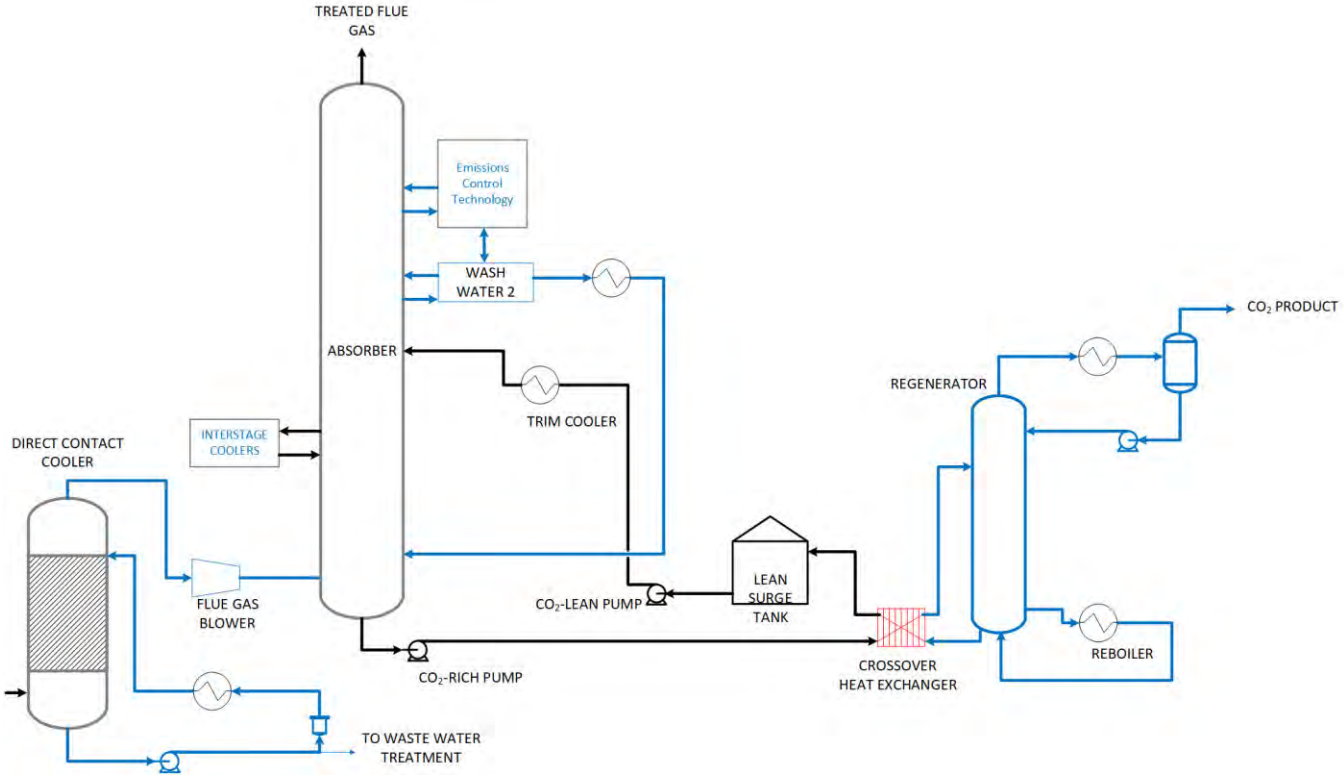

Figure 1. Simplified Flowsheet of the NAS CO_2 Capture Process for cement production studied under this project.

RTI's NAS process is anticipated to be inherently low in operational risks with the adoption of the conventional absorption process that is well known and widely used in the industry. However, the large footprint of the absorption process for such large scale treating of a cement flue gas and the use of large quantities of organic solvent to capture CO_2 require a thorough consideration of the impact to the environment and the surrounding communities. To this end, we are evaluating the environmental health and safety impacts on a commercial cement production plant equipped with RTI NAS's CO_2 capture process at 2,400,000 TPY CO_2 capture capacity. The six EH&S analyses required per FOA are described below.

EH&S Analysis

1. All potential ancillary or incidental air and water emissions, and solid wastes produced from the proposed technology and their magnitude

The FEED study has determined that there will be only one stack being added to the Balcones site. The stack will be at the top of the acid wash section of the absorber stack where treated flue gas stream is a major flow. This single stack also collects gas relief, emissions, and still off gas from various units within the CO_2 capture process. For example, The A-2001 stack, which is separate from the absorber stack, receives reliefs from PSVs as well as miscellaneous other vents from the process, including A-0221 and C-0151, but ultimately the discharge merges into the absorber stack. The outbreathing vent from the Solvent Sump (V-1401) will be discharged to the Absorber Stack. Other emissions are from direct vent to the atmosphere or fugitive emissions from different units within the NAS CO_2 capture plant. The reported emissions in Table 1includes baseline emissions (i.e., no capture plant) for minor species namely PM, THC, SO_2, CO, NOx, and HCl from Balcones plant for both cases.

Table 1: Summary of the air emissions from NAS CO_2 capture plant for the design case.

Species	Net Change in Emissions (with CCS – without CCS), Design Case
	mg/Nm^3
VOC	79
HAP	12
CO_2	net 92.7% reduction
TEG	0.0
CO	37
PM2.5*	reduced to nil
NOx	21
SO_2*	reduced to nil

The total liquid effluent to be discharged from NAS CO_2 capture plant to wastewater treatment facility (WWTF) at Balcones site is determined to be 88,243 lb/hr under the max condition. While the process water bleed from Feed Direct Contact Cooler V-0111 produces the largest amount of wastewater, that stream is processed to recover water and 185,484 lb/hr, or 95% is recycled to the CO_2 capture process. The remaining 9,762 lb/hr is sent to WWTF. This additional wastewater generated from the capture plant will be neutralized and processed before discharge to a pond on site.

While most information on the solid wastes generated from various equipment within the NAS CO_2 capture process are not provided by the equipment vendor, the largest solid waste to be produced by NAS CO_2 capture process is likely to be the spent adsorbent from the activated carbon beds which translates to 106.8 lb/hr of solid waste to be disposed of from the site.

2. Description of the various toxicological effects of the substances in the NAS

The NAS amine is the main component for which toxicological effects are relevant. RTI's NAS consists of two components: an amine specie blended with a hydrophobic organic diluent at a specific ratio. Though comprehensive toxicity studies of the NAS have yet to be conducted to determine its impact on the health and environment, we reviewed relevant experimental data from data generated in the past projects during the scale-up of the technology (DE-FE0013865, DE-FE0026466, DE-FE0031660) and published literature of the two components to get an estimate on health and environmental impacts. It is obvious that extensive ecological and toxicological studies will be required to determine the exposure limits, acceptable contamination level in waterways, and biological toxicity to understand the extent of the impact from using the NAS at a large scale when the NAS process is adopted commercially. Overall assessment of the NAS solvent is given in this section while the subsequent sections provide a more detailed review of the amine and diluent.

None of the NAS chemicals are included in the General Industry Process Safety Management list of highly hazardous chemicals, the OSHA list of carcinogens, chemical specific standards, or the Table Z-1 Limits for Air Contaminants. The components of the NAS solvent and their hazardous potential against other relevant chemical categories as listed in Table 2 were reviewed. It was determined that these NAS components are not listed in any of them.

Table 2: Other chemical hazardous categories used in NAS solvent toxicity evaluation

Abbreviation	Group Name	Description
DHS	Chemical Weapons and Precursors	Chemical weapons and precursors listed by Department of Homeland Security (DHS) or United States Chemical Weapons Convention.
IDLH	Immediately Dangerous to Life or Health	Known chemicals with Immediately Dangerous to Life or Health (IDLH) <= 10 ppm
TLV	ACGIH TLV	Known Threshold Limit Values (TLVs) <= 0.1 ppm or <= 0.01 mg/m^3
CARC	Carcinogens	A chemical is considered to be a carcinogen if it is listed as a carcinogen or a potential carcinogen by IARC, NTP, or OSHA.
OSHA	OSHA Regulated Chemicals	Chemicals listed in Occupational Safety & Health Administration (OSHA) with specific requirements including air sampling.
REPR	Reproductive Toxins	Identified by The Office of Environmental Health Hazard Assessment (OEHHA) of the California Environmental Protection Agency, Proposition 65.
UC1	Unique Chemicals - Protocol	Chemicals that are considered highly hazardous but not listed in any of the identified databases.
UC2	Unique Chemicals - Hazard Communication	Chemicals with specific hazard(s) that warrant hazard communication but not listed in any of the identified databases.

UC1 and UC 2 are RTI internal lists of chemicals that are found to have certain toxicity but are not included in any of the official chemical hazard categories.

The Clean Water Act (CWA) is a regulatory framework that oversees the discharge of pollutants into the waters of the United States. Wastewater pollutant discharges from the NAS CO_2 capture plant may require an industrial discharge permit issued by the local Publicly Owned Treatment Works (POTW) authority, or a National Pollutant Discharge Elimination System (NPDES) permit depending on the plant location. To determine compliance responsibilities, the consultation with local jurisdiction is needed. Effluent guidelines and standards apply to steam electric power generating plants operating as utilities and are incorporated into the NPDES permit program. In compliance with the Superfund Amendments and Reauthorization Act (SARA) Title III, State Emergency Response Commission (SERC), and Local Emergency Planning Committees (LEPCs) within each state, districts need to be notified of the additional hazardous substances and wastes that could potentially be generated from the power plant equipped with the CO_2 capture unit for updating their emergency-response plans. The cement plant's safety and environmental officers are required to update and include the additional hazardous chemicals produced from the CO_2 capture unit and their inventory and submit the records to SERC, LEPC, or local fire department.

Amine

As per the NAS amine SDS, the chemical is a combustible, corrosive liquid, and causes skin and eye irritation. The amine does not present an explosion hazard. The Hazardous Material Identification System ratings indicate that this amine is low on toxicity (health = 2), flammability (fire = 2), and physical hazard (reactivity = 1). The amine is not identified as a carcinogen or carcinogen potential based on OSHA and NTP. It is not listed on toxic chemical listings of SARA Title III Section 313 nor subjected to the reporting requirement listed under Section 302. Currently

RTI's amine component is not listed as a toxic chemical under Chemicals under the Toxic Substances Control Act (TSCA). Although the evaluation of the NAS's amine results in low toxicity and relatively benign substance, the release of this amine through gas emissions or wastewater discharge is possible and will need to be minimized from both environmental and cost perspectives. The current state of NAS technology development has shown the release of 30 ppm through the treated gas without applying a novel emission control technology (ECT) developed in a separate project (DE-FE0031660). The ECT, particularly the use of the acid wash downstream of the water wash section, can further reduce the amine emissions in the treated gas down to <1 ppm. The current development of the acid wash is at TRL6 and the technology has been incorporated into the NAS CO_2 capture plant in this FEED study. The ECT will be demonstrated with NAS at 1 TPD scale at Victorville in a separate DOE-IEDO project towards the end of this year, bringing it to TRL 6 as well.

Organic Diluent

As per the organic diluent SDS, the diluent has ratings of (health = 1), flammability (fire = 1), and physical hazard (reactivity = 0). For the toxicity and ecotoxicity evaluation, the diluent contains no components considered to be either persistent, bioaccumulative and toxic, or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher. The diluent is harmful to aquatic life and should not be released to drain or waterways. The Derived No Effect Level (DNEL) for worker is listed in Table 3. The diluent exhibits extremely low volatility (vapor pressure < 0.001 mbar at 20 °C) and is chemically stable with no hazardous reactions present under the conditions of normal use. Two components in the diluent exhibit mild skin irritation while animal testing of these components did not show any carcinogenic effects. The diluent is highly biodegradable at 99% degradability. A component in the diluent shows K_{oc} of 4.39-4.96, i.e., low soil mobility. It is listed on EPA's chemical substance inventory under the Toxic Substances Control Act (TSCA). The gas emissions result from TCM testing has shown a minimal release of the diluent compounds both in the treated gas and CO_2 product. In general, <1 ppm of the diluent compounds was found in these gases. If circumstances require water drain of water wash section, waste will contain trace amount to the diluent and thus needed to be treated as hazardous waste.

Table 3: The Derived No Effect Level (DNEL) for worker of RTI's NAS diluent component - Derived No Effect Level (DNEL) according to Regulation (EC) No. 1907/2006:

Substance name	End Use	Exposure routes	Potential health effects	Value
Polyethylene glycol dibutylether	Workers	Inhalation	Long-term systemic effects	87.5 mg/m^3
CAS-No.: 31885-97-9	Workers	Dermal	Long-term systemic effects	12.5 mg/kg-bw/day

The toxicological information related to the chemicals in the solvent are contained in the SDS sheets. The organic diluent is commercially available and is expected to be in accordance with local regulations and industry practices and is not discussed further in detail herein.

3. Properties related to volatility, flammability, explosivity, other chemical reactivity, and corrosivity

NAS is a formulation of a hydrophobic amine in an organic diluent. NAS is a liquid characterized by relatively high density and low volatility, thus rendering it suitable for industrial

applications. NAS has no measurable flash point. The NAS technology also employs an acid wash process for emissions control, effectively minimizing potential environmental and safety risks.

Corrosion coupon evaluations performed during the Technology Centre Mongstad (TCM) engineering demonstration confirmed the low-corrosivity nature of the NAS solvent [1]. This finding indicates a reduced potential for material degradation and supports consideration of lower-grade carbon steel for certain process equipment, subject to detailed design verification. Complementary testing at the National Carbon Capture Center's Slipstream Testing Unit (NCCC-SSTU) in 2018 further corroborated these results, showing metal ion concentrations substantially lower than those observed during previous MEA baseline studies. These results suggest that the NAS solvent poses minimal corrosion risk under expected operating conditions, contributing positively to overall plant safety and maintainability.

Analysis of various metal concentrations, including barium (Ba), selenium (Se), arsenic (As), cadmium (Cd), lead (Pb), and silver (Ag), in NAS solvent samples confirm compliance with U.S. Environmental Protection Agency's Resource Conservation and Recovery Act (RCRA) limits, highlighting safe handling and minimal environmental impact.

The favorable physical properties and low corrosivity profile of the NAS solvent substantiate its application in industrial settings, potentially supporting the use of lower-grade materials while ensuring adherence to regulatory requirements for environmental safety.

4. The compliance and regulatory implications of the proposed technology

This technology is not materially different from natural gas acid gas removal processes which contact natural gas with amine solutions to remove H_2S and CO_2. There are hundreds if not thousands of such installations in operation across the U.S. and Canada and they can be safely operated in compliance with all applicable laws.

Since the process is removing components which would otherwise be emitted in the stack gas of the power plant, the environmental implication is essentially nil. Provisions of the Clean Air Act and NSPS requiring removal of specified amounts of SO_x, NO_x and particulates are not affected since this is accomplished upstream of this system. Emissions of amine and its degradation products are expected to be very small after implementing the ECT to minimize the environmental impact and lower the solvent loss over time. amine emissions and other contaminants presented in the CO_2 product will need to be removed through condensation and dehydration to meet the CO_2 pipeline standards. These contaminants could post a risk of bacteria growth within the CO_2 pipeline and reservoir.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, applies to closed and abandoned hazardous waste sites. Individual chemicals of the NAS composition are not included on the hazardous substance list, but certain glycol ethers are a generic category listed with no Reportable Quantity being assigned. The components used in NAS's diluent are noted in the EPA's Toxic Substances Control Act (TSCA) inventory.

None of the NAS chemical components are included individually in the list of Hazardous Air Pollutants (HAP) in the Clean Air Act (CAA), however the glycol ether category may apply. Chemical components of the NAS do not apply to the key pollutants list EPA regulates as part of the air toxics standards, New Source Performance Standards (NSPS) program, for fossil fuel-fired electric utility steam generating units. None of the components apply to the list of chemicals in the air toxics section 112(r), prevention of accidental releases (Risk Management Plan, RMP, rule).

Sections 311-312 (Hazardous Chemical Inventory Reporting) of the Superfund Amendments and Reauthorization Act (SARA) Title III apply to facilities with hazardous chemicals in quantities above listed thresholds. Depending on quantities on site, these requirements would apply to the NAS, including TIER chemical inventory reporting. Section 313 requires certain facilities to report releases and waste management information for the Section 313 listed chemicals that are manufactured, processed, or used in quantities above listed thresholds. None of the NAS components are on the individual Section 313 chemical list, however Diethylene Glycol Dibutyl Ether (CAS 112-73-2) is included in the category code N230 for certain glycol ethers.

5. Engineering analysis of potentially hazardous materials identified

The use of a lower heat of regeneration solvent, such as RTI's NAS, is essential to the economic success of this technology. It is not the only solvent that can be used for post-combustion carbon capture. It can be substituted with other solvents such as monoethanolamine (MEA). However, replacing it with other solvents will substantially increase the energy needed for solvent regeneration.

Emissions of NAS amine can be further minimized in any stream which is ultimately to be emitted to the environment by implementing the ECT such as acid wash. The use of acid wash at TCM shows highly encouraging test results in controlling the overall amine emissions out of the CO_2 capture plant to be below 1 ppm. Environmental releases due to leaks, piping failures, spills, drips etc. are handled by appropriate containment infrastructure. All such drips will be collected and recycled or disposed of appropriately. Vessels and storage containers will be designed to meet applicable codes and use compatible materials so that corrosion with resultant leakage is eliminated. Solvent offloading from drums or containers will be engineered to avoid improperly matched connections to transfer pumps, incompatible elastomers or hoses etc. No direct access to plant sewer from the process skid will be provided. Personnel will employ appropriate PPE to avoid contact during routine and maintenance procedures.

6. Precautions for safe handling and conditions for safe storage

The precautions for safe handling of NAS are:

- Avoid contact with the skin, eyes and clothing. Avoid inhalation of mists/vapors.
- Use with local exhaust ventilation.
- Wear NIOSH-certified chemical goggles.
- Wear full face shield if splashing hazard exists.
- Wear chemical resistant protective gloves.
- Wear protective clothing.
- Eye wash fountains and safety showers must be easily accessible.

A solvent-side slipstream reclaim process can be used to handle potential nitrosamine formed during the CO_2 capture process. An activated carbon bed process can be used for the removal of nitrosamine from the solvent in the pilot-scale CO_2 capture process.

The solvent is not highly volatile; its releases into the air around the plant by vaporization from stored solvent is expected to be minimal with appropriate storage practices and solvent handling. Exposure to NAS is negligible partly due to the low volatility but also because the solvent will be contained in a closed system. Exposure is most likely when handling solvent offloading from shipping containers. Exposure is also possible when carrying out certain maintenance procedures such as changing spent cartridges or filters. Job safety analysis (JSA) will be conducted on all these

procedures. PPE will be worn as needed such as hazard suits, gloves, face shields, breathing apparatus, shoes safe for chemical exposure and so on. The specifics will be evaluated as these JSA are developed. Since the solvent is itself a hazardous material, all solid and liquid wastes will be disposed of in approved hazardous waste disposal facilities and be transported by licensed hazardous waste haulers. There will be no onsite waste disposal treatment.

Exposure Controls / Personal Protection

Personal Protection

Eye/Face Protection: Use chemical goggles or face shield as needed.
Skin Protection: Use protective clothing chemically resistant to this material. Selection of specific items such as face shield, boots, apron, or full body suit will depend on the task.
Hand protection: Use chemical resistant protective gloves, nitrile rubber (Buna N), chloroprene rubber (Neoprene), and polyvinylchloride (Pylox). NOTICE: The selection of a specific glove for a particular application and duration of use in a workplace should also take into account all relevant workplace factors such as, but not limited to: Other chemicals which may be handled, physical requirements (cut/puncture protection, dexterity, thermal protection), potential body reactions to glove materials, as well as the instructions/specifications provided by the glove suppliers.
Respiratory Protection: Wear respiratory protection if ventilation is inadequate. Wear a NIOSH-certified (or equivalent) organic vapor respirator. For emergency or non-routine, high exposure situations, use a NIOSH-certified full facepiece pressure demand self-contained breathing apparatus (SCBA) or a full facepiece pressure demand supplied-air respirator (SAR) with escape provisions.
Ingestion: Avoid ingestion. Ingestion may cause gastric disturbances. Do not consume or store food or tobacco in the work area; wash hands and face before smoking or eating.

Engineering Controls

Ventilation: Use local exhaust ventilation, or other engineering controls to maintain airborne levels below exposure limit requirements or guidelines. If there are no applicable exposure limit requirements or guidelines, general ventilation should be sufficient for most operations. Local exhaust ventilation may be necessary for some operations.

Nitrosamine Exposure

Exposure of any potential nitrosamine to pilot plant operators and employees is mainly possible through incidental ingestion, dermal exposure, and inhalation. For purposes of this evaluation, inhalation was selected as the most plausible and conservative route of exposure to potential nitrosamine. Incidental ingestion of solvents and dermal exposure are considered to be negligible due to the use of personal protective equipment (PPE).

The possible health and environmental effects of post-combustion amine-based CO_2 capture plant and its associated minor release of amine and amine degradation products have been investigated extensively through the Norwegian CLIMIT-program, and the CO_2 Technology Centre Mongstad (TCM) prior to the full-scale capture plant operation and reported at GHGT-11.[1]

Air emissions monitoring of nitrosamines in ambient air has been primarily undertaken in industrial areas around potential sources of nitrosamine precursors. The analytical methods used to produce these results however have a low maturity and have not been adopted as national standards and there is no evidence of successful method validation. Table 4 below summarizes the data available at various industrial sites and at the carbon capture test site at Mongstad, Norway.

Table 4. Nitrosamine concentration in air at various industrial sites

Compound	Reported Emission Concentration (ng/Nm^3)	Comments
Total N-nitrosamines in air Austria	10 to 40	16 sites around an industrial area of Linz, Austria. In this study, 363 ambient air samples were taken and NDMA was detected in 54 samples, N-ethyl-N-nitroso-ethanamine (N-nitrosodiethylamine or NDEA) in 45 samples and 4-nitrosomorpholine (NMOR) in 2 samples. 6% of the samples contained >0.01 µg/m3 total N-nitrosamines
NDMA in ambient air	30 to 1000	A study of fifteen sites in the Los Angeles area in the USA around various industrial sites that manufacture secondary amines
NDMA in ambient air	None detected	Around a chemical disposal site in New Jersey
NDMA in ambient air	400 and 32,000	Around various industrial sites that manufacture secondary amines in Baltimore, USA
NDMA in ambient air	8.4	California, USA
NDMA concentrations in air	30 to 60 (city center)	Monitoring of N-nitrosamines undertaken in Moscow. Concentrations of NDMA of "several hundred ng/m^3" were reported in an industrial emissions area and >100 ng/m^3 in a "heavy traffic area"
Ambient air levels of NDMA	10 (rural), ~ 46 (urban)	2010 summary of other ambient measurements
9 nitrosamine and 5 nitramine compounds in ambient air	None detected	Baseline study of air quality around the Mongstad refinery, Norway prior to operation of the carbon capture pilot plant (limit of detection 0.01 to 0.09 ng/m^3)
Ambient concentrations of amine compounds	ND to 31	Baseline study of air quality around the Mongstad refinery, Norway prior to operation of the carbon capture pilot plant (methylamine, Dimethylamine and Diethylamine)
Ambient concentrations in air of piperazine	10-60	-

The above table shows that no nitrosamines were found during the baseline study of air quality around the Mongstad refinery with amine operations. Baseline monitoring of a wide range of amine and nitrosamine/nitramines in water and soil has also been undertaken around the Mongstad refinery in Norway (prior to the operation of the pilot scale carbon capture plant). This study found no nitrosamines and nitramines were detected above the detection limits (DL) in any of the samples taken (DL water 0.7 to 1.5 ng/liter and DL for soil/moss 1 to 2 ng/g). The potential health and environmental hazards associated with nitrosamines formed in NAS solvent is being evaluated through a comprehensive, multi-tiered analytical program. This effort includes controlled

atmospheric-chamber studies to assess nitrosamine formation, partitioning, and degradation under post-emission condition. Complementary nuclear magnetic resonance (NMR) analyses will be conducted to identify solvent-borne nitrosamine species, precursor compounds, and mechanistic pathways responsible for their generation within the NAS matrix. In parallel, a targeted nitrosamine-management strategy will be developed to mitigate formation and accumulation in the working solvent, including evaluation of solvent additives, process-condition adjustments, and purification or polishing approaches. Together, these studies will provide a robust understanding of nitrosamine behavior and inform the design of effective control measures to ensure safe, environmentally responsible operation of the NAS process.

CONCLUSIONS

The EH&S risk analysis has been completed that includes possible risk mitigation factors.

This topical report summarizes the key plant EH&S concepts and approach. EH&S risks commensurate with the state of development of RTI's NAS technology and the stage of the project are identified and the mitigating factors which will be implemented for management of the risks are detailed. Responses to the six DOE-required question areas are separately provided.

Key findings of the preliminary EH&S analysis process are:

- No significant EH&S risks to plant operators, other employees, and surrounding area environment were identified that would adversely affect the implementation of NAS technology for post-combustion carbon capture.
- The NAS CO_2 capture plant with the implementation of ECT will not generate appreciable new air emissions because all gas streams taken from the power plant and exhausted from the capture plant will consist of the same components with ppm levels of amine in the treated flue gas only.
- The toxicological issues related to the NAS amine, as per the SDS, shows that the NAS is low in toxicity and highly biodegradable and is, therefore, not expected to bio-accumulate. The known degraded amine species derived from NAS will not be bio-accumulated due to their volatility and biodegradability in the environment. Many of the nitrosamines such as NDMA, NDEA, and NDPA are known to be quickly photo-oxidized and does not bio-accumulate. As such, nitrosamines derived from NAS is expected to share the similar reactivity towards ozone and sunlight.
- The NAS flash point has been tested using the Pensky Martin Closed Cup method (ASTM D93) by multiple third-party labs and was determined to have no measurable flash point. It is stable under normal conditions without possible hazardous polymerization reaction, has a relatively low volatility and low corrosivity.
- The SDS sheet lists hazards associated with the NAS and the recommended precautions: Avoid contact with eyes. Avoid inhalation of vapor. Wear protective clothing as necessary to minimize contact. The primary employee health hazard is contact exposure to NAS during material handling. Appropriate personal protective equipment (PPE) is required to reduce/eliminate direct exposure. These include lab goggles, nitril gloves, chemical resistant clothing. Provide local exhaust ventilation to control vapors/mists. Wear respiratory protection if ventilation is inadequate, such as a NIOSH-certified (or equivalent) organic vapor respirator.

REFERENCES

1. Jessop, K. E., et al. (2025). "Non-aqueous CO_2 capture solvent corrosion results from testing at Technology Centre Mongstad." International Journal of Greenhouse Gas Control **148**.

Appendix K NETL CO2U LCA Report

CARBON CAPTURE PLANT FEED STUDY FOR CEMENT MANUFACTURING LCA REPORT

DE-FOA-0002515 Carbon Capture Research and Development for Natural Gas and Industrial Point Sources, and Front-End Engineering Design Studies for Carbon Capture Systems at Industrial Facilities and Natural Gas Plants

OCTOBER 6, 2025

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ACRONYMS AND ABBREVIATIONS

atm	Atmosphere (14.696 psi)
CCS	Carbon capture and storage
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DOE	Department of Energy
EPA	Environmental Protection Agency
ft	Foot
GHG	Greenhouse gas
h, hr	Hour
H_2	Hydrogen
ISO	International Organization for Standardization
K	Thousand
kg	Kilogram
kW, kWe	Kilowatt electric
kWh	Kilowatt-hour
LCA	Life cycle analysis
m	Meter
M	Thousand
MM	Million
N_2O	Nitrous oxide
NETL	National Energy Technology Laboratory
NG	Natural gas
NOx	Oxides of nitrogen
O_2	Oxygen
SO_2	Sulfur dioxide
MT	Metric ton (1,000 kg)
U.S.	United States

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EXECUTIVE SUMMARY

This life cycle analysis (LCA) is being commissioned for the United States (U.S.) Department of Energy (DOE) National Energy Technology Laboratory (NETL) to satisfy the award requirements for Funding Opportunity Announcement (FOA) DE-FOA-0002515, titled Carbon Capture Research and Development for Natural Gas and Industrial Point Sources, and Front-End Engineering Design Studies for Carbon Capture Systems at Industrial Facilities and Natural Gas Plants. The Principal Investigator (PI) for this project is Vijay Gupta at RTI International. This LCA report has been prepared in accordance with ISO 14040/14044 requirements for public release of comparative assessments for third parties.

The study presents an LCA of RTI International's proposed carbon capture system (CCS) at the Balcones Cement Plant in New Braunfels, Texas, with a nominal cement production capacity of 2.7 million metric tonnes of cement and 2.2 million metric tonnes of CO_2 emissions annually. RTI International, in collaboration with CEMEX Inc., SLB, and KBR Inc., is conducting a Front-End Engineering Design (FEED) study to develop AACE (Association for the Advancement of Cost Engineering) Class 3 cost estimates for a commercial CO_2 capture system integrated with the Balcones cement facility. The proposed product system is based on system/subsystem models and prototypes demonstrated in a relevant environment, with the project currently at TRL 6. It would capture and geologically sequester 95% of CO_2 directly emitted from the plant as well as additional CO_2 produced by the CCS system. This LCA incorporates CO_2 saline aquifer transport and storage, combustion emissions at the facility, process operations and chemical inputs to the facility, and construction impacts for required materials and equipment.

The goal is to compare and understand the differences between the NETL Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 environmental impacts, with a particular focus on global warming impacts, from the CEMEX Balcones cement plant with and without RTI's proposed CCS system for the U.S. DOE Carbon Utilization Program and as a public record per the funding opportunity announcement requirement. The scope includes the proposed product system of the CEMEX Balcones Cement Plant with carbon capture and storage, with the functional unit being a metric tonne (MT) of Type IL and Type I/II cement produced. The system boundary is cradle-to-gate, stopping at the gate of a MT of cement produced. Data representativeness assumes the CCS facility has a lifetime of 25 years, with global warming potential assessed on a 100-year basis. Electric power requirements will be modeled from the Texas Reliability Entity (TRE). No credit or allocation will be applied for co-products, and recycling and recycled content will follow the cut-off rule. See **Exhibit ES-1** and **Exhibit ES-2** for a simplified system boundary with reference flows between key processes or life cycle stages.

Exhibit ES-1. Process flow diagram for the proposed product system

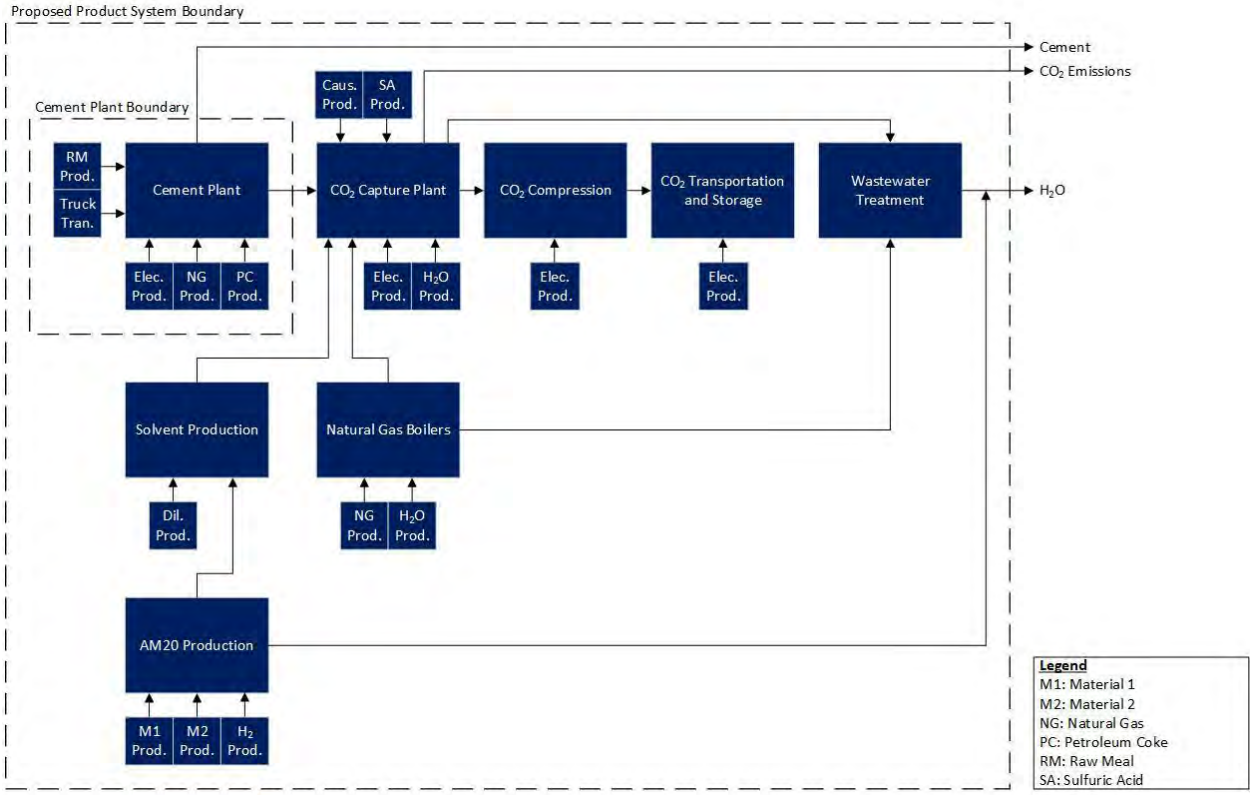
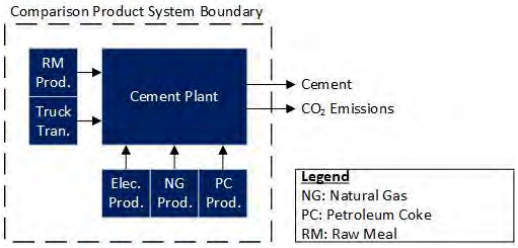


Exhibit ES-2. Process flow diagram for the comparison product system



This project was modeled using OpenLCA software as per the guidelines given in the Carbon Dioxide Utilization Life Cycle Analysis Guidance for the U.S. DOE Office of Fossil Energy and uses the EcoInvent 3.10 Cutoff System Processes and NETL databases as LCIs. Further, this study uses the TRACI 2.1 impact assessment method combined with the latest global warming potential (GWP) factors included in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) report.

The life cycle results for the AR5, 100-year GWP are presented in **Exhibit ES-3** and **Exhibit ES-4** for both Types IL and I/II cement products.

Exhibit ES-3. GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type IL cement

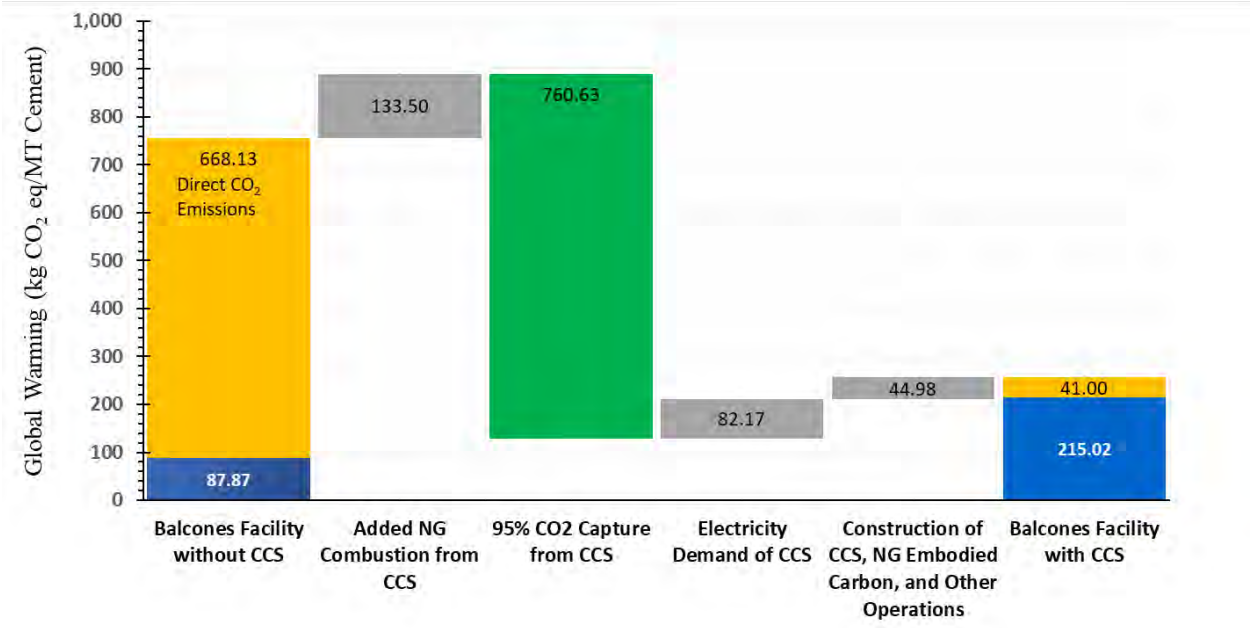
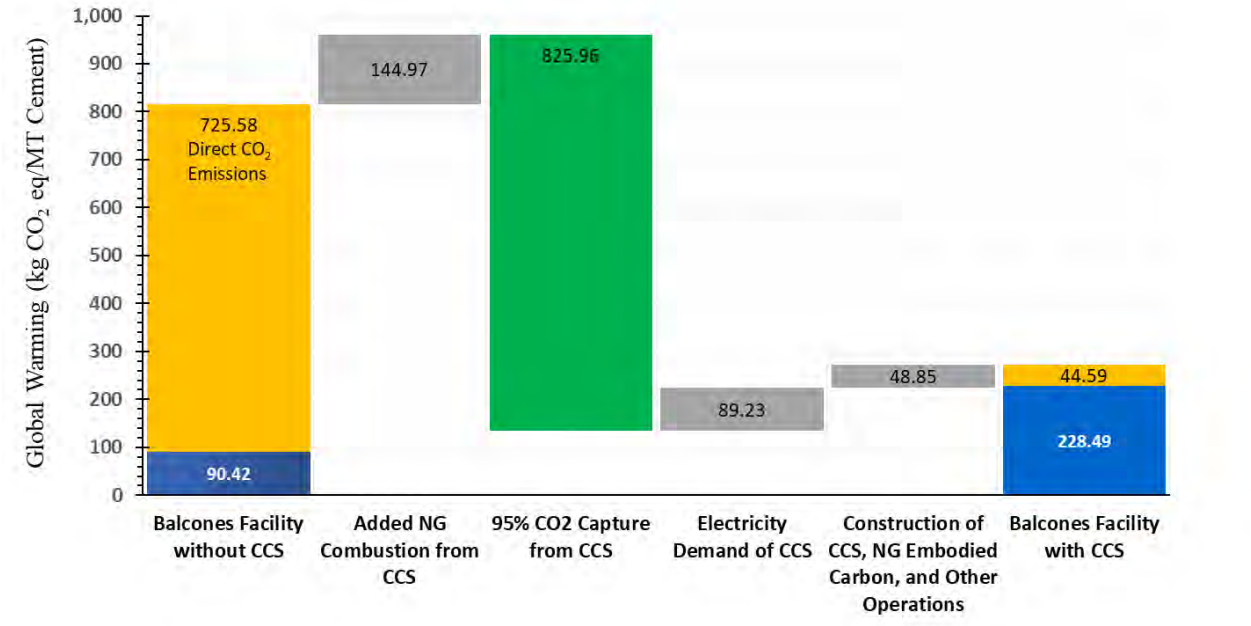


Exhibit ES-4. GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type I/II cement



An estimated 668.13 kg CO_2/MT-cement produced and 725.58 kg CO_2/MT-cement produced are emitted as direct CO_2 emissions for Type IL and Type I/II cements, respectively, without the FEED CCS system. Per CEMEX's environmental product declaration, the overall CO_2 emissions from production of cement at its Balcones plant is 756 kg CO_2eq/MT of Type IL cement and 816 kg CO_2eq/MT of Type I/II cement when including supporting processes. Employing the FEED carbon

capture process is estimated to save 499.98 kg CO_2e/MT Type IL cement produced and 542.92 kg CO_2e/MT Type I/II cement produced, limiting direct CO_2 emissions to 41.00 kg CO_2e/MT cement and 44.59 kg CO_2/MT cement at the cement plant for Type IL and Type I/II cements, respectively. This represents a 66.1% (Type IL) and 66.5% (Type I/II) reduction in overall GHG emissions for Portland cement production.

Further, this study includes a sensitivity analysis on the impact of higher and lower amounts of natural gas combustion, electricity demand, and make-up AM20. The sensitivity analysis results for the AR5, 100-year GWP are presented in **Exhibit ES-5**. The combustion of natural gas and electricity demand were varied ±10% and the AM20 production was varied ±25%. The sensitivity analysis shows that ±10% variation in the combustion of natural gas changed GWP by ±1.4% for Type IL cement and Type I/II cement. The sensitivity analysis also shows that ±10% variation in electricity demand changed GWP by ±3.2% for Type IL cement and ±3.3% for Type I/II cement. Changes in AM20 make-up is less impactful overall as ±25% variation only changed GWP by ±0.5% for Type IL cement and Type I/II cement.

Given the large reductions of approximately two thirds in the Balcones cement plant's carbon footprint for both Types IL and I/II cement from the proposed CCS system, the PIs recommend further project evaluation of the Proposed Product System.

The following proprietary information was obscured from the report:

- Information pertaining to the identity of components found in RTI International's non-aqueous solvent (NAS) CO_2 capture technology.

Exhibit ES-5. Sensitivity Analysis

		25% Change in Make-up Amine		10% Change in CCS Electricity Demand		10% Change in CCS Natural Gas Use	
		Type IL	Type I/II	Type IL	Type I/II	Type IL	Type I/II
TRACI Impact Category	Units	±Percent Difference from Baseline	±Percent Difference from Baseline	±Percent Difference from Baseline	±Percent Difference from Baseline	±Percent Difference from Baseline	±Percent Difference from Baseline
Acidification Potential - TRACI 2.1 (NETL)	kg SO2e	0.3%	0.3%	0.8%	0.8%	1.6%	1.7%
Eutrophication Potential - TRACI 2.1 (NETL)	kg Ne	0.4%	0.4%	6.0%	6.1%	0.3%	0.3%
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	kg CO2e	0.5%	0.5%	3.2%	3.3%	1.4%	1.4%
Ozone Depletion Potential - TRACI 2.1 (NETL)	kg CFC-11e	0.4%	0.5%	0.5%	0.5%	0.001%	0.001%
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	kg PM2.5e	0.2%	0.2%	3.7%	3.9%	0.1%	0.1%
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	kg O3e	0.1%	0.1%	0.4%	0.4%	2.4%	2.5%
Water Consumption (NETL)	kg water	5.1%	5.1%	5.5%	5.5%	0.01%	0.01%

1 GOAL AND SCOPE

1.1 STUDY GOAL

The purpose of this study is to evaluate the proposed CO_2 capture system (CCS) at the CEMEX Balcones Cement Plant designed by RTI International, CEMEX, SLB, and KBR.

The specific goals of this life cycle analysis (LCA) are described below:

1. Intended application – The intended application of this LCA is to compare the life cycle greenhouse gas (GHG) impact of the proposed project – a commercial 1,600,000 t-CO_2/yr (nominal capacity of 2,400,000 t-CO_2/yr) scale CCS integrated with a cement facility, modeled the *Proposed Product System*, to a *Comparison Product System – the facility without a CCS*.
2. Reasons for carrying out the study – To understand how the environmental impact (measured as life cycle GHG impact) of the proposed CCS life cycle compares to the life cycle of a system without CCS that produces the same products.
3. Intended audience – The intended audience for the LCA described herein is the United States (U.S.) Department of Energy (DOE) Carbon Utilization Program.
4. Public disclosure – The LCAs conducted as part of the U.S. DOE Funding Opportunity Announcement (FOA) requirement will become part of the public record for the award within the final scientific/technical report.

1.2 STUDY SCOPE

The study presents an LCA of RTI International's proposed carbon capture system (CCS) at the Balcones Cement Plant in New Braunfels, Texas, with a nominal cement production capacity of 2.7 million metric tonnes of cement and 2.2 million metric tonnes of CO_2 emissions annually. The proposed CCS would capture and geologically sequester 95% of CO_2 directly emitted from the cement plant as well as additional CO_2 produced by the CCS system. RTI International, in collaboration with CEMEX Inc., SLB, and KBR Inc., is conducting a Front-End Engineering Design (FEED) study to develop AACE (Association for the Advancement of Cost Engineering) Class 3 cost estimates for a commercial CO_2 capture system integrated with the Balcones cement facility. This LCA incorporates CO_2 saline aquifer transport and storage, combustion emissions at the facility, process operations and chemical inputs to the facility, and construction impacts for required materials and equipment.

The goal is to compare and understand the differences between the NETL Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 environmental impacts, with a particular focus on global warming impacts, from the CEMEX Balcones cement plant with and without RTI's proposed CCS system for the U.S. DOE Carbon Utilization Program and as a public record per the funding opportunity announcement requirement. The scope includes the product system of the CEMEX Balcones Cement Plant with carbon capture and storage.

1.2.1 Functional Unit of the Study

1. The functional unit of the study for the proposed CO_2 capture system is 1 metric tonne (MT) of cement of both Type IL and Type I/II.
2. To match this functional unit, the product outputs of the Comparison Product System were also normalized per 1 MT of cement of both Type IL and Type I/II.

1.2.2 System Boundary

The system boundary is cradle-to-gate, stopping at the gate of a MT of cement produced. Data representativeness assumes the CCS facility has a lifetime of 25 years, with global warming potential assessed on a 100-year basis. Electric power requirements will be modeled from the Texas Reliability Entity (TRE). No credit or allocation will be applied for co-products, and recycling and recycled content will follow the cut-off rule. **Exhibit 1-1** and **Exhibit 1-2** show the process flow diagram for both the proposed and comparison product system respectively.

Exhibit 1-1. Process flow diagram for the proposed product system

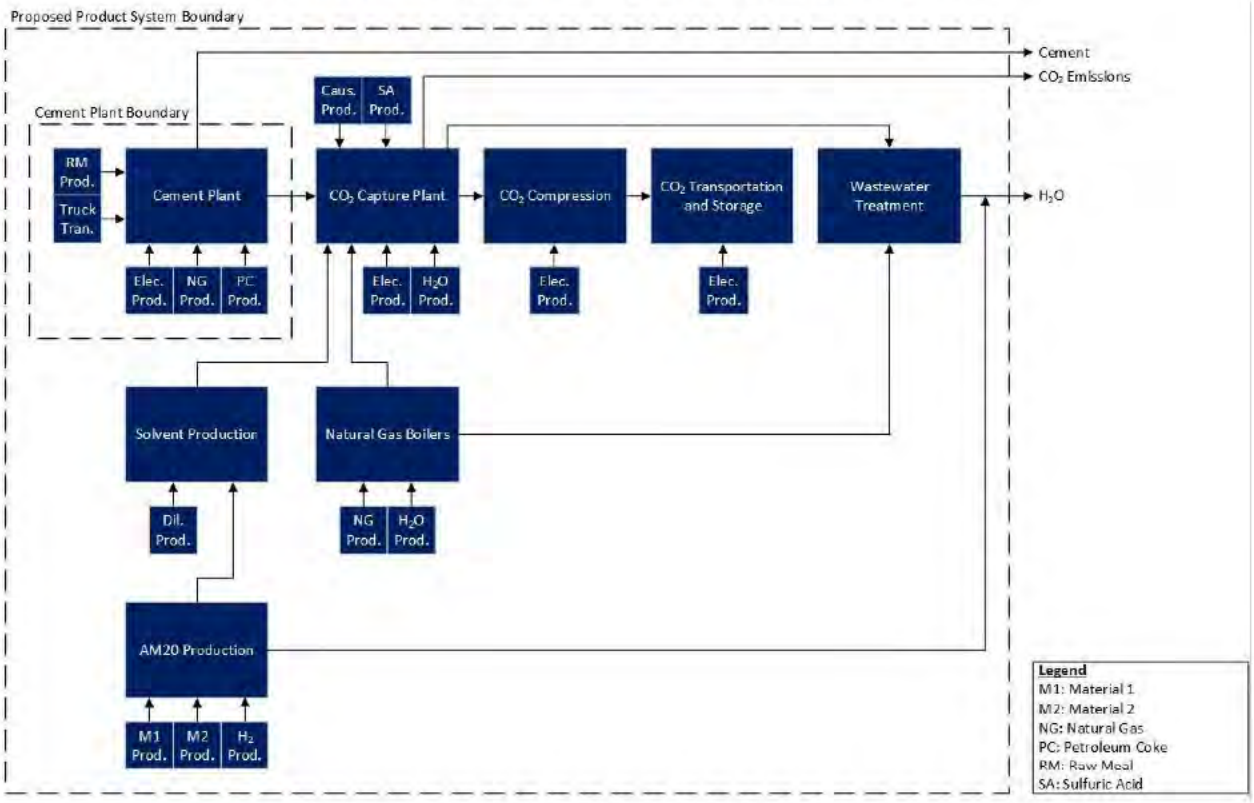
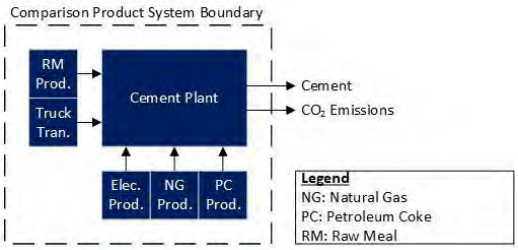


Exhibit 1-2. Process flow diagram for the comparison product system



1.2.3 Carbon Dioxide Source

The CO_2 source is the flue gas stream from Kiln 1, Kiln 2, and the natural gas boiler.

1.2.4 Technology Representativeness

The proposed product system is based on system/subsystem models and prototypes demonstrated in a relevant environment. Thus, this project is TRL 6.

The CCS technology has been tested at laboratory scale and engineering scale at RTI International. The CCS technology has been demonstrated at the National Carbon Capture Center (NCCC) in the United States, as well as the SINTEF Tiller Plant and the Technology Centre Mongstad (TCM) in Norway. Work is currently underway to demonstrate the CCS technology at a cement plant and a pulp and paper mill in the United States.

1.2.5 Geographical Representativeness

The Balcones Cement Plant is located in in New Braunfels, Texas. All life cycle stages are modeled in the region applicable to New Braunfels, Texas. Where regional data were not available, United States LCI data were used for modeling. Where United States LCI data were not available, rest-of-the-world or global representation in OpenLCA was used for modeling.

1.2.6 Temporal Representativeness

The expected production start year is 2026. The CO_2 captured in this study was assumed geologically sequestered.

The study considers a plant lifespan of 25 years. Our LCA modeled the current U.S. grid mix for the TRE for the year 2021 for high voltage from the EcoInvent v3.10 database.

1.2.7 Life Cycle Impact Assessment Methods for Results Interpretation

This study uses the Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1 method combined with the latest global warming potential (GWP) factors included in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) report. The following impact categories have been modeled and are included in this report:

1. GWP (kg CO_2e), based on IPCC AR5, 100-year time horizon; accounting for carbon climate feedback; abbreviation: GWP-100
2. Non-GHG impact assessment method
    a. acidification potential (kg SO_2e); abbreviation: AP
    b. particulate matter formation potential (kg $PM_{2.5}$e); abbreviation: PMFP
    c. photochemical smog formation potential (kgO_3e); abbreviation: PSFP
    d. eutrophication potential (kg Ne); abbreviation: EP
    e. ozone depletion potential (kg CFC-11e); abbreviation: ODP
    f. optional: water consumption (l); abbreviation: WC

1.2.8 Completeness Requirements

This study uses a heat and materials balance as a proxy for life cycle completeness, as required in *Carbon Dioxide Utilization Life Cycle Analysis Guidance for the U.S. DOE Office of Fossil Energy*. [1]

The carbon balance of the Balcones Cement Plant has been shared with the U.S. DOE Office of Fossil Energy.

1.2.9 Sensitivity and Uncertainty Analysis

The sensitivity analysis results for the AR5, 100-year GWP are presented in **Exhibit 1-3**. The combustion of natural gas and electricity demand were varied ±10% and the make-up AM20 was varied ±25%. The sensitivity analysis shows that ±10% variation in the combustion of natural gas changed GWP by ±1.4% for Type IL cement and Type I/II cement. The sensitivity analysis also shows that ±10% variation in electricity demand changed GWP by ±3.2% for Type IL cement and ±3.3% for Type I/II cement. Changes in AM20 make-up is less impactful overall as ±25% variation only changed GWP by ±0.5% for Type IL cement and Type I/II cement.

Exhibit 1-3. Sensitivity Analysis

		25% Change in Make-up Amine		10% Change in CCS Electricity Demand		10% Change in CCS Natural Gas Use	
		Type IL ±Percent Difference from	Type I/II ±Percent Difference from	Type IL ±Percent Difference from	Type I/II ±Percent Difference from	Type IL ±Percent Difference from	Type I/II ±Percent Difference from
TRACI Impact Category	**Units**	**Baseline**	**Baseline**	**Baseline**	**Baseline**	**Baseline**	**Baseline**
Acidification Potential - TRACI 2.1 (NETL)	kg SO2e	0.3%	0.3%	0.8%	0.8%	1.6%	1.7%
Eutrophication Potential - TRACI 2.1 (NETL)	kg Ne	0.4%	0.4%	6.0%	6.1%	0.3%	0.3%
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	kg CO2e	0.5%	0.5%	3.2%	3.3%	1.4%	1.4%
Ozone Depletion Potential - TRACI 2.1 (NETL)	kg CFC-11e	0.4%	0.5%	0.5%	0.5%	0.001%	0.001%
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	kg PM2.5e	0.2%	0.2%	3.7%	3.9%	0.1%	0.1%
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	kg O3e	0.1%	0.1%	0.4%	0.4%	2.4%	2.5%
Water Consumption (NETL)	kg water	5.1%	5.1%	5.5%	5.5%	0.01%	0.01%

2 LIFE CYCLE INVENTORY ANALYSIS

2.1 MODELING PLATFORM

This project was modeled using OpenLCA software as per the guidelines given in the Carbon Dioxide Utilization Life Cycle Analysis Guidance for the U.S. DOE Office of Fossil Energy [1]. As part of the submission, several files supporting this report have been shared with the U.S. DOE Office of Fossil Energy for model verification. The file names, software, and purpose of each file is listed in **Exhibit 2-1**.

Exhibit 2-1. List of files associated with this report

File Name	Software	Description
NETLCO2ULCAReport_CEMEX_Balcones_FEED_10062025.docx	Microsoft Word	Summary of LCA in report form
CEMEX_Balcones_FEED_10062025_openLCA.zip	openLCA	Complete openLCA model for the Balcones Cement Plant
CEMEX_Balcones_FEED_LCA_Calculations.xlsx	Microsoft Excel	Supporting calculations, assumptions, and results for this LCA

2.2 UNIT PROCESS DESCRIPTIONS

The complete list of unit processes used in the proposed product system is displayed in **Exhibit 2-2**. Further information on unit process data generator and data documenter are provided in the metadata of each unit process in the openLCA database. The system modeled in this report uses a combination of EcoInvent 3.10 Cutoff System Processes LCI as well as the NETL provided LCI as our databases (see exhibit 2-2 for details). Supporting calculations have been shared with the U.S. DOE Office of Fossil Energy. **Exhibit 2-3** provides a list of open LCA variables modeled in this study.

Exhibit 2-2. List of unit processes used in proposed and comparison product system with descriptions and sources

Unit Process Name	Description	Source
AM20 Production	Estimate of the amine synthesis process was assumed to use imination and hydrogenation. Proprietary info has been concealed.	PI created, Ecoinvent 3.10 Database
CementPlantCCSLCA	Dummy Variable/Process used to create the LCA product system.	PI created
Cemex Balcones Cement Plant EPD_Type I/II Cement	This proxy process was created to mimic the results in relevant impact categories from the Cemex Balcones Cement Plant Environmental Product Declaration (EPD) to the pertinent mid-point NETL TRACI impact assessment categories. The actual inputs and outputs should be ignored and were added merely for the process to output equivalent values within the EPD. Thus, this process should only be run using the NETL TRACI impact assessment method. Cemex Balcones Cement Plant EPD: Cemex Construction Materials South, LLC. (2023). Cemex Balcones Cement Plant Environmental Product Declaration. EPD 451. Retrieved from: https://pcr-epd.s3.us-east-2.amazonaws.com/922.EPD_Balcones.pdf	PI created
Cemex Balcones Cement Plant EPD_Type IL Cement	This proxy process was created to mimic the results in relevant impact categories from the Cemex Balcones Cement Plant Environmental Product Declaration (EPD) to the pertinent mid-point NETL TRACI impact assessment categories. The actual inputs and outputs should be ignored and were added merely for the process to output equivalent values within the EPD. Thus, this process should only be run using the NETL TRACI impact assessment method. Cemex Balcones Cement Plant EPD: Cemex Construction Materials South, LLC. (2023). Cemex Balcones Cement Plant Environmental Product Declaration. EPD 451. Retrieved from: https://pcr-epd.s3.us-east-2.amazonaws.com/922.EPD_Balcones.pdf	PI created

Unit Process Name	Description	Source
CO2 Capture Plant Operations	PI-created process to model the CCS facility operations for the RTI proposed CCS. Spent solid consumables were modeled as landfilled inert material.	PI created, NETL CO2U openLCA database, Ecoinvent 3.10 Database
CO2 Solvent Synthesis	PI-created process to model mixing ratio of amine and diluent.	PI created
CO2 Transport and Sequestration	This PI-created process uses the NETL provided Saline Aquifer Transport and Storage process.	NETL CO2U openLCA database
Construction of CCS Facility	This PI-created process is to model (i.e., estimate) the environmental impacts from the construction of the proposed 95% capture RTI International (RTI) carbon capture system (CCS) using RTI's proprietary CO2 solvent, with an assumed lifetime for the CCS facility (See Lifetime_CCSPlant global parameter). The inputs are scaled to a per metric tonne (MT) of cement produced basis over the service life of the CCS facility. These normalized calculations were provided in a separate Excel spreadsheet.	NETL CO2U openLCA database, Ecoinvent 3.10 Database
Diluent Production	PI-created process to model diluent production using a proxy with similar synthesis reaction mechanisms and Global Warming Potential (~4 kg CO2eq/kg) per correspondence with the manufacturer.	PI created, Ecoinvent 3.10 Database

Exhibit 2-3. List of openLCA variables modeled for this study

Name	Description
AC_Beds	Number of activated carbon (AC) beds [number of units].
AC_ReplacementlIFETIME	Lifetime of AC until needing replacement [years].
AM20AirEmissions	Sum of all AM20 (amine) emissions [kg/hr].
CausticUse	Use of caustic (NaOH) [kg/hr].
CCSFacility_VOC_Emissions	Fugitive VOC emissions from the CCS Facility [kg/hr].
Cement_Production_Rate	Average cement produced per hour [MT/hr].
Clinker_Factor	Mass average cement plant clinker factor between Type IL and Types I & II cement.
Clinker_Factor_TypeI_II_Cement	Clinker Factor (i.e., mass fraction of Clinker) for Types I and II cement.
Clinker_Factor_TypeIL_Cement	Clinker Factor (i.e., mass fraction of Clinker) for Types IL cement (aka Portland Limestone Cement).
Clinker_Production_Rate	Average clinker produced per hour [MT/hour].
CO2_CaptureRate	Fraction of directly produced CO2 mass captured by the CCS system [CO2 mass captured/total CO2 mass] where total CO2 mass = CO2 mass captured + CO2 mass emitted.
CO2_Produced_per_kg_NG_Combustion	The kg of CO2 directly produced from combustion of 1 kg of natural gas according to the NETL "Combustion of Natural Gas - US" process [kg CO2/kg NG].
DaysPerYearOperation	Days per year cement plant operates [days/year].
Direct_CementPlant_CO2_Production_Rate	Average mass of CO2 produced by the cement plant per hour. This would represent 100% of the direct CO2 emissions if no CCS system were installed [kg CO2/hr].

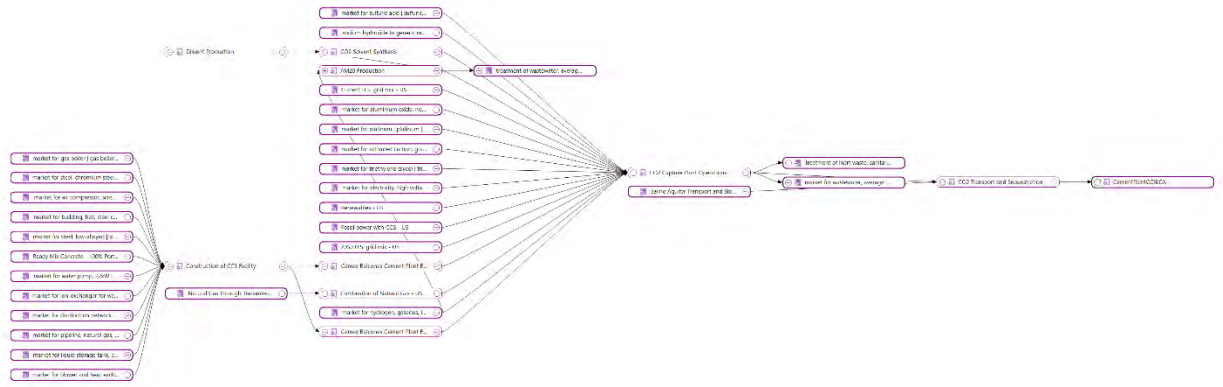
Name	Description
Direct_CO2Production_Cement Plant_PerMTcement	Mass of CO2 directly produced, and that would otherwise be emitted without CCS, per metric tonne (MT) of cement produced. [kg CO2/MT cement].
Elect_Prod_Scenario	0 = TRE Grid, High Voltage 1 = Current U.S. Grid Mix 2 = 2050 U.S. Grid Mix 3 = Fossil Power with CCS 4 = Renewables Default = 0 This is just for electrical energy provided to the CCS plant (not the cement plant). This will allow us to model different electricity sources (e.g., renewables, 2050 grid mix, etc.) in addition to TRE as the current source in order to forecast. However, in order to also apply these electrical energy sources to the Cement plant too, we would just need to subtract the electricity impacts from the EPD impacts (e.g., to predict how clean cement production could be using all renewable energy, or via the other electricity production scenarios). The current EPD used 'US-EI custom process "Electricity, high voltage, at grid, eGrid (2021), TRE/US-EI U"' which had an electricity grid mix of: 46.27% Natural Gas, 17.81% Coal, 21.88% Wind, 9.61% Nuclear, 3.49% Solar, 0.43% Petroleum Coke, 0.0% Geothermal, 0.16% Hydro, 0.18% Biomass, 0.06% oil, with a global warming potential of 0.564 kg CO2eq per /kWh. In order to subtract the impacts from electricity production, we just need to determine the amount of electricity demand per metric tonne of cement produced (for both types of cement) and use a comparable Electricity Process and within EcoInvent, or other LCI, and subtract those impacts from the EPD processes and add another input adding the same amount of electricity use with the noted providers for values of 0, 1, 2, 3, and 4.
ElectEnergyPerMTcement	Electrical energy demand for entire CCS plant per metric tonne of cement produced [kWhrs/MT].
H2_Use	Hydrogen gas use [kg/hr].
HoursPerDayOperation	Hours per day of cement production on each operating day[hours/day].
InitialSolventFillVolume	Initial fill volume of Solvent in cubic meters [ft^3].
Lifetime_CCSPlant	Lifetime of CCS Plant [Years].
MakeupAmine	The hourly rate of amine (AM20) make-up needed [kg/hr].

Name	Description
MakeupTEG	Make-up Triethylene Glycol for the TEG Dehydration Package [kg/hr].
MassACperBed	Mass of activated carbon (AC) per bed [kg/bed].
MassFractionProductionRate_IL_TypeCement	Fraction of the mass production rate of Type IL Cement (aka Portland Limestone Cement) with a Clinker Factor of 0.85, with the remaining fraction of production being Type I and Type II cement having a Clinker Factor of 0.923.
MoleFractionCO2inFinalProduct	Mole Fraction of CO2 in the final captured CO2 product to be sequestered [mole CO2/mole gas] Per HMB simulations.
NG_forCCS	Natural gas use for the CCS system [kg NG/hr].
NG_forCSSperMTcement	Natural gas for CSS operations per metric tonne of cement produced.
O2_PolishingCatalyst_Lifetime	Life time of the O2 Polishing Catalyst [years].
O2_PolishingCatalyst_Mass	Amount of O2 Polishing Catalyst Used [kg] Assumes the following catalyst type: https://chemical-catalysts-and-adsorbents.basf.com/dam/jcr:4f13197a-79bb-42dc-8534-01d7c7fecfd5/BF10641_0.3Pt_AS_R4758_PDS_R20-12.pdf.
PM_CementPlant_Production Rate	Production rate of PM2.5 from the Cement Plant before the CCS system [kg/hr].
PMperMTCement_RemovedBy CCS	Particulate Matter less than 2.5 microns (PM2.5) removed by the CCS system from both the cement plant and NG combustion from the CCS. This assumes 100% capture of all PM2.5 and an emission rate of 0.0000447487941137248 kg PM2.5/kg NG combusted based on the DOE NETL Combustion of Natural Gas process. Units = [kg PM2.5/MT Cement].
RateNO2_RemovedByCCS	Mass rate of NO2 from both the cement plant and from CCS NG combustion removed from the flue by the CCS system [kg/hr].
RateSO2_RemovedByCCS	Mass rate of SO2 from both the cement plant and from CCS NG combustion removed from the flue by the CCS system [kg/hr].

Name	Description
SolidWastePerMTCement	Mass of Solid Waste per metric tonne of cement production [kg/MT Cement].
SolventDensity	Solvent Density at ambient conditions (20degC and ~1atm) [kg/L].
SulfuricAcidUse	Sulfuric Acid use [kg/hr].
TEGAirEmissions	Mass of Triethylene Glycol (TEG) emitted to the air from the TEG Dehydration Package [kg TEG/hr].
TEGInitialFill	Mass of Triethylene Glycol to initially charge the TEG Dehydration Package [kg].
TimeToProdFunctionalUnit	Time to produce the functional unit [hr]. Typically the inverse of the per hour production rate of the functional unit.
TotalCCSPlantPowerReq	Total plant power needs [kW].
Wastewater_CCS	Rate of wastewater production from the CCS plant [kg/hr].
WaterDemand_CCS	Water demand for the CCS plant [kg/hr] or [L/hr].
WWVOCAirEmissions	Wastewater Treatment Package VOC emissions [kg/hr].

All unit processes used in the comparison product system are displayed in **Exhibit 2-4**. Further information on unit process data generator and data documenter are provided in the metadata of each unit process in the openLCA database.

Exhibit 2-4. Unit processes map generated using open LCA for this project



2.3 Data Sources and Quality Assessment

The source of each unit process is described in Section 2.2.

Proxy data was used in this analysis for the diluent used in the CO_2 solvent synthesis unit process. The diluent is a proprietary chemical mixture, so a technically representative chemical found in the Ecoinvent 3.10 Database was chosen as a proxy. Therefore, all data meets the technical representative requirement. All data used for electricity grid inputs, is geographically representative of U.S. production. Other data is either an average of rest of the world or global average as U.S. data was not available. The electricity consumption mixes are representative of deployment year 2026. All other data represents as close to the year 2026 as possible. Exact dates are found in the unit processes themselves in the attached openLCA database.

2.4 Results of Inventory Completeness Check

The complete model is included in this submission. As seen in the complete model, no unit processes or supporting supply chains were excluded from this LCA.

2.5 Results of Life Cycle Inventory Model Sensitivity Check

No life cycle inventory model sensitivity check was conducted by the PIs; however, a sensitivity analysis of inputs was conducted (see section 1.2.9).

2.6 ALLOCATION PROCEDURES (OPTIONAL)

No allocation was used by the PIs.

3 LIFE CYCLE IMPACT ASSESSMENT

3.1 LIFE CYCLE IMPACT ASSESSMENT METHODS

This LCA includes all impact categories provided in the NETL-modified version of TRACI. The 100-year GWP factors for CO_2, CH_4, and N_2O utilized in this analysis are depicted in **Exhibit 3-1**.

Exhibit 3-1. IPCC AR5 GWPs [1]

GHG	20-year	100-year	Units
CO_2	1	1	kg CO_2e
CH_4	87	36	kg CO_2e
N_2O	268	298	kg CO_2e
SF_6	17,500	23,500	kg CO_2e

This analysis utilizes the latest factors available in TRACI 2.1, with modified *characterization factors* for GWP to reflect the current state of science from the IPCC. The following describes the non-GWP midpoint impact assessment categories included in this analysis:

- **Acidification Potential (AP):** The increased concentration of hydrogen ions in a local environment. This can be from the direct addition of acids, or by indirect chemical reactions from the addition of substances such as ammonia. [2] Reporting units are kg SO_2-equivalent.
- **Eutrophication Potential (EP):** The "enrichment of an aquatic ecosystem with nutrients (nitrogen, phosphorus) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass." [3] Reporting units are kg nitrogen (N)-equivalent.
- **Photochemical Smog Formation Potential (PSFP):** Ground-level ozone, formed by the reaction of NO_x and volatile organic compounds (VOCs) in the presence of sunlight. [2] Reporting units are kg trichlorofluoromethane (CFC-11)-equivalent.
- **Ozone Depletion Potential (ODP):** The deterioration of ozone within the stratosphere by chemicals such as CFCs. Stratospheric ozone provides protection for people, crops, and other plant life from radiation. [2] Reporting units are kg ozone (O_3)-equivalent.
- **Particulate Matter Formation Potential (PMFP):** Particulate matter (PM) includes "a mixture of solid particles and liquid droplets found in the air" that are smaller than 10 microns in diameter. [4] Smaller diameter particulate matter (2.5 microns or smaller) can be formed by chemical reactions in the atmosphere (e.g., SO_2 and NO_x). Almost all PM impacts are caused by PM 2.5 microns or smaller ($PM_{2.5}$). [5] Reporting units are kg $PM_{2.5}$-equivalent.
- **Water Consumption (WC):** Water consumption is measured as the volume difference between water withdrawal and discharge and is measured in units of liters (l).

3.2 Data Quality Assessment

The data quality assessment is provided below:

- **PI process is based on system/subsystem models and prototypes demonstrated in a relevant environment.**
- **The uncertainty analysis was conducted for the following parameters:**
  - **Natural Gas: ±10%**
  - **Electricity: ±10%**
  - **AM20 Production: ±25%**
- **The CCS will not begin construction before Q1 2026. As more data becomes available, the PIs will include highs and lows from real operations data in the uncertainty analysis.**

3.3 Life Cycle Impact Assessment Results

The impact assessment results for the proposed product system are displayed in Exhibit 3-2.

Exhibit 3-2. Life cycle impact assessment results for the proposed product system

Impact Category	Impact Results with CCS		Unit
	Type IL	Type I/II	
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	256.02	273.08	kg CO2e
Acidification Potential - TRACI 2.1 (NETL)	1.90	2.04	kg SO2e
Eutrophication Potential - TRACI 2.1 (NETL)	0.794	0.855	kg Ne
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	0.50	0.52	kg PM2.5e
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	44.14	47.59	kg O3e
Water Consumption (NETL)	64,883.16	70,327.15	kg water
Ozone Depletion Potential - TRACI 2.1 (NETL)	9.44E-06	1.01E-05	kg CFC-11e

The impact assessment results for the comparison product system are displayed in **Exhibit 3-3.**

Exhibit 3-3. Life cycle impact assessment results for the comparison product system

Impact Category	Impact Results without CCS		Unit
	Type IL	Type I/II	
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	756	816	kg CO2e
Acidification Potential - TRACI 2.1 (NETL)	1.4	1.5	kg SO2e
Eutrophication Potential - TRACI 2.1 (NETL)	0.259	0.274	kg Ne
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	0.32	0.32	kg PM2.5e
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	30.8	33.1	kg O3e
Water Consumption* (NETL)	1960	2000	kg water
Ozone Depletion Potential - TRACI 2.1 (NETL)	8.70E-06	9.34E-06	kg CFC-11e

*Note: Per the EPD, the Water Consumption figures were merely based on the direct water use rather than Water Consumption occurring along the life cycle of contributing processes (i.e., the embodied water use – e.g., from electricity generation, construction of the plant, etc.). Therefore, a more apt comparison might be the direct additional water demand of 176.2 kg/MT of cement for Type IL, which would be a 9% increase, or 191.4 kg/MT of cement for Type I/II, which would be a 10% increase.

4 LIFE CYCLE INTERPRETATION

The life cycle results for the AR5, 100-year GWP are presented in **Exhibit 4-1** and **Exhibit 4-2** as waterfall charts. These results show the proposed product system (i.e., with CCS) with the comparison product system (i.e., without CCS) for each type of cement. The comparison product system is shown in the first column and is divided into direct and indirect CO_2 emissions. The direct CO_2 emissions are shown in orange and the indirect CO_2 emissions are shown in blue. CO_2 emissions that were added with CCS to the proposed product system are shown in gray and CO_2 emissions that are captured with CCS are shown in green. The proposed product system is shown in the last column and is divided into direct and indirect CO_2 emissions. The direct CO_2 emissions are shown in orange and the indirect CO_2 emissions are shown in light blue. The proposed product system shows a 66.1% decrease in GHG emissions for the Type IL cement and a 66.5% decrease in GHG emissions for the Type I/II cement. Similar results for the other impact categories have been shared with the U.S. DOE Office of Fossil Energy and are available in Appendix A: Impact Results for All Impact Categories.

Exhibit 4-1. GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type IL cement

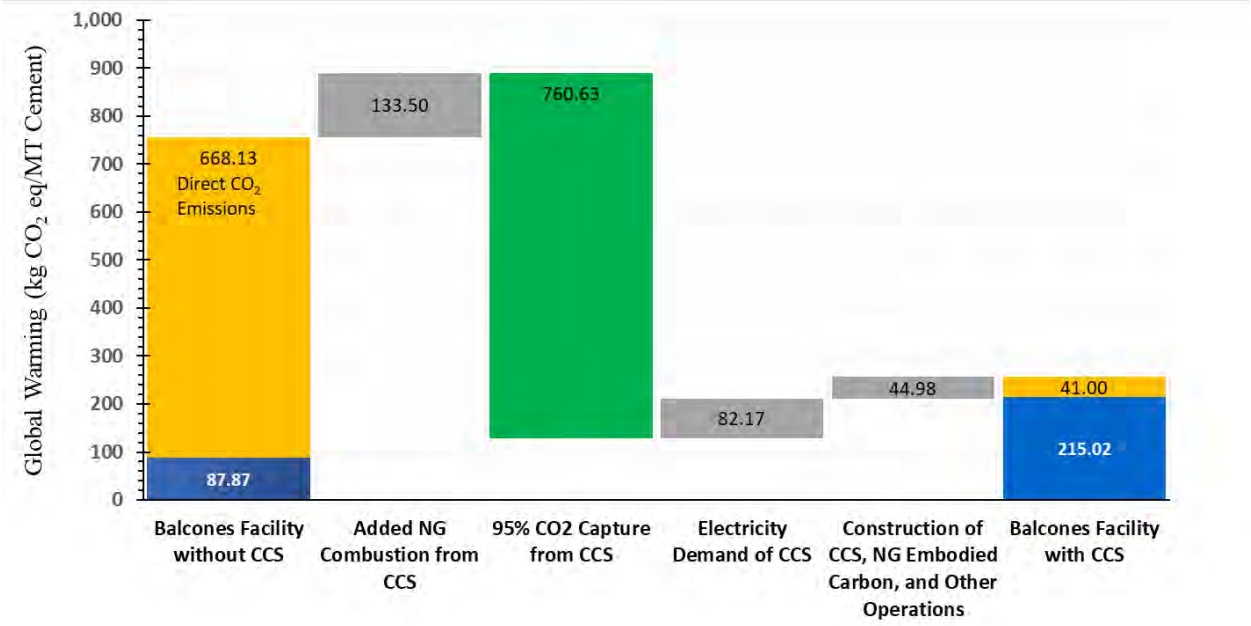
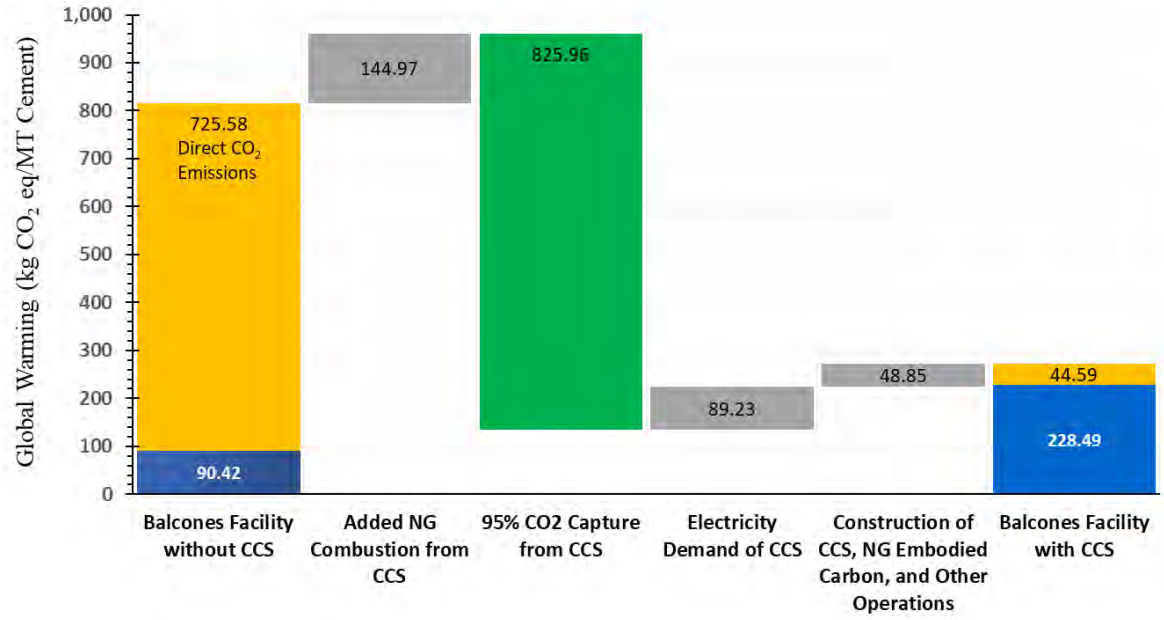


Exhibit 4-2. GWP-100-year life cycle interpretation results for proposed product system on a per MT cement basis for Type I/II cement



An estimated 668.13 kg CO_2/MT-cement produced and 725.58 kg CO_2/MT-cement produced are emitted as direct CO_2 emissions for Type IL and Type I/II cements, respectively, without the FEED CCS system. Per CEMEX's environmental product declaration, the overall CO_2 emissions from production of cement at its Balcones plant is 756 kg CO_2eq/MT of Type IL cement and 816 kg CO_2eq/MT of Type I/II cement when including supporting processes. Employing the FEED carbon capture process is estimated to save 499.98 kg CO_2e/MT Type IL cement produced and 542.92 kg CO_2e/MT Type I/II cement produced, limiting direct CO_2 emissions to 41.00 kg CO_2e/MT cement and 44.59 kg CO_2/MT cement at the cement plant for Type IL and Type I/II cements, respectively. This represents a 66.1% (Type IL) and 66.5% (Type I/II) reduction in overall GHG emissions for Portland cement production.

Given the large reductions of approximately two thirds in the Balcones cement plant's carbon footprint for both Types IL and I/II cement from the proposed CCS system, the PIs recommend further project evaluation of the Proposed Product System.

The sensitivity analysis results for the AR5, 100-year GWP are presented in **Exhibit 4-3**. The combustion of natural gas and electricity demand were varied ±10% and the make-up AM20 was varied ±25%. The sensitivity analysis shows that ±10% variation in the combustion of natural gas changed GWP by ±1.4% for Type IL cement and Type I/II cement. The sensitivity analysis also shows that ±10% variation in electricity demand changed GWP by ±3.2% for Type IL cement and ±3.3% for Type I/II cement. Changes in AM20 make-up is less impactful overall as ±25% variation only changed GWP by ±0.5% for Type IL cement and Type I/II cement.

Exhibit 4-3. Sensitivity Analysis

		25% Change in Make-up Amine		10% Change in CCS Electricity Demand		10% Change in CCS Natural Gas Use	
		Type IL ±Percent Difference from	Type I/II ±Percent Difference from	Type IL ±Percent Difference from	Type I/II ±Percent Difference from	Type IL ±Percent Difference from	Type I/II ±Percent Difference from
TRACI Impact Category	**Units**	**Baseline**	**Baseline**	**Baseline**	**Baseline**	**Baseline**	**Baseline**
Acidification Potential - TRACI 2.1 (NETL)	kg SO2e	0.3%	0.3%	0.8%	0.8%	1.6%	1.7%
Eutrophication Potential - TRACI 2.1 (NETL)	kg Ne	0.4%	0.4%	6.0%	6.1%	0.3%	0.3%
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	kg CO2e	0.5%	0.5%	3.2%	3.3%	1.4%	1.4%
Ozone Depletion Potential - TRACI 2.1 (NETL)	kg CFC-11e	0.4%	0.5%	0.5%	0.5%	0.001%	0.001%
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	kg PM2.5e	0.2%	0.2%	3.7%	3.9%	0.1%	0.1%
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	kg O3e	0.1%	0.1%	0.4%	0.4%	2.4%	2.5%
Water Consumption (NETL)	kg water	5.1%	5.1%	5.5%	5.5%	0.01%	0.01%

Note: As the electrical grid and transportation systems are decarbonized in the future, further CO_2eq emissions could be realized as the embodied carbon within the processes used in this model would decrease.

The CCS will not begin construction before Q1 2026. Thus, the PI process is largely theoretical and yet to be fully operated. In addition, no market research has been done to confirm to which products and technology pathways the products should be compared. Thus, these results are not final and are subject to change and should only be considered as preliminary.

5 CRITICAL REVIEW

The U.S. DOE Carbon Utilization Program will serve as the critical reviewer for this study.

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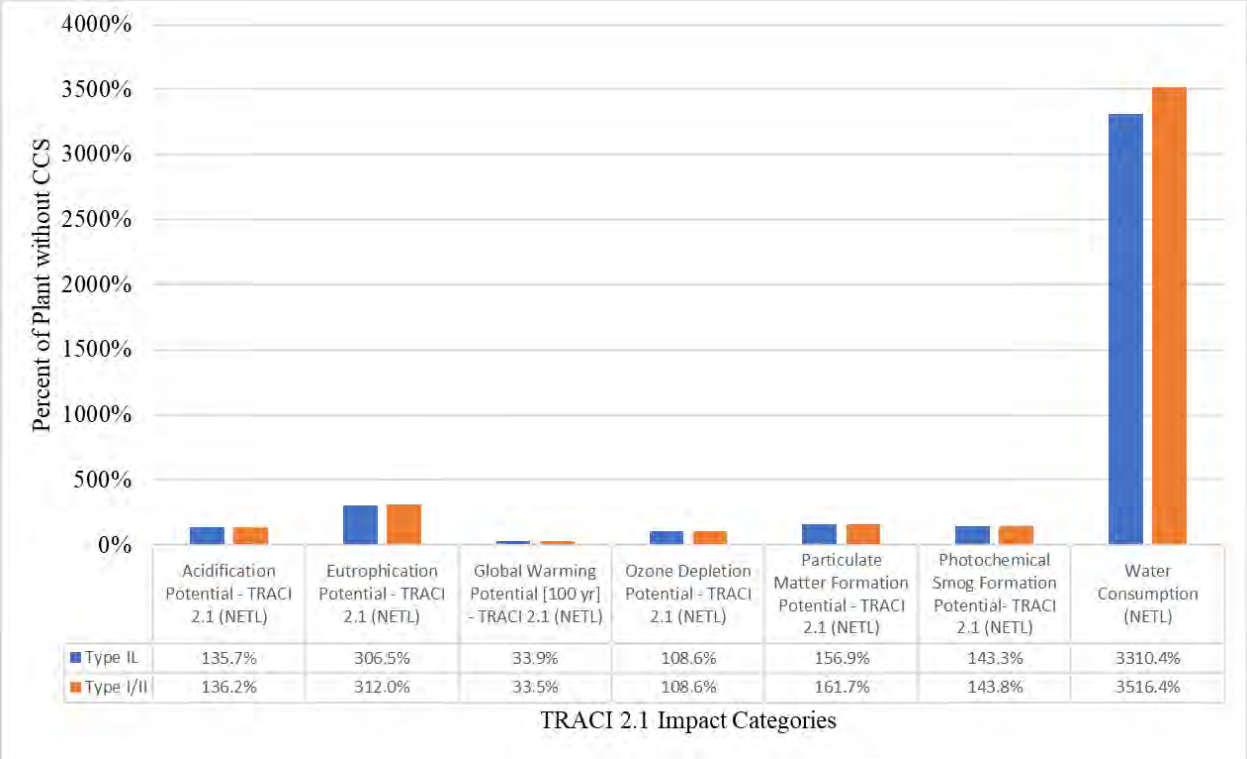
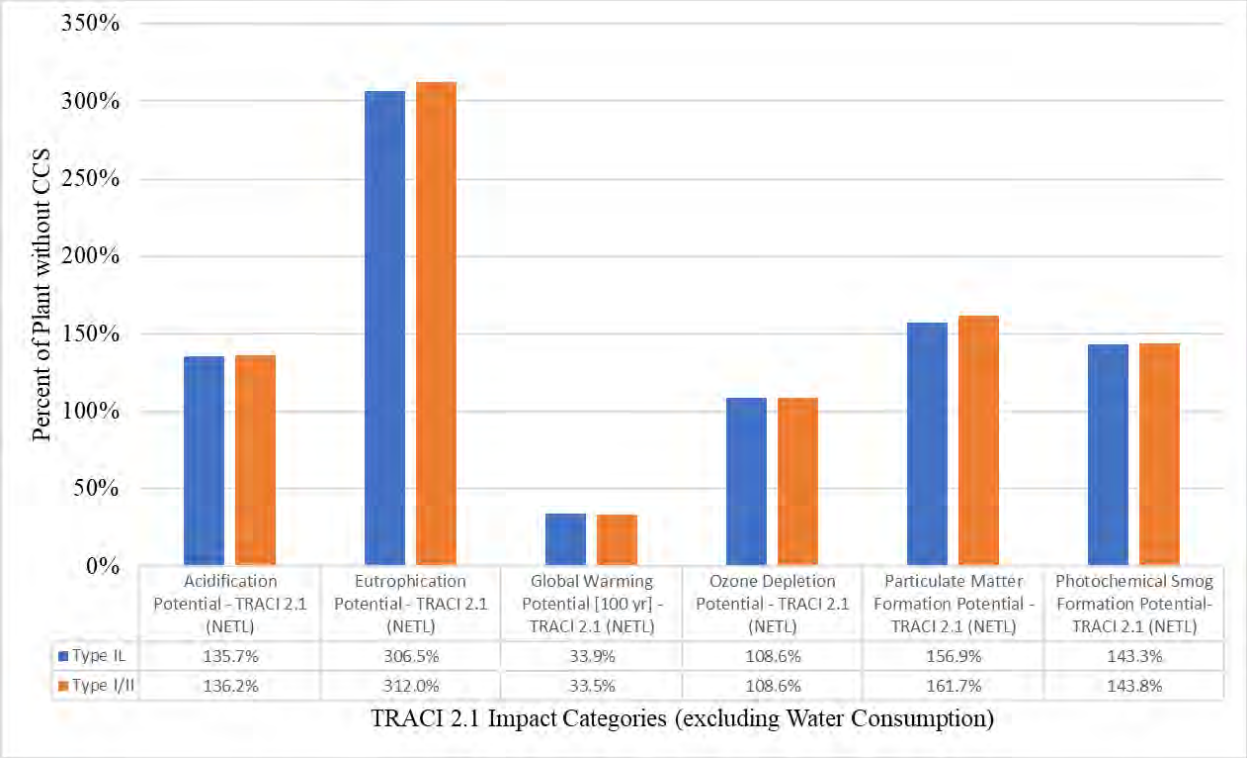
APPENDIX A: LIFE CYCLE IMPACT RESULTS FOR ALL IMPACT CATEGORIES



	Acidification Potential - TRACI 2.1 (NETL)	Eutrophication Potential - TRACI 2.1 (NETL)	Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	Ozone Depletion Potential - TRACI 2.1 (NETL)	Particulate Matter Formation Potential - TRACI 2.1 (NETL)	Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	Water Consumption (NETL)
Type IL	135.7%	306.5%	33.9%	108.6%	156.9%	143.3%	3310.4%
Type I/II	136.2%	312.0%	33.5%	108.6%	161.7%	143.8%	3516.4%

Note: Per the EPD, the Water Consumption figures were merely based on the direct water use rather than Water Consumption occurring along the life cycle of contributing processes (i.e., the embodied water use – e.g., from electricity generation, construction of the plant, etc.). Therefore, a more apt comparison might be the direct additional water demand of 176.2 kg/MT of cement for Type IL, which would be a 9% increase, or 191.4 kg/MT of cement for Type I/II, which would be a 10% increase.



	Acidification Potential - TRACI 2.1 (NETL)	Eutrophication Potential - TRACI 2.1 (NETL)	Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	Ozone Depletion Potential - TRACI 2.1 (NETL)	Particulate Matter Formation Potential - TRACI 2.1 (NETL)	Photochemical Smog Formation Potential- TRACI 2.1 (NETL)
Type IL	135.7%	306.5%	33.9%	108.6%	156.9%	143.3%
Type I/II	136.2%	312.0%	33.5%	108.6%	161.7%	143.8%

L Technoeconomic Analysis Topical Report

CARBON CAPTURE PLANT FEED STUDY FOR CEMENT MANUFACTURING

Topical Report:

Technoeconomic Analysis

WORK PERFORMED UNDER AGREEMENT
DE-FE0032220

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EXECUTIVE SUMMARY

RTI, in collaboration with Cemex , SLB and KBR Inc, is conducting a FEED (front-end engineering design) study to develop an AACE (Association for the Advancement of Cost Engineering) Class 3 cost estimate for CO_2 capture using RTI's Non-Aqueous Solvent (NAS) technology for retrofit application at the Balcones cement plant in New Braunfels, TX. The project aims to capture 95% of the total emissions from the two kilns and the natural gas boiler used to produce steam for regenerating the solvent used in the capture process. The captured CO_2 has a purity of > 95% CO_2, and is dried, compressed to 15.3 MPa (2,215 psia), ready for sequestration. The CO_2 capture plant nominal capacity is 2.4 MTPA.

Due to limited water availability at the Balcones plant, some design decisions were made which increased the CAPEX and OPEX contributions of the plant. Hybrid cooling was utilized, where 84% of the total cooling load is met using air cooled heat exchangers, and the remaining 16% of cooling load met using water cooled systems. The water cooling is reserved for the water-wash sections for water-balanced operations and for controlling emissions. A heat-integrated CO_2 compressor system with boiler feed water to raise steam in lieu of interstage coolers was used to limit water usage. The larger area requirements due to the use of air coolers for the CO_2 capture plant resulted in re-locating the capture plant site away from the CO_2 capture plant, across the railway line and the road.

The CO_2 capture plant design proposes the use of an acid wash system for emissions control. In its current configuration, the acid wash removes any residual amine from the treated gas by reacting the amine with the acid to form an amine-sulfate salt. This salt is typically treated as waste, and the lost amine must be replenished through the addition of makeup amine. However, this approach introduces operational inefficiencies in terms of chemical costs and waste handling.

Experimental work conducted by RTI has demonstrated that this amine can be successfully separated from the acid wash waste stream with a recovery rate of at least 95%. The process entails neutralizing the amine-sulfate salt to regenerate the parent amine, which then separates out as an organic phase due to its hydrophobic properties. The recovered organic amine can be recycled into the NAS solvent loop, creating a closed-loop process. By reducing the loss of amine and limiting the need for fresh chemical makeup, this recovery process offers significant cost savings.

Experimental testing has demonstrated the technical feasibility and maturity of the amine recovery from acid wash waste stream technology, thereby eliminating significant implementation risks. The technology is planned for inclusion as part of the standard design package for subsequent projects. However, it was not incorporated into the current FEED design, as its development progressed in parallel and reached completion after the FEED design freeze. The cost and performance impacts associated with its implementation have been evaluated and incorporated into the Techno-Economic Analysis (TEA) to inform future design and deployment decisions.

A detailed TEA has been carried out for CO_2 capture at Cemex's Balcones plant with using RTI-NAS technology. The TEA uses data from the AACE Class 3 level FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants.

Three different cases are evaluated. Case A is the base case with the capture plant as currently designed with hybrid cooling and heat-integrated CO_2 compressors. Case B is a hypothetical case where the constraint for the limited water supply was removed and the plant and CO_2 compressors are water cooled and the plant is sited in proximity to the cement plant. Case C is a comparative

case that evaluates the impact of co-generation of steam and electricity. A comparative "Cemex" case is also presented which uses the Cemex financial parameters (except for capital charge factor), Cemex's estimate for the owner's cost, labor estimates based on local wages, and utility prices.

The cost of capture, excluding T&S, using Cemex parameters was estimated to be \$101.6/t-CO_2. Using DOE parameters and assumptions results in the cost of capture of \$112.9/t-CO_2. Relaxing the constraint of limited water availability reduces the cost of capture to \$98.3/t-CO_2. Also, using a cogeneration plant for steam and electricity reduces the cost of capture for the base case from \$112.9/t-CO_2 to \$103.9/t-CO_2. Results from the TEA are summarized in Table 1-1.

The estimated cost of CO_2 capture for the cement plant using RTI's NAS technology is \$112.9/t-CO_2, For the techno-economic assessment (TEA) based on the Cemex parameters and assumptions (the "Cemex case"), the capture cost—excluding transportation and storage (T&S)—is \$101.6/t-CO_2. When amine recovery from the acid waste stream is incorporated, operating expenses (OPEX) are reduced, resulting in a lower overall cost of capture. Under this configuration, the capture cost—excluding T&S—decreases to \$104.2/t-CO_2 for the Base case using DOE financial parameters, and to \$93.0/t-CO_2 when applying the Cemex financial parameters.

A sensitivity analysis was performed and the sensitive parameters identified included the capacity factor and the CAPEX. where a 15% change indicated the highest impact from the capacity factor. The unit price of natural gas and electricity had the lowest impact, with the cost of capture increasing by 4% with a 30% increase in the utility prices. The solvent price also had a low impact, with the cost of capture rising by 5% with a 30% increase in the unit price of NAS.

Table 1-1: Summary of the TEA results

Case	Cemex - confidential	Case A: Base Case	Case B: Water-cooled	Case C: Co-gen
Financial Parameters	Cemex - confidential	DOE	DOE	DOE
Cooling	Hybrid	Hybrid	Cooling Tower	Hybrid
CO_2 compressors	Heat-integrated	Heat-integrated	water-cooled	Heat-integrated
Ductwork	Extended	Extended	Conventional	Extended
Electricity	grid	grid	grid	Co-gen
CAPEX, MM				
Total Plant Cost (TPC)	$759	$759	$621	$783
Total Overnight Cost (TOC)		$926	$759	$953
Total As Spent Capital (TASC)		$1,035	$848	$1,066
OPEX, MM/yr (100% CF Basis)				
Fixed OPEX (OCfix)		$22.5	$18.7	$23.2
Var. OPEX, less Fuel (OCvar)		$58.4	$56.9	$57.4
Fuel + Purchased Power (OCfuel)		$70.7	$62.6	$57.2
Total OPEX	$143.8	$151.7	$138.2	$137.8
Plant Output				
CO_2 Capture Product, tonne/hr	274.0	274.0	274.0	274.0
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000	2,400,000	2,400,000
CO_2 Avoided, tonne/hr	218.4	218.4	218.4	200.5
Total CO_2 Avoided	1,913,600	1,913,600	1,913,600	1,756,200
Common Factors Used				
Capital Charge Factor (CCF)		0.0884	0.0884	0.0884
Capacity Factor (CF)	0.74	0.74	0.74	0.80
Costs of CO_2 Captured ($/tonne)	101.6	112.9	98.3	103.9
Costs of CO_2 Avoided ($/tonne)		141.6	123.3	141.9
Cost of CO_2 Capture Breakdown				
CAPEX	37.2	46.3	38.0	44.0
Fixed O&M		12.8	10.6	12.1
Variable O&M	64.3	24.4	23.7	23.9
Fuel & Purchased Power		29.5	26.1	23.8
Total	101.6	112.9	98.3	103.9
T&S	33.9	10.0	10.0	10.0
Cost of Capture w T&S	135.5	122.9	108.3	113.9
With Amine Recovery				
Costs of CO_2 Captured ($/tonne)	93.0	104.2	89.6	95.3
Actual CO_2 Captured annually	1,766,300	1,766,300	1,766,300	1,914,302
CO_2 Capture Product, tonne/hr	201.63	201.63	201.63	218.53

Section 1 Introduction

RTI, in collaboration with Cemex, SLB and KBR Inc, is conducting a FEED (front-end engineering design) study to develop an AACE (Association for the Advancement of Cost Engineering) Class 3 cost estimate for CO_2 capture using RTI's Non-Aqueous Solvent (NAS) technology for retrofit application at the Balcones cement plant in New Braunfels, TX. The project aims to capture 95% of the total emissions from the two kilns and the natural gas boiler used to produce steam for regenerating the solvent used in the capture process. The captured CO_2 has a purity of > 95% CO_2, and is dried, compressed to 2215 psia (152.7 bara), ready for sequestration.

The Balcones plant has 2 kilns. Kiln #1 has 4 preheater stages with a design capacity of 3,125 tons clinker/day and kiln #2 has 5 preheater stages with an inline calciner with a design capacity of 3,600 tons clinker/day. The plant uses selective non-catalytic reduction to reduce NOx, a dry sorbent injection to reduce SOx and fabric filter baghouse for control of particulate matter. Total CO_2 emissions at nominal capacity is 2.2 MTPA.

The technoeconomic analysis uses data from the FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants [1].

Section 2 Evaluation Basis

The study evaluates the use of RTI's Non-Aqueous Solvent technology for 95% CO_2 capture from a cement plant downstream of the baghouse for particulate control. The captured CO_2 has a purity of > 95% CO_2, and is dried, compressed to 2215 psia (152.7 bara), ready for sequestration.

2.1 DESIGN BASIS

The plant is located in New Braunfels, TX, with ambient conditions and site characteristics as shown in Table 2-1.

Table 2-1: Ambient conditions and site characteristics for the reference plant

Parameter	Description
Location	New Braunfels, TX.
Elevation (ft)	645 ft (196.6 meters)
Barometric Pressure, psia (bar)	14.696 (1.01325 bar)
Design Ambient Temperature, Dry bulb, °F (°C)	80 (26.7)
Design Ambient Temperature, Wet bulb, °F (°C)	77 (25.0)
Topography	Level
Transportation	Rail
Water	on-site well water available at average rate of 191 GPM
Access	Land locked, having access by rail and highway
CO_2 storage	Compressed to 2215 psia (152.7 bara) , transported 20 miles (32 kilometers) and sequestered in a saline formation.

2.2 CAPITAL COST ESTIMATION METHODOLOGY

The capital cost estimate was developed by KBR during Front End Loading (FEL-3) engineering and targeted as a Class 3 estimate based on the AACE International practice from the published Cost Estimate Classification System (18R-97, page 3, Rev. 8/7/20). KBR Estimating used the Aspen Economic Evaluation tools to organize, extend, compile, and sort the estimate data according to the agreed cost breakdowns. Specifically, Aspen Capital Cost Estimator (ACCE) V14.2 was used for this project.

The main tool utilized to compile the estimate was the Aspen Economic Evaluation Capital Cost Estimator, V14.2 version (ACCE). The tool relies on quantities and sizing information to generate costs and field labor hours from its own database of costs. The estimate is made up of a combination of sources of cost. The estimate was generated with the ACCE tool using regional cost conditions, KBR historical costs information, and vendor budgetary quotes.

The cost estimate uses a code of accounts into major systems as outlined below:

- Unit 01 – CO_2 Capture System

- Unit 02 – CO_2 Compression, Dehydration, and Polishing
- Unit 11 – Raw, Potable, and Demineralized Water System
- Unit 12 – Boiler & Steam System
- Unit 14 – Solvent & Chemical Storage Utilities
- Unit 15 – Cooling Water System
- Unit 16 – Air / Nitrogen System
- Unit 18 – Wastewater Treatment Plant
- Unit 20 – Stack
- Unit 22 – Utility Headers
- Unit 23 – Power Generation

2.2.1 Cost Basis

The estimate was generated in U.S. dollars ($) with a 4th Quarter 2024 cost basis. The ACCE base escalation indices were adjusted based on current market conditions to bring the system generated costs to "today's" cost. Equipment quotes or costs provided by vendors, licensors, and contractors were brought up to the same overall cost basis. Forward-looking escalation was included in the estimate.

2.2.2 Capital Cost Estimates

Relevant information like the technical datasheets, requisition package, specifications, etc., was used to obtain vendor budgetary quotes. The budgetary quotes were checked against the associated design specifications to see what is included and excluded. Any items excluded from the quote were estimated with allowances. Equipment quotes were obtained on all critical mechanical equipment, which make up 94% of the total mechanical equipment costs in the estimate. In addition, quotes were obtained on most electrical equipment and instruments. In general, the lowest technically viable quotes were considered for the estimate, but averages were used in a few cases due to uncertainty in the accuracy of the quote and items included by the vendor. Contractor quotes were also included for Power Overhead Feeder, Gatehouse, Warehouse, Engineering & Control Room Building, Control Room & Change Room Building, Maintenance Building, Lab, and Compressor Sheds. The combined value of the vendor budgetary quotes and contractor estimates make up 66% of the total project equipment & material costs. The remaining bulk materials and equipment were estimated by ACCE indexed based on experience.

The capital costs are broken down to the five levels that are typically used by DOE. These include the BEC (bare erected cost), EPCC (engineering, procurement and construction cost), TPC (total plant cost), TOC (total owner's cost) and TASC (total as spent capital).

2.2.3 Home Office, Engineering Fees and Project/Process Contingencies

Engineering & Home Office costs for detailed design were included in the estimate based on the typical factors for this type of scope. The Construction Management Team (CMT) costs are based on the project schedule, field hours, expected staffing plan, and per-diems. It includes Construction Quality Assurance (QA) for the supervision of general construction activities with a materials management representative, and a Health, Environment, and Safety (HSE) representative. The

temporary facilities, vehicles, and indirect supplies associated with the CMT were included. Construction Management costs include support during Start-up/Commissioning.

Process contingency is intended to compensate for uncertainty in cost estimates caused by performance uncertainties associated with the development status of a technology. A 17% process contingency was applied to the RTI CO_2 capture process.

A Cost Risk Analysis was performed by KBR for the project through a Monte Carlo simulation The analysis included conversations with the engineering disciplines and other KBR departments involved in the development of the estimate to assign proper expected variability ranges to quantities and costs. After discussions with Cemex, the P70 value of the results, corresponding to 6.9%, was included as the project contingency cost in the estimate summary.

2.2.4 Owner's Cost

Owner's cost was then added to TPC to come up with the total overnight cost (TOC) for the system. Owner's costs as defined in the DOE Baseline Study include the following:

- preproduction costs –
  - 6 months of all labor cost
  - 1 month of maintenance materials
  - 1 month of non-fuel consumables
  - 1 month of waste disposal
  - Start-up and commissioning costs (2% TPC)
- inventory capital
  - 60-day supply of fuel and consumable at 100% capacity factor (CF)
  - 0.5% TPC (spare parts)
- initial cost for catalyst and chemicals per design
- land cost was not considered as the cement plant already has the land available for the capture plant.
- other owner's costs, estimated at 15% of TPC as per DOE baseline study [1]. For the Cemex case, the Owner's cost was estimated to be $24MM and includes the electrical substation, air emissions permitting, construction and land use permits, topography, soil and water studies, legal fees and technology, environmental and financial consultants for the project.
- financing costs at 2.7% TPC, as per DOE baseline study [1].

2.3 OPERATION & MAINTENANCE COSTS

The operation and maintenance (O&M) costs pertain to those charges associated with operating and maintaining CO_2 capture plants over their expected life. These costs include:

- operating labor
- maintenance – material and labor
- administrative and support labor
- consumables
- fuel
- waste disposal

There are two components of O&M costs; fixed O&M, which is independent of power generation, and variable O&M, which is proportional to power generation. Variable O&M costs were estimated based on 74% CF, which is consistent with a historical value of 1.8 MTPA CO_2 emissions from the cement kilns.

2.3.1 Fixed Costs

Operating labor cost was determined based on the number of operators required to work in the plant. Other assumptions used in calculating the total fixed cost include:

- 2022 base hourly labor rate, $/hr. $40.72
- length of work-week, hrs. 50
- labor burden, % 30
- administrative/support labor, % O&M labor 25
- annual maintenance labor, % TPC 0.63
- annual maintenance material, % TPC 0.96
- property taxes and insurances, % TPC 2

2.3.2 Variable Costs

The cost of consumables, including fuel, was determined based on the individual rates of consumption, the unit cost of each specific consumable commodity, and the plant annual operating hours. Waste quantities and disposal costs were evaluated similarly to the consumables.

The unit costs for major consumables and waste disposal was selected from the DOE/NETL - 2023/3856 Baseline Report, Analysis of Carbon Capture Retrofits for Cement Plants [1] or vendor quotes. Natural gas fuel is purchased at $4.61/MMBtu, and power is purchased at a price of $67.3/MWh, and are consistent with the values used in the DOE/NETL 2023/3856 Baseline Report.

2.4 FINANCIAL MODELING BASIS

2.4.1 Cost of Capture

The primary metric used to evaluate overall financial performance is the cost of capture (COC) for the retrofit CO_2 capture plant. All costs were expressed in the "first-year-of-construction" year dollars, and the resulting COC was also expressed in "first-year-of-construction" year dollars.

The same financial modeling methodology was used for this study as per the 2023/3856 Baseline Report [1] and guidelines in the QGESS *Cost Estimation Methodology for NETL Assessments of Power Plant Performance* [2] document. This is a simplified method that is a function of the plant TPC, capital charge factor (CCF), fixed and variable operating costs, CF, as shown in the equation below:

$$COC\left(\frac{\$}{tonne\ CO_2}\right) = \frac{TOC * CCF + FOM + VOM + PF + PP}{tonnes\ CO_2\ captured\ per\ year}$$

Where:

TOC	Total Overnight Cost of equipment added for CO_2 capture
CCF	Capital Charge Factor
FOM	Annual fixed O&M costs

VOM	Annual variable O&M costs
PF	Purchased Fuel
PP	Purchased Power

The CCF used in evaluating the COC was 8.84%, and developed by NETL's Energy Markets Analysis Team in December 2022 based on market data respective to the cement sector, as outlined in the DOE-NETL 2023/3856 Baseline report [1].

Section 3 **RTI's** Non-Aqueous Solvent (RTI-NAS) CO_2 Capture Technology

3.1 PROCESS OVERVIEW

RTI's CO_2 capture process uses RTI-NAS, a formulation of hydrophobic, sterically hindered, carbamate-forming amines in an organic diluent with low (<10 wt%) water content to capture >95% of CO_2 from a cement plant and the associated captive natural gas boiler for providing steam for solvent regeneration. The solvent is continuously recirculated between an absorber and a regenerator column. Flue gas from a cement plant and the captive boiler, after scrubbing SO_2 to < 1 ppm and cooling the flue gas, enters the absorber column where 95% of the CO_2 is captured. CO_2 absorption occurs at low temperatures in the absorber column. The amine in the RTI-NAS solvent reacts with CO_2 via carbamate chemical reaction pathway. The CO_2-rich solvent is regenerated in the regenerator using LP steam from the natural gas boiler. During the solvent regeneration process, the solvent is heated, and the reverse reactions predominate to release CO_2. The CO_2 released in this process at 65.3 psia (4.5 bara), is dried, compressed to 2215 psia (152.7 bara) and sent for sequestration.

RTI'S NAS technology has been extensively tested at the bench and pilot scale and has the potential to reduce the thermal regeneration energy demand to ~2.0 GJ/t-CO_2 captured [3]. This low energy demand is due to the solvent formulation and the process configuration of the CO_2 capture plant. Key attributes of the RTI-NAS solvent are:

- Low energy required for solvent regeneration resulting in low steam consumption
- High working capacity resulting in low liquid/gas ratio
- High solvent thermal and oxidative stability resulting in longer service life
- Low corrosivity

3.2 PROCESS DESCRIPTION

The CO_2 capture plant is designed to remove at least 95% of CO_2 from the flue-gas from the cement plant, downstream of the baghouse filter unit. The captured CO_2 has a purity of > 95% CO_2, and is dried, compressed to 2215 psia (152.7 bara), ready for sequestration. A schematic of the process flow diagram is provided in

Figure 3-1. A single train is needed to treat the flue gas from the cement plant. The process equipment comprises a direct contact cooler with integrated SO_2 polishing, a flue gas blower, the absorption column with the intercoolers, an advanced emissions control technology and acid wash to control amine emissions, the regeneration column, associated pumps, storage and receiver vessels, and a CO_2 drying and compression train.

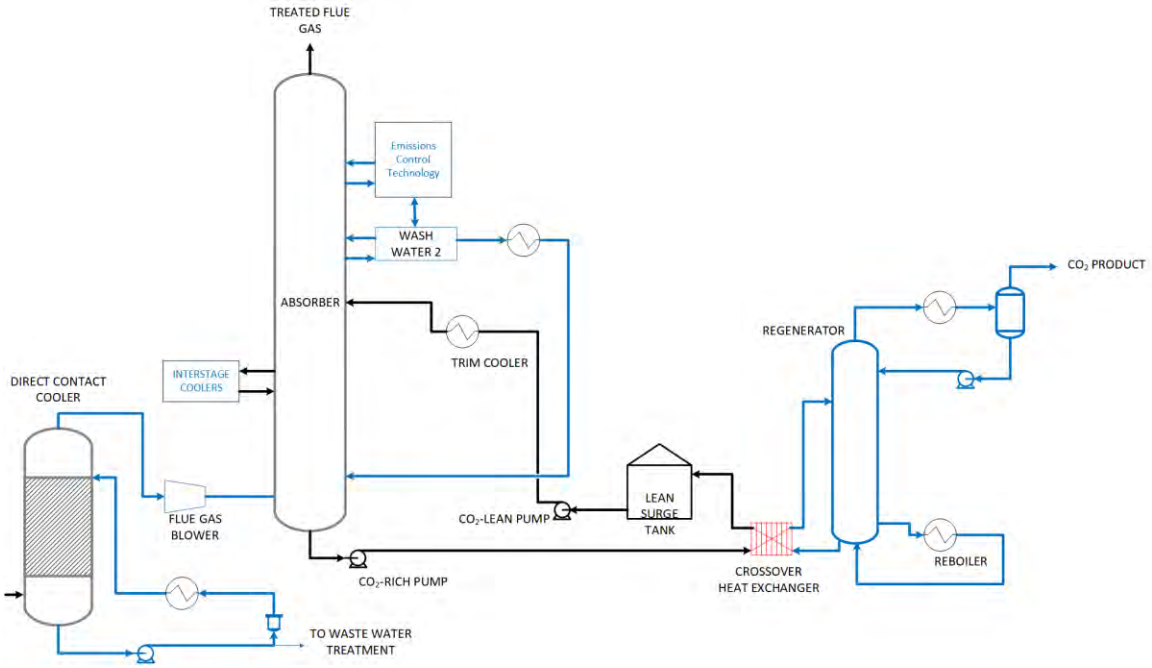

Figure 3-1: PFD of the RTI CO_2 Capture Plant

3.2.1 Integrated Direct Contact Cooler and Caustic Scrubber

The combined flue gas from Kiln 1, Kiln 2, and the natural gas-fired boiler is routed to the Feed Direct Contact Cooler, where it is cooled and conditioned prior to CO_2 absorption. In this unit, the gas stream is contacted with a caustic solution, which facilitates the removal of sulfur dioxide (SO_2) to a concentration of less than 1 ppmv. The water in the recirculation loop passes through the DCC Circulation Filter, the Feed Scrubber Wash Air Cooler, and the Feed Scrubber Wash Cooler before returning to the top of the DCC. During the cooling process, excess water vapor condenses from the flue gas. This condensate is collected and sent to the Wastewater Treatment Plant (WWTP), where it is treated and reused elsewhere in the process.

3.2.2 Flue Gas Blower

After cooling and conditioning the flue gas, its pressure is boosted in a blower to overcome the pressure drop encountered in the DCC and the absorber column. The caustic scrubber also reduces the acid gas components in the flue gas, thus reducing the need for use of special alloys in the blower.

3.2.3 CO_2 Absorber and Regenerator

The Absorber Column is a vertically packed, integrated unit designed for CO_2 removal from flue gas. It consists of three main sections: the CO_2 absorption section, followed by a water wash section and an acid wash section for downstream treatment. Cooled flue gas from the Flue Gas Blowers enters the bottom of the absorber and flows upward in a counter-current direction to the lean amine solvent, which is introduced at the top of the CO_2 absorption section. As the gas rises through the packed Absorption beds, CO_2 is absorbed into the solvent. Interstage cooling is applied between the beds to remove the heat of absorption and maintain optimal solvent loading efficiency.

The partially loaded solvent is collected in the Absorber Interstage Surge Tanks, from which it is circulated by the Absorber Interstage Circulation Pumps through the Absorber Interstage Air Coolers. These air coolers reduce the solvent temperature before it is reintroduced into the column above the next packed stage. At the bottom of the column, the CO_2-rich solvent is collected and discharged by the Rich Solvent Pumps. The stream is then split: the majority is routed through the Lean/Rich Solvent Heat Exchanger for energy recovery, while a small bypass stream is sent directly to the top of the Regenerator Column as cold rich solvent. The treated flue gas, now with significantly reduced CO_2 content, continues upward into the water wash and acid wash sections for final cleanup before exiting the absorber.

CO_2-lean solvent from the Regenerator Column is routed through the Lean/Rich Solvent Heat Exchanger, where it transfers heat to the incoming CO_2-rich solvent from the Absorber, delivered by the Rich Solvent Pumps. This integration reduces reboiler duty and improves energy efficiency. After heat exchange, the lean solvent flows to the Lean Solvent Surge Tank, and from there, it is cooled in the Lean Solvent Air Cooler before being sent to the top of the Absorber Column. During normal operation, approximately 10% of the lean solvent flow is diverted through the Particulate Filter and Carbon Filter to remove solids and degradation products, maintaining solvent quality. The filtered stream is then recombined with the main flow upstream of the absorber.

The Regenerator Reboiler uses a flow of LP steam to provide energy for regeneration. Vapors from the reboilers return to the column, and CO_2 gas from the column top is cooled in the Regenerator Overhead Condenser before entering the Condensate Drum. Captured CO_2 is sent to the CO_2 Compressor Package, while reflux is recycled to the column. In the event of downstream upsets, vented gas is routed to the stack.

The lean solvent, after exchanging heat with the incoming rich solvent is further cooled in a trim cooler and fed back to the top of the absorber. A makeup amine stream is also added to the lean solvent, to make up for any amines lost in the absorber or the regenerator.

3.2.4 CO_2 Product Gas Dehydration and Compression

The CO_2 Compressor Package compresses CO_2 from the Regenerator Column and integrates polishing and TEG dehydration to meet pipeline specifications. The system consists of a five-stage integrally geared compressor with heat exchangers and suction/knock-out drums. Heat from the intercoolers is recovered using boiler feedwater (BFW), generating LP steam for the utility header. Intermediate process steps include O_2 Polishing and TEG Dehydration between stages 3 and 4 of compression. The O_2 Polishing Reactor reduces O_2 content in the CO_2 stream to <10 ppmv using a catalyst that reacts with hydrogen. Hydrogen is supplied via electrolysis in the vendor-provided Electrolyzer Package, which uses demineralized water sourced from OSBL.

The TEG Dehydration Package removes moisture from the CO_2 stream, with TEG. The polished and dehydrated CO_2 is returned to stage 4 of the compressor for final cooling and compression before being delivered to the pipeline.

Section 4 Cement Plant with CO_2 Capture

4.1 PROCESS DESCRIPTION

The overall block flow diagram for the cement plant integrated with the RTI CO_2 capture plant is shown in Figure 4-1.

The flue gas from the kilns (stream 1) is combined with the flue gas from the natural gas boiler (stream 4) and the combined stream (stream 5) is sent to the RTI NAS CO_2 capture plant. The CO_2-product stream is compressed, dehydrated and polished to meet pipeline specifications for transport and subsequent sequestration (stream 7). The RTI CO_2 capture plant removes 95% of the CO_2 in the flue gas, along with remaining SO2, and the clean gas from the RTI CO_2 capture plant is sent to the stack (stream 6). Natural gas (stream 2) is used to generate steam in a natural gas fired boiler. LP steam from the boiler is used in the capture plant for solvent regeneration and the condensate is returned to the boiler.

The HMB for the cement plant integrated with the RTI CO_2 capture plant is provided in Table 4-1**Error! Reference source not found.**

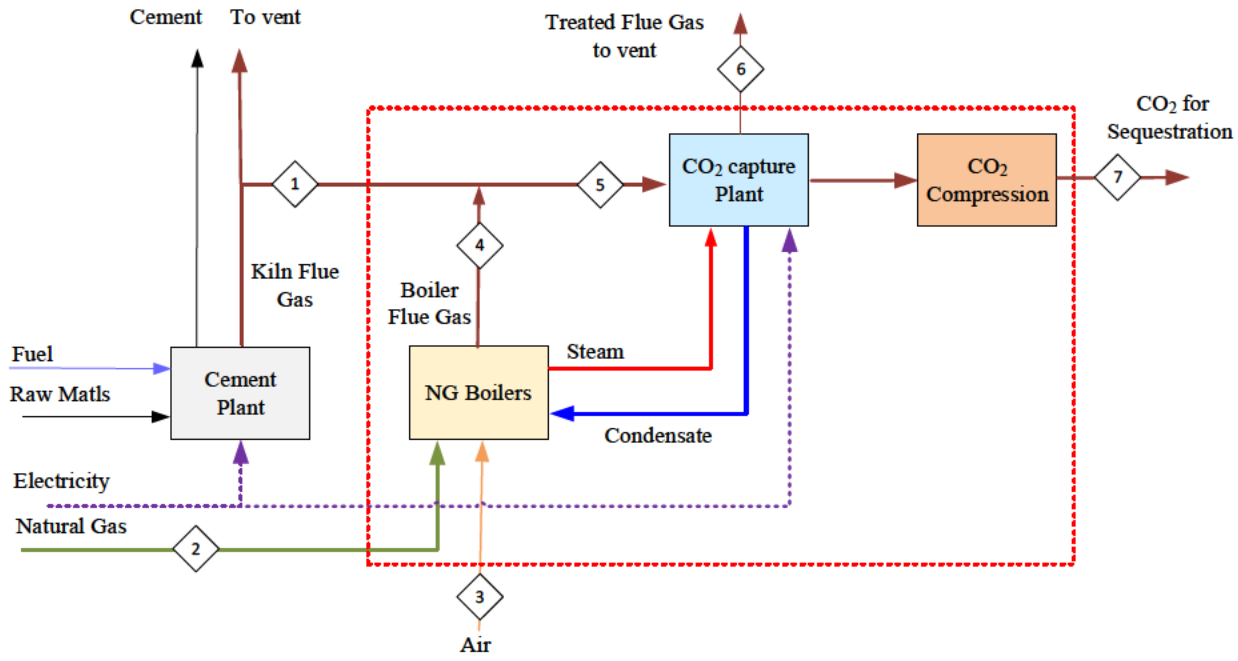

Figure 4-1: BFD for the integrated cement plant and the RTI CO_2 capture plant.

Table 4-1: Stream table, Cement plant with RTI CO_2 capture process

	1	2	3	4	5	6	7
V-L mole fraction							
CO_2	0.1404	0.0100	0.0003	0.0869	0.1284	0.0080	0.9980
H_2O	0.1350	0.0000	0.0099	0.1758	0.1442	0.0573	0.0001
O_2	0.1057	0.0000	0.2074	0.0204	0.0864	0.1111	1E-05
N_2	0.6189	0.0160	0.7732	0.7083	0.6391	0.8212	0.0200
Ar	0.0000	0.0000	0.0092	0.0085	0.0019	0.0024	0.0000
SO_2	4.8E-06				3.7E-06		
CH_4		0.9310					
C_2H_6		0.0320					
C_3H_8		0.0070					
C_4H_{10}		0.0040					
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Flowrate (kmol/hr)	39,716	962	10,584	11,574	51,290	39,914	6,261
Flowrate (kg/hr)	1,164,950	16,675	305,413	322,089	1,487,039	1,119,275	275,598
Temperature (°C)	128.5	26.7	15.0	150.6	133.4	35.0	35.0
Pressure (MPa, abs)	0.099	0.101	0.101	0.100	0.099	0.100	15.258
Enthalpy (kJ/kg)	-2887.6	-4475.1	-97.6	-2619.0	-2829.4	-596.6	-9181.9
Density (kg/m^3)	0.87	0.71	1.22	0.79	0.85	1.09	823.999
Molecular Weight	29.33	17.33	28.86	27.83	28.99	28.04	44.01

Section 5 Technoeconomic Evaluation

5.1 TECHNOECONOMIC EVALUATION CASE STUDIES

The technoeconomic analysis uses the same parameters as the DOE Baseline study for retrofit CO_2 capture for cement plants [1]. Comparative cases are presented to allow for more direct comparison with the DOE cases. The Base Case A, and comparative cases B & C evaluated with their assumptions are shown in Table 5-1. The Cemex case evaluated using Cemex confidential parameters is shown for comparison.

Table 5-1: Description of Cases used for TEA.

Case	Cemex	Case A	Case B	Case C
Financial Parameters**	Cemex confidential	DOE	DOE	DOE
Cooling	Hybrid Cooling (80F air cooling followed by water-cooled)	Hybrid Cooling (80F air cooling followed by water-cooled)	Water cooling with cooling tower	Hybrid Cooling (80F air cooling followed by water-cooled)
CO_2 compressor	Heat integrated with BFW used to raise steam in the interstage coolers	Heat integrated with BFW used to raise steam in the interstage coolers	Conventional water cooled heat exchangers for interstage coolers	Heat integrated with BFW used to raise steam in the interstage coolers
Ductwork from kiln to capture plant	Extended duct over the railway spurs and road to capture island	Extended duct over the railway spurs and road to capture island	Assumed capture island in proximity so extended duct not needed	Extended duct over the railway spurs and road to capture island
Electricity	Off the grid	Off the grid	Off the grid	Co-generation. Natural gas boilers used to raise MP steam used to expand across a turbine to generate power and produce LP steam. Any additional electricity needed is off the grid.
Steam generation	Natural gas boilers used to raise LP steam	Natural gas boilers used to raise LP steam	Natural gas boilers used to raise LP steam	

** This includes capital charge factor, operating and maintenance labor estimates, estimate for Owner's cost, property taxes and insurance costs, water source (supplied by on site wells for Cemex, and 50% groundwater, 50% municipal for DOE cases), financing costs, start-up and commissioning costs.

The HMB results were used to size the process equipment and develop the CAPEX and OPEX cost estimate using a combination of vendor quotes and ACCE. These were then used to determine the cost of capture, as outlined in section 2.4.1 earlier. All cases use the same HMB and CAPEX cost estimates and hence results will be shown for Base Case A. The comparative cases will be discussed in the next section.

5.2 CASE A: BASE CASE

The Cemex Balcones Cement Plant is in a hot humid subtropical region and has limited water availability from the on-site Cemex wells. The CO_2 capture process requires cooling for the direct contact cooler used to reduce the temperature of the flue gas, absorber intercoolers, trim cooler, water wash and CO_2 product stream condenser. In addition, cooling is also needed to cool the CO_2-product between stages during compression. To address this challenge, it was decided to treat and re-use the water condensed in the direct contact cooler, and to use hybrid cooling where 84% of the total cooling load is met using air cooled heat exchangers, and the remaining 16% of cooling load met using water cooled systems. 80 °F was selected as the design temperature for the air coolers, as a compromise between the CAPEX for the air coolers and capture rate as it allows the plant to reach 95% capture rate averaged over summer and winter months. The flue gas stream is cooled using air coolers and then further cooled using water cooling to the designed dewpoint temperature. The absorber intercoolers, the intercoolers and the CO_2-product condensers all use only air cooling, and the water cooling is reserved for the water-wash sections where it is critical to maintain final wash temperature to be close to dewpoint temperature of the inlet flue gas for water-balanced operations and for controlling emissions.

Lack of cooling water resulted in the need for a steam integrated CO_2 compressor system where the interstage coolers uses the boiler feed water to raise steam. The larger area requirements for the CO_2 capture plant with air coolers also resulted in re-locating the capture plant site away from the CO_2 capture plant, across the railway line and the road.

5.2.1 Plant Performance Summary

Overall performance of the plant, along with the auxiliary power requirements is provided in Table 5-2.

Table 5-2: Overall plant performance summary for the cement plant with RTI CO_2 capture process

	Case B
Cement Production rate, M tonnes/year	2.4
Clinker percentage	92%
CO_2 capture rate, %	95
CO_2 capture system, cooling duty, GJ/hr	1,141
Natural Gas Feed Flow, kg/hr	17,249
HHV Thermal Input, KWt	250,557
LHV Thermal Input, KWt	210,836
Raw water withdrawal, m^3/min	1.1
Raw water consumption, m^3/min	-0.2
Auxiliary Load Summary	
CO_2 Capture (without air coolers), kWe	19,554
CO_2 Capture air coolers, kWe	10,038
CO_2 Compressor, kWe	29,473
Balance of Plant, kWe	4,081
Total Auxiliaries, MWe	63.1

5.2.2 Carbon Balance

The carbon balance of the plant is shown in Table 5-3. The carbon input to the plant consists of carbon in the kiln flue gas, carbon in the air, and carbon in the natural gas Carbon leaves primarily as CO_2 product and stack gas. The carbon capture efficiency is defined as follows:

$$Carbon\ Capture\ Efficiency = (1 - \frac{(carbon\ in\ stack\ gas - carbon\ in\ air)}{(total\ carbon\ In - carbon\ in\ air)}) \times 100\%$$

Table 5-3: Carbon balance for the Cement plant with RTI CO_2 capture

Carbon In			Carbon Out		
	kg/hr	lb/hr		kg/hr	lb/hr
Kiln Flue Gas	66,914	147,519	Stack Gas	3,832	8,448
Natural Gas	12,029	26,519	CO_2 Product	75,149	165,676
Air	38	84			
Total	**78,980**	**174,122**	**Total**	**78,981**	**174,123**

Carbon capture efficiency is 95.1%.

5.2.3 Water Balance

Water demand represents the total water required by a process. Some water is recovered in a process and is re-used as internal recycle. The difference between water demand and internal recycle is raw water withdrawal. Raw water that is either incorporated into a product, or is lost due to evaporation, drift losses etc., and is thus not returned to the source from where it was withdrawn, is termed as process discharge. The difference of raw water withdrawal and process discharge is the raw water consumption.

The water balance for the cement plant with CO_2 capture is shown in Table 5-4. Water that is recovered from processes such as direct contact cooler is treated and recycled to the cooling tower. It is assumed that 95% of the DCC condensate is recycled.

Table 5-4: Water balance for the cement plant with CO_2 capture

Case A	Water Demand	Internal Recycle	Raw water withdrawal	Process Water discharge	Raw water consumption
	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)
CO_2 Capture Process	19.9	371.1	-351.2	39.4	-390.6
CO_2 Compression Recovery				4.8	-4.8
CO_2 Drying				1.5	-1.5
Feedwater & Electrolyzer Losses	198.4		198.4	198.4	
Cooling Tower	437.7		437.7	98.3	339.4
TOTAL	**656**	**371**	**285**	**342**	**-58**

5.2.4 Equipment List

For equipment list, please refer to ISBL and OSBL Equipment List in the FEED report, which provides details on the equipment type, design conditions, operating quantity and spares. In general, spares are included for all ISBL pumps (DCC recirculation pump, absorber intercooler pumps, lean and rich solvent pumps, absorber water-wash pumps and acid wash pump).

5.2.5 Capital Cost Estimates

The CAPEX cost estimates, broken down by code of accounts from the FEED study is provided in Table 5-5.

Table 5-5: TPC summary for the cement plant with retrofit RTI CO_2 capture

ACCT #	Description	Equipment Cost ($1000)	Material Cost ($1000)	Labor ($1000)	BEC ($1000)	CM & EPC ($1000)	TIC ($1000)	Contingency Project $(1000)	Contingency Process $(1000)	TPC ($1000)
1	CO_2 Carbon Capture	$175,047	$ 60,884	$ 71,674	$307,606	$ 57,364	$364,969	$ 52,293	$ 25,157	$ 442,419
2	CO_2 Compress & Dehydration	$ 22,845	$ 1,939	$ 2,812	$ 27,596	$ 5,146	$ 32,742	$ -	$ 2,257	$ 34,999
11	Raw/Potable/Demin water	$ 3,798	$ 5,215	$ 7,244	$ 16,257	$ 3,032	$ 19,289	$ -	$ 1,330	$ 20,618
12	Boiler & Steam System	$ 18,302	$ 2,055	$ 4,516	$ 24,873	$ 4,638	$ 29,512	$ -	$ 2,034	$ 31,546
14	Solvent/Chem Storage	$ 976	$ 1,745	$ 3,150	$ 5,872	$ 1,095	$ 6,967	$ -	$ 480	$ 7,447
15	Cooling water	$ 2,664	$ 833	$ 1,824	$ 5,321	$ 992	$ 6,313	$ -	$ 435	$ 6,748
16	Air & Nitrogen	$ 2,614	$ 397	$ 954	$ 3,965	$ 739	$ 4,704	$ -	$ 324	$ 5,028
18	Waste water treatment	$ 1,682	$ 618	$ 1,569	$ 3,869	$ 721	$ 4,590	$ -	$ 316	$ 4,906
20	Stack	$ 1,378	$ 916	$ 1,270	$ 3,564	$ 665	$ 4,228	$ -	$ 291	$ 4,520
22	Utility Headers	$	$ 54,125	$ 39,021	$ 93,146	$ 17,370	$110,516	$ -	$ 7,618	$118,134
23	Power Generation	$ 979	$ 49,483	$ 15,081	$ 65,543	$ 12,223	$ 77,765	$ -	$ 5,360	$ 83,126
	Total:	$230,285	$ 178,211	$149,115	$ 557,611	$ 103,985	$661,596	$ -	$ 45,603	$759,491

The breakup of the major equipment cost (uninstalled) is provided in Table 5-6:

Table 5-6: Breakup of the major equipment cost for the RTI CO_2 capture plant.

Equipment	% Contribution to TPC
Air Coolers	44%
Absorber and regenerator columns	18%
CO_2 compressor	7%
DCC (with associated pumps)	7%
Activated Carbon Beds for emissions control	6%
Centrifugal Pumps	6%
CO_2 conditioning	5%
Heat Exchangers (other than air coolers)	4%
Flue Gas Blower	2%
Rest (filters/tanks/vessels)	1%
TOTAL	**100%**

Air coolers have the highest contribution to the total equipment cost, accounting for 44% of the total cost. Next are the absorber and regenerator column, with 18% of the total equipment cost. Along with the CO_2 compressors, DCC, activated carbon beds and centrifugal pumps, these 6 equipment categories account for 88% of total equipment cost. Equipment for CO_2 conditioning to meet pipeline specifications accounts for 5% of the total equipment cost.

Table 5-7 shows the calculation and addition of owner's costs to determine the TOC, used to calculate COC.

Table 5-7: Total owner's cost for the cement plant with CO_2 capture

Owner's Costs	x 1,000
Preproduction Costs	
6 months All Labor	$3,667
1 Month Maintenance Materials	$813
1 Month Non-Fuel Consumables	$4,050
1 Month Waste Disposal	$8
25% of 1 Months Fuel Cost at 100% CF	$0
2% of TPC	$15,190
Total	**$52,698**
Inventory Capital	
60-day supply of non-fuel consumables at 100% CF	$8,100
Total	**$8,100**
Initial Cost for Catalyst and Chemicals	**$0**
Land	
Other Owner's Cost	**$113,924**
Financing Costs	**$20,506**
Total Owner's Costs	**$166,257**
Total Overnight Costs (TOC)	**$925,748**
TASC Multiplier (IOU, high-risk, 35 years)	**1.118**
Total As-Spent Cost (TASC)	**$1,034,986**

The cost for spare parts is not included here as these costs were already included in the CAPEX estimate for the capture plant by KBR. The estimated Total Owner's cost for the RTI's CO_2 capture retrofit to the cement plant, in 2022 dollars is $114 MM, resulting in the total overnight cost of $926 MM.

5.2.6 Operating Costs

Table 5-8 shows the operating cost breakdown for the cement plant retrofitted with RTI CO_2 capture.

Table 5-8:Operating expenses for the cement plant with CO_2 capture

Initial and annual operating and maintenance costs						
Case	Balcones			Cost Base		Nov 2022
CO_2 Capture Plan Size	2,400,000 TPY			Capacity		74
Operating & Maintenance Labor						
Operating Labor				**Operating Labor Requirements per Shift**		
Operating Labor Rate (base):		40.72	**$/hour**	Skilled		0.0
Operating Labor Burden:		30.00	**% of**	Operator:		2.3
Labor O-H Charge Rate:		25.00	**% of**	Foreman:		0.0
				Lab Techs,		0.0
				Total:		**2.3**
Fixed Operating Costs						
					Annual Cost	
					($)	**$(t-CO2/yr)**
Annual Operating Labor:					$1,082,012	$0.61
Maintenance Labor:					$4,784,796	$2.71
Administrative & Support Labor:					$1,466,702	$0.83
Property Taxes and Insurance (2% TPC):					$15,189,829	$8.60
Total:					**$22,523,339**	**$12.75**
Variable Operating Costs						
					($)	**$(t-CO2/yr)**
Maintenance Material:					$7,177,194	$4.06
Consumables						
	Initial	**Per Day**	**Per**	**Initial**	**Annual Cost**	**$(t-CO2/yr)**
Water (/1000 gallons):						
Makeup and Waste Water Treatment Chemicals (ton):						
Caustic soln (50%, ton)						
Sulfuric acid (98% ton)						
Activated Carbon (lb)						
De-oxo catalyst (lbs)						
NAS solvent						
Triethylene Glycol (gal):						
Subtotal:				**$263,631**	**$35,765,736**	**$20.25**
Waste Disposal						
Triethylene Glycol (gal):						
Spent adsorbent (ft3)						
Spent de-oxo catalyst (ft3)						
Prescrubber Waste (ton)						
Subtotal:					**$67,928**	**$0.04**
Variable Operating Costs Total:				**$263,631**	**$43,012,180**	**$24.35**
Fuel and Purchased Power Cost						
Natural Gas (MMBtu)		19,907	$4.61	$0	$24,651,632	$13.96
Electricity (MWh)		1,515.5	$67.28	$0	$27,389,819	$15.51
Total:					**$52,041,451**	**$29.46**

Total electrical power consumption for the RTI CO_2 capture plant is 61.3 MW. The CO_2 compressor consumes 27 MW of power. A major driver for this is the limited availability of the cooling water for the interstage cooling in the CO_2 compression train. To overcome this issue, a steam integrated CO_2 compressor is used where the boiler feed water (BFW) is used to raise low pressure steam in lieu of interstage cooling. This results in higher interstage compressors, leading to higher CO_2 compression power.

Limited availability of cooling water also results in the use of hybrid coolers, with air cooler fans accounting for 10 MW of electricity consumption.

The air coolers occupy 4 acres of the carbon capture plant location, and result in ~40% additional NAS solvent as initial fill. The total NAS makeup accounts for the NAS losses due to emissions, oxidative and thermal degradation as well as losses due to heat stable salts (HSS) and reaction with NOx. The solvent losses were estimated using data from recent NAS demonstration at TCM.

The CO_2 capture plant design proposes the use of an acid wash system for emissions control. The current design includes an acid wash system to control emissions requiring ongoing amine makeup and RTI International has developed an amine recovery process that is planned for inclusion in standard design packages for future projects. It was not incorporated into the current FEED design, as its development progressed in parallel with the FEED. The cost and performance impacts associated with its implementation have been evaluated and incorporated into the Techno-Economic Analysis (TEA) to inform future design and deployment decisions. When the amine recovery is implemented, the levelized cost of capture is projected to decrease by at least ~9%.

5.2.7 Cost of Capture

Table 5-9 shows a summary of the CAPEX, operating expense (OPEX), and cost of CO_2 capture for the cement plant retrofitted with RTI CO_2 capture case. Results for the "Cemex" case is also shown for comparison. Figure 5-1 shows the relative contribution of the various cost components towards the cost of CO_2 capture for the Base Case (Case A), and for with amine recovery from acid wash waste stream (Case A.2).

Table 5-9: Financial results for the cement plant retrofitted with RTI NAS CO_2 capture.

Case	Cemex Case	Case A: Base Case	Case A2: Base Case with amine recovery
CAPEX, MM			
Total Plant Cost (TPC)	$759	$759	$760
Total Overnight Cost (TOC)		$926	$921
Total As Spent Capital (TASC)		$1,035	$1,030
OPEX, MM/yr (100% Capacity Factor Basis)			
Fixed Operating Cost (OC_{fix})		$22.5	$22.5
Variable Operating Cost, less Fuel (OC_{var})		$58.4	$38.2
Fuel + Purchased Power (OC_{fuel})		$70.7	$70.7
Total OPEX	$143.8	$151.7	$131.5
Plant Output			
CO_2 Capture Product, tonne/hr (metric)	274.0	274.0	274.0
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000	2,400,000
CO_2 Avoided, tonne/hr (metric)	218.4	218.4	218.4
Total CO_2 Avoided	1,913,600	1,913,600	1,913,600
Common Factors Used for COC Calculation			
Capital Charge Factor (CCF)		0.0884	0.0884
Capacity Factor (CF)	0.74	0.74	0.74
Costs of CO_2 Captured ($/tonne)	**101.6**	**112.9**	**104.2**
Costs of CO_2 Avoided ($/tonne)		**141.6**	**130.7**
Cost of CO2 Capture Breakdown			
CAPEX	37.2	46.3	46.3
Fixed O&M		12.8	12.8
Variable O&M	64.3	24.4	14.9
Fuel & Purchased Power		29.5	29.5
Total	**101.6**	**112.9**	**104.2**
T&S	33.9	10.0	10.0
Cost of Capture w T&S	**135.5**	**122.9**	**114.2**
Actual CO_2 Captured annually	1,766,300	1,766,300	1,766,300
CO_2 Capture Product, tonne/hr (metric)	201.63	201.63	201.63

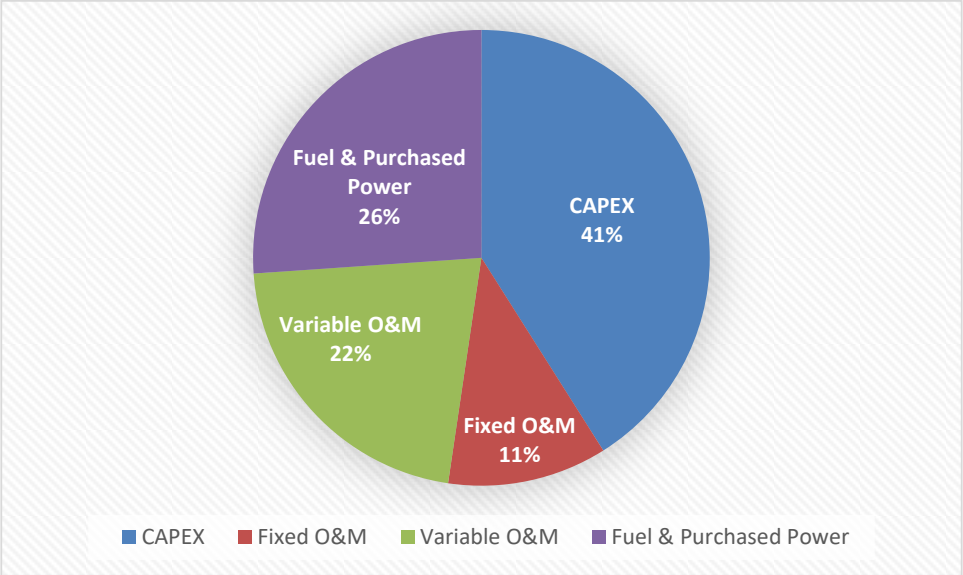

Figure 5-1: Relative contribution of the various cost components towards the cost of capture for Base Case A.

5.2.8 Cost of CO_2 Capture

The estimated cost of CO_2 capture for the cement plant using RTI's NAS technology is \$112.9/t-CO_2, For the techno-economic assessment (TEA) based on the Cemex parameters and assumptions (the "Cemex case"), the capture cost—excluding transportation and storage (T&S)—is \$101.6/t-CO_2. The total cost of capture for the Cemex case, including T&S, is \$135.5/t-CO_2. For the Base case, the T&S cost is assumed to be \$10/t-CO_2, consistent with the DOE Baseline Study for retrofit CO_2 capture at cement plants [1].

When amine recovery from the acid waste stream is incorporated, operating expenses (OPEX) are reduced, resulting in a lower overall cost of capture. Under this configuration, the capture cost—excluding T&S—decreases to \$104.2/t-CO_2 for the Base case using DOE financial parameters, and to \$93.0/t-CO_2 when applying the Cemex financial parameters.

5.2.9 Cost of CO_2 Avoided

Cost of CO_2 avoided for the cement plant with CO_2 capture using RTI-NAS technology is \$141.6/t-CO_2. When amine recovery from the acid waste stream is incorporated, the cost of CO_2 avoided drops to \$130.7/t-CO_2.

5.3 COMPARATIVE TEA CASES

5.3.1 Case B: Use of water for cooling with cooling tower

Limited availability of cooling water at the Balcones plant necessitated the use of hybrid cooling, coupled with a heat-integrated CO_2 compressor, as implemented in Case A (base case). The large land area required for air coolers also meant that the capture plant had to be sited away from the cement plant, requiring a longer flue gas duct to convey flue gas to the unit. The alternative scenario, Case B, assumes water-cooled heat exchangers with a larger cooling tower and siting the

capture plant closer to the cement plant. Both cases are assumed to achieve the same solvent temperatures and CO_2 capture performance, and share the same heat and materials balance (HMB). The differences are limited to equipment type, plant siting, and associated water requirements. A comparative analysis was conducted to evaluate the impact on cost of capture if cooling water were available. The process changes and their TEA impacts are summarized in Table 5-10.

Table 5-10 Process changes resulting from switch from hybrid cooling to water cooling and its impacts on TEA.

ID	Process Change	Impact on CO_2 capture plant TEA
B.1	Replacement of air coolers with water cooled heat exchangers	▪ Reduced CAPEX from lower cost exchangers ▪ Reduced power consumption from absence of air cooler fans ▪ Added CAPEX from larger cooling tower ▪ Added power consumption from cooling tower fans ▪ Increased water demand from cooling tower losses ▪ Solvent initial fills reduced by 40% leading to lower initial fill costs.
B.2	Replacement of integrated CO_2 compressor with water-cooled interstage coolers	▪ CAPEX is roughly the same for the two cases ▪ Reduced power consumption due to lower interstage temperatures resulting from water-cooled exchangers ▪ Added CAPEX from larger cooling tower ▪ Added power consumption from cooling tower fans ▪ Increased water demand from cooling tower losses
B.3	Siting of CO_2 capture plant near the cement plant	▪ Reduced land area requirements(~ 4 acres) leading to shorter flue gas ducts and associated CAPEX.

Results from the TEA for the three scenarios implemented cumulatively are provided in Table 5-11. The switch from hybrid cooling (Case A) to a fully water-cooled design (Case B) reduces the levelized cost of CO_2 capture by approximately 9%, decreasing it from \$112.9/t-CO_2 to \$101.6/t-CO_2. When combined with siting the CO_2 capture plant closer to the cement facility and implementing water-cooled CO_2 compressors, the cost of capture decreases further to \$98.3/t-CO_2, representing a 13% reduction relative to the base case. These savings are primarily driven by lower CAPEX for exchangers, reduced fan power consumption, and shorter flue gas ducting, while additional CAPEX and power for the larger cooling tower partially offset these benefits.

Note: The cost of capture comparison is conservative, as it does not account for potential reductions in civil works and structural steel associated with the smaller plot area required for water cooling. Including these savings would likely further reduce the total cost of capture for Case B.

Table 5-11 Summary of TEA results for Case B

Case	Case A: Base Case	Case B.2: Water-cooled	Case B.1: Water-cooled	Case B.3: Water-cooled
Cooling	**Hybrid (Air + water)**	**Cooling Tower**	Cooling Tower	Cooling Tower
CO_2 compressors	Heat-integrated	**Heat-integrated**	**water-cooled compressors**	water-cooled compressors
Ductwork	Extended	Extended	Extended	**Conventional**
Electricity	from the grid	from the grid	from the grid	from the grid
CAPEX, MM				
Total Plant Cost (TPC)	$759	$640	$641	$621
Total Overnight Cost (TOC)	$926	$781	$783	$759
Total As Spent Capital (TASC)	$1,035	$874	$876	$848
OPEX, MM/yr (100% Capacity Factor Basis)				
Fixed OPEX (OCfix)	$22.5	$19.2	$19.2	$18.7
Variable OPEX, less Fuel (OCvar)	$58.4	$56.9	$57.2	$56.9
Fuel + Purchased Power (OCfuel)	$70.7	$66.9	$62.6	$62.6
Total OPEX	$151.7	$143.0	$139.0	$138.2
Plant Output				
CO_2 Capture Product, tonne/hr (metric)	274.0	274.0	274.0	274.0
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000	2,400,000	2,400,000
CO_2 Avoided, tonne/hr (metric)	218.4	218.4	218.4	218.4
Total CO_2 Avoided	1,913,600	1,913,600	1,913,600	1,913,600
Common Factors Used for COC Calculation				
Capital Charge Factor (CCF)	0.0884	0.0884	0.0884	0.0884
Capacity Factor (CF)	0.74	0.74	0.74	0.74
Costs of CO_2 Captured ($/tonne)	**112.9**	**101.6**	**100.0**	**98.3**
Costs of CO_2 Avoided ($/tonne)	**141.6**	**127.4**	**125.4**	**123.3**
Cost of CO2 Capture Breakdown				
CAPEX	**46.3**	**39.1**	**39.2**	**38.0**
Fixed O&M	**12.8**	**10.9**	**10.9**	**10.6**
Variable O&M	**24.4**	**23.7**	**23.8**	**23.7**
Fuel & Purchased Power	**29.5**	**27.9**	**26.1**	**26.1**
Total	**112.9**	**101.6**	**100.0**	**98.3**
T&S	**10.0**	**10.0**	**10.0**	**10.0**
Cost of Capture w T&S	**122.9**	**111.6**	**110.0**	**108.3**
With Amine Recovery Costs of CO_2 Captured ($/tonne)	**104.2**	**92.9**	**91.2**	**89.6**
Actual CO_2 Captured annually	1,766,300	1,766,300	1,766,300	1,766,300
CO_2 Capture Product, tonne/hr	201.63	201.63	201.63	201.63

5.3.2 Case C: Co-generation of heat and electricity

The CO_2 capture plant currently uses a natural gas boiler to generate low-pressure steam (LPS) for solvent regeneration. As part of the sensitivity analysis, a co-generation option was evaluated, in which the existing boiler would be replaced with a larger unit to produce high-pressure (HP, 620 psig) steam. The HP steam would expand through a turbine to generate electricity, with the resulting LPS used in the CO_2 capture process. Capital cost estimates for the co-generation option were developed based on vendor quotes for the larger boiler and the turbine, as well as estimates of the additional natural gas required and the net power generated. Any remaining electricity demand above that generated on-site would be supplied from the grid. A summary of the cost estimates for the co-generation option is presented in Table 5-12.

Table 5-12: Evaluation of Cogeneration Options

Parameter	Unit	LP Boiler	MP Boiler	HP Boiler Option 1	HP Boiler Option 2
Configuration		2 x 50%	2 x 50%	2 x 50%	2 x 50%
Steam Type		Saturated	Superheated	Superheated	Superheated
Steam Pressure	psig	125	290	620	620
Steam Temperature	°F	392	540	721	721
Price	USD (MM)	$12.54	$14.08	$15.96	$15.96
Total Boiler Required		2	2	2	2
Total Cost	USD (MM)	$25.08	$28.16	$31.92	$31.92
Power Requirement	kW	63,146	63,146	63,146	63,146
10% Over Design	kW	69,461	69,461	69,461	69,461
Power Design Requirement	MW	70	70	70	70
Turbine Quantity		N/A	2	2	1
Turbine Model		N/A	BT50	BT50	BT63
Steam Flow	lb/hr	N/A	950,000	950,000	950,000
Steam Inlet Conditions	psig / °F	N/A	290 / 537	620 / 721	620 / 721
Steam Outlet Conditions	Psig / °F	N/A	37 / 283	37 / 283	37 / 283
Generated Electricity	MW	N/A	18	26	56.5
Total Generated Energy	MW	N/A	36	52	56.5
Turbine Cost	USD (MM)	0	$3.25	$3.50	$7.00
Total Turbine Cost	USD (MM)	0	$6.50	$7.00	$7.00
Boiler-Steam Turbine Cost	USD (MM)	$25.08	$34.66	$38.92	$38.92
Installation Factor		1.60	1.60	1.60	1.60
Differential Cost	USD (MM)		$9.58	$13.84	$13.84
Installed Cost	USD (MM)		$15.36	$22.20	$22.20
Project contingency (20%)	USD (MM)		$3.07	$4.44	$4.44
TPC	**USD (MM)**		**$18.44**	**$26.64**	**$26.64**

Results from the TEA for the co-generation option are provided in Table 5-13.

Table 5-13: TEA results for the Co-gen case compared against the Case A - Base Case.

Case	Case A: Base Case	Case C: Co-gen
Cooling	Hybrid (Air + water)	Hybrid (Air + water)
CO_2 compressors	Heat-integrated	Heat-integrated
Ductwork	Extended	Extended
Electricity	from the grid	Co-gen option
CAPEX, MM		
Total Plant Cost (TPC)	$759	$783
Total Overnight Cost (TOC)	$926	$953
Total As Spent Capital (TASC)	$1,035	$1,066
OPEX, MM/yr (100% Capacity Factor Basis)		
Fixed Operating Cost (OCfix)	$22.5	$23.2
Var Operating Cost, less Fuel (OCvar)	$58.4	$57.4
Fuel + Purchased Power (OCfuel)	$70.7	$57.2
Total OPEX	$151.7	$137.8
Plant Output		
CO_2 Capture Product, tonne/hr (metric)	273.97	273.97
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000
CO_2 Avoided, tonne/hr (metric)	218.4	200.5
Total CO_2 Avoided	1,913,600	1,756,200
Common Factors Used for COC Calculation		
Capital Charge Factor (CCF)	0.0884	0.0884
Capacity Factor (CF)	0.74	0.80
Costs of CO_2 Captured ($/tonne)	**112.9**	**103.9**
Costs of CO_2 Avoided ($/tonne)	**141.6**	**141.9**
Cost of CO_2 Capture Breakdown		
CAPEX	**46.3**	**44.0**
Fixed O&M	**12.8**	**12.1**
Variable O&M	**24.4**	**23.9**
Fuel & Purchased Power	**29.5**	**23.8**
Total	**112.9**	**103.9**
T&S	**10.0**	**10.0**
Cost of Capture w T&S	**122.9**	**113.9**
With Amine Recovery Costs of CO_2 Captured ($/tonne)	**104.2**	**95.3**

Actual CO_2 Captured annually	1,766,300	1,914,302
CO_2 Capture Product, tonne/hr (metric)	201.63	218.53

With the cogeneration option, the total CO_2 captured increases due to increase in the natural gas consumption, resulting in a higher capacity factor. The CAPEX does not change as the increase in CO_2 flowrate is within the 10% margin. The increase in OPEX is accounted for by increasing the capacity factor from 74% to 80%. The cogeneration for steam and electricity reduces the cost of capture from \$112.9/t-CO_2 to \$103.9/t-CO_2. Including the amine recovery from the acid wash waste stream, the costs for the Base case and the co-generation case are \$104.2/t-CO_2 and \$95.3/t-CO_2 respectively,

Section 6 Sensitivity Analysis

6.1 SENSITIVITY ANALYSIS OF PROCESS PARAMETERS ON COST OF CO_2 CAPTURE

A sensitivity analysis was carried out to determine the effects of various parameters of RTI's CO_2 capture system on the overall cost of CO_2 captured. Key parameters evaluated were (a) natural gas price, (b) electricity price, (c) solvent price, (d) plant CAPEX, (e) capacity factor, and (f) capital charge factor. The CAPEX and capacity factor were varied by +/- 15%, while the remaining parameters were varied by +/- 30%, and the cost of CO_2 capture was evaluated. The sensitivity analysis was done for Case A: Base case with the capture plant as currently designed with hybrid cooling and heat-integrated CO_2 compressors, and for Case B: where the constraint for the limited water supply was removed and the plant and CO_2 compressors are water cooled and the plant is sited in proximity to the cement plant. Results are plotted in Figure 6-1 and Figure 6-2.

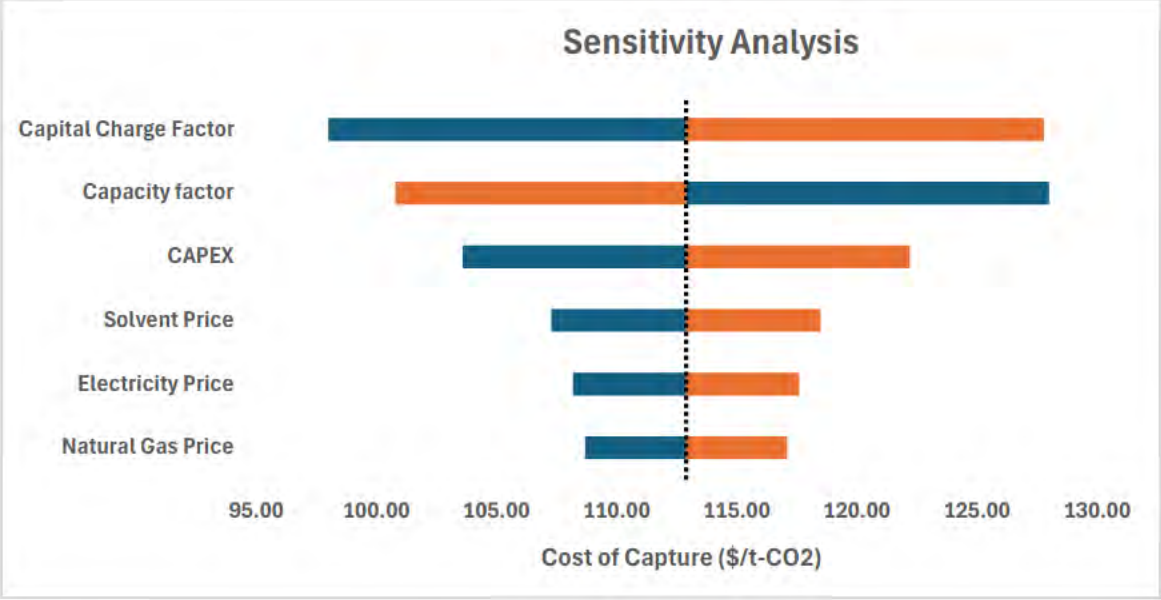

Figure 6-1: Tornado plot for sensitivity analysis for cost of CO_2 capture for Base Case A

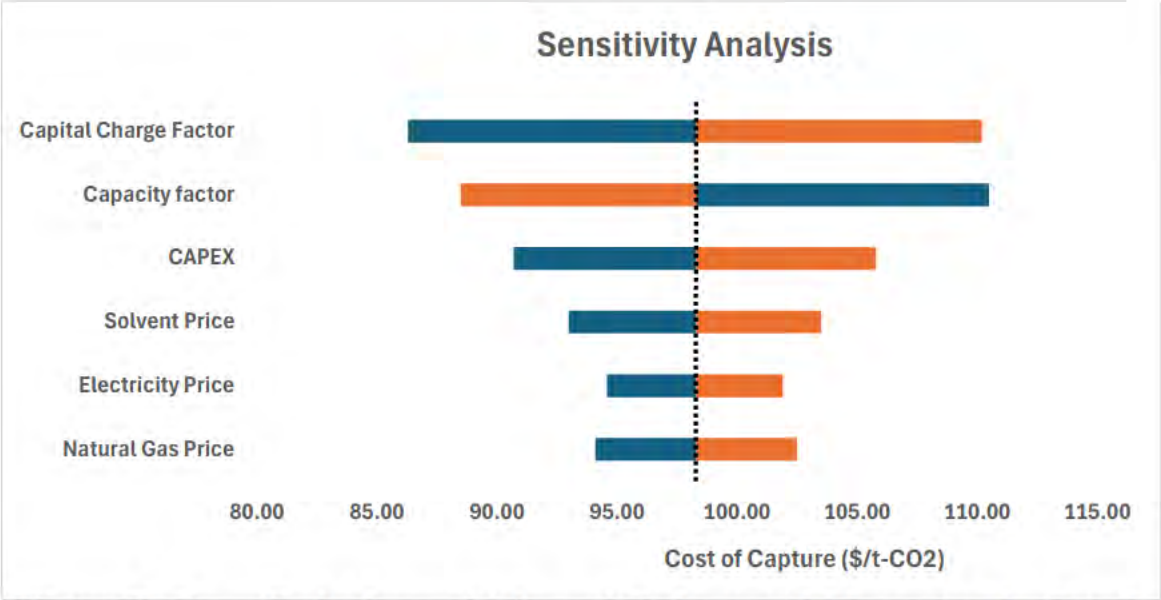

Figure 6-2: Tornado plot for sensitivity analysis for cost of CO_2 capture for Case B

For the Base Case A, or the parameters studied, the sensitivity analysis indicated the highest impact from the capacity factor. A 15% reduction in capacity factor results in an increase of 13% for the cost of CO_2 capture. The next sensitive parameter was the CAPEX, where a 15% increase in CAPEX increased the cost of CO_2 capture by 8%. The unit price of natural gas and electricity had the lowest impact, with the cost of capture increasing by 4% with a 30% increase in the utility prices. The solvent price is also a low impact factor, with the cost of capture rising by 5% with a 30% increase in the unit price of NAS.

Results for the Case B mirrors the results from Case A with a 15% reduction in capacity factor results in an increase of 12% for the cost of CO_2 capture

Section 7 Conclusions

The technoeconomic analysis uses data from the FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants [1].

The Cemex Balcones Cement Plant is in a hot humid subtropical region and has limited water availability from the on-site Cemex on-site wells. The CO_2 capture process requires cooling for the direct contact cooler, absorber intercoolers, trim cooler, water wash and CO_2 product stream condenser. In addition, cooling is also needed to cool the CO_2-product between stages during compression. To address this challenge of limited water, it was decided to treat and re-use the water condensed in the direct contact cooler, and to use hybrid cooling where 84% of the total cooling load is met using air cooled heat exchangers, and the remaining 16% of cooling load met using water cooled systems. 80 °F was selected as the design temperature for the air coolers, as a compromise between the CAPEX for the air coolers and capture rate as it allows the plant to reach 95% capture rate averaged over summer and winter months. Lack of cooling water resulted in the need for a steam integrated CO_2 compressor system where the interstage coolers uses the boiler feed water to raise steam. The larger area requirements for the CO_2 capture plant with air coolers also resulted in re-locating the capture plant site away from the CO_2 capture plant, across the railway line and the road. A detailed TEA has been carried out for CO_2 capture at Cemex's Balcones plant with using RTI-NAS technology. The TEA uses data from the AACE Class 3 level FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants.

A detailed TEA has been carried out for CO_2 capture at Cemex's Balcones plant with using RTI-NAS technology. The TEA uses data from the AACE Class 3 level FEED study using DOE's approach for estimation of levelized cost of capture for retrofit applications for cement plants.

Three different cases are evaluated. Case A is the base case with the capture plant as currently designed with hybrid cooling and heat-integrated CO_2 compressors. Case B is a hypothetical case where the constraint for the limited water supply was removed and the plant and CO_2 compressors are water cooled and the plant is sited in proximity to the cement plant. This allows for a more direct comparison with the DOE Baseline cases of CO_2 capture for retrofit applications for cement plants. Case C is a comparative case that evaluates the impact of co-generation of steam and electricity using a high pressure (620 psig superheated steam at 721 °F) and expanding that in a turbine to generate power, and using the resulting low-pressure steam for solvent regeneration.

A comparative "Cemex " case is also presented which uses the Cemex financial parameters (such as property taxes and insurance), Cemex's estimate for the owner's cost (that includes the electrical substation, cost estimates for air emissions permitting, construction and land use permits, topography, soil and water studies, legal fees and technology, environmental and financial consultants for the project), labor estimates based on local wages, utility prices and water supply. The capital charge factor was assumed to be same as for DOE cases.

Results from the TEA are summarized in Table 7-1.

Table 7-1: Summary of the TEA results

Case	Cemex - confidential	Case A: Base Case	Case B: Water-cooled	Case C: Co-gen
Financial Parameters	**Cemex - confidential**	**DOE**	**DOE**	**DOE**
Cooling	Hybrid	Hybrid	Cooling Tower	Hybrid
CO_2 compressors	Heat-integrated	Heat-integrated	water-cooled compressors	Heat-integrated
Ductwork	Extended	Extended	Conventional	Extended
Electricity	grid	grid	grid	Co-gen
CAPEX, MM				
Total Plant Cost (TPC)	$759	$759	$621	$783
Total Overnight Cost (TOC)		$926	$759	$953
Total As Spent Capital (TASC)		$1,035	$848	$1,066
OPEX, MM/yr (100% Capacity Factor Basis)				
Fixed Operating Cost (OCfix)		$22.5	$18.7	$23.2
Var. Operating Cost, less Fuel (OCvar)		$58.4	$56.9	$57.4
Fuel + Purchased Power (OCfuel)		$70.7	$62.6	$57.2
Total OPEX	$143.8	$151.7	$138.2	$137.8
Plant Output				
CO_2 Capture Product, tonne/hr	274.0	274.0	274.0	274.0
Total CO_2 Captured (@ 100% CF)	2,400,000	2,400,000	2,400,000	2,400,000
CO_2 Avoided, tonne/hr	218.4	218.4	218.4	200.5
Total CO_2 Avoided	1,913,600	1,913,600	1,913,600	1,756,200
Common Factors Used for COC Calculation				
Capital Charge Factor (CCF)		0.0884	0.0884	0.0884
Capacity Factor (CF)	0.74	0.74	0.74	0.80
Costs of CO_2 Captured ($/tonne)	**101.6**	**112.9**	**98.3**	**103.9**
Costs of CO_2 Avoided ($/tonne)		**141.6**	**123.3**	**141.9**
Cost of CO_2 Capture Breakdown				
CAPEX	**37.2**	**46.3**	**38.0**	**44.0**
Fixed O&M		**12.8**	**10.6**	**12.1**
Variable O&M	**64.3**	**24.4**	**23.7**	**23.9**
Fuel & Purchased Power		**29.5**	**26.1**	**23.8**
Total	**101.6**	**112.9**	**98.3**	**103.9**
T&S	**33.9**	**10.0**	**10.0**	**10.0**
Cost of Capture w T&S	**135.5**	**122.9**	**108.3**	**113.9**
With Amine Recovery Costs of CO_2 Captured ($/tonne)	**93.0**	**104.2**	**89.6**	**95.3**

Actual CO_2 Captured annually	1,766,300	1,766,300	1,766,300	1,914,302
CO_2 Capture Product, tonne/hr	201.63	201.63	201.63	218.53

A sensitivity analysis was performed and the sensitive parameters identified included the capacity factor and the CAPEX. where a 15% change indicated the highest impact from the capacity factor. The unit price of natural gas and electricity had the lowest impact, with the cost of capture increasing by 4% with a 30% increase in the utility prices. The solvent price also had a minimal impact, with the cost of capture rising by 5% with a 30% increase in the unit price of NAS.

Section 8 **References**

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3. Zhou, S.J., et al., *Pilot Testing of a Non-Aqueous Solvent (NAS) CO_2 Capture Process*, in *14th International Conference on Greenhouse Gas Control Technologies, GHGT-14*. 2018: Melbourne, Australia.

Appendix A Acronyms and Abbreviations

AACE	Association for the Advancement of Cost Engineering
ACCE	Aspen Capital Cost Estimator
BEC	Bare Erected Cost
BFD	Block Flow Diagram
BFW	Boiler Feed Water
CAPEX	Capital Expenditure
CCF	Capital Charge Factor
CF	Capacity Factor
CMT	Construction Management Team
°C	Degree Celsius
CO_2	Carbon Dioxide
COC	Cost of Capture
DCC	Direct Contact Cooler
DOE	Department of Energy
EPCC	Engineering, Procurement and Construction Cost
°F	Degree Fahrenheit
FEED	front-end engineering design
FEL	Front End Loading
FOM	Fixed Operating Cost
GJ	Giga-Joules
hr	hour
H_2O	Water
HMB	Heat and Materials Balance
HPS	High Pressure Steam
HSE	Health, Environment and Safety
HSS	Heat Stable Salts
ISBL	Inside Battery Limit
LP	Low Pressure
MPa	Mega Pascal
MTPA	Million Tons per Annum
MW	Mega Watt
NAS	Non-aqueous Solvent
O&M	Operating and Maintenance
O_2	Oxygen
OC	Operating Cost
OPEX	Operating Expenditure
OSBL	Outside Battery Limit
P70	70% probability factor
PF	Purchased Fuel
PFD	Process Flow Diagram
PP	Purchased Power
QA	Quality Assurance
QGESS	Quality Guidelines for Energy System Studies
RTI-NAS	RTI's Non-aqueous Solvent

SO_2	Sulfur Dioxide
SRD	Specific Reboiler Duty
TASC	Total as Spent Capital
TCM	Technology Centre, Mongstad
TEA	Technoeconomic Analysis
TEG	Triethylene Glycol
TOC	Total Overnight Cost
TPC	Total Plant Cost
TX	Texas
VOM	Variable Operating & Maintenance

M Technology Maturation Plan

APPENDIX G – TECHNOLOGY MATURATION PLAN

TECHNOLOGY MATURATION PLAN
Carbon Capture FEED Study for Cement Manufacturing
April 14, 2025

SUBMITTED UNDER FUNDING OPPORTUNITY ANNOUNCEMENT

DE-FOA-0002515

SUBMITTED BY
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3040 Cornwallis Rd.
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SUBMITTED TO

U.S. Department of Energy National Energy Technology Laboratory

1.0 INTRODUCTION

Since 2009, RTI International has been developing a process for post-combustion CO2 capture based on novel, non-aqueous solvents (NAS) from ideation and proof of concept (Technology Readiness Level [TRL] 2) to the current front-end engineering design (FEED) for a NAS CO2 capture plant at the CEMEX Balcones cement plant in New Braunfels, TX.

1.1 Purpose of the Project

The objective of this project is to perform a front-end engineering design (FEED) study for carbon dioxide (CO_2) capture from cement flue gas using non-aqueous solvents (NAS) with 95% capture efficiency. The desired outcome of the FEED in this project is to develop an Association of the Advancement of Cost Engineering (AACE) Class 3 cost estimate for a commercial 2.4 MM tonnes-CO_2/year (t-CO_2/yr.) scale CO_2 capture system integrated with a cement facility. The detailed cost estimates will be used to perform a techno-economic analysis (TEA) of the resulting process configuration. The CO_2 life cycle analysis (LCA) will account for CO_2 being produced/removed/utilized from the cement with CO_2 capture facility as well as CO_2 generated offsite that is required to operate the facility. Lastly, a business case analysis (BCA) and an environmental, health, and safety (EH&S) risk analysis will be performed to evaluate the commercial viability and impact to the environmental and safety of the proposed process.

1.2 Technology Readiness Assessment System

Technology Readiness Assessment (TRA) System is the integrated RTI's NAS solvent technology for post-combustion CO_2 capture from point sources. Critical components of the TRA system are:

(a) Solvent formulation
- that allows > 90 % CO_2 capture
- has low parasitic energy penalty for CO_2 regeneration
- allows for solvent regeneration at higher pressures up to ~ 4.4 bar

(b) Process for water balanced stable operations

(c) Any emission (amine, degradation products) below regulatory requirements.

1.3 Commercial Application

Commercial applications for the TRA systems being developed under this project include CO_2 capture from point sources such coal- or natural gas-fired power plants, or an industrial site such as a cement plant, a pulp and paper mill or an iron and steel plant. A specific application currently being pursued here is the CO_2 capture from a cement manufacturing plant, where 95% of CO_2 from the process, and the associated natural gas boiler for raising steam for solvent regeneration are captured.

2.0 MATURATION OF THE TRA SYSTEM

2.1 Beginning Technology Readiness Level (TRL) of the TRA System

Development of NAS started at RTI with developing critical data to show proof of concept under internal R&D funding. Using this data, RTI was able to secure DOE funding from ARPA-E to do a more detailed solvent screening and identify promising solvent formulations and evaluate them at lab-scale. Successful completion of that project led to a series of DOE-NETL funded projects where the solvent development progressed from lab-scale development to bench-scale development at RTI's bench-scale gas absorption system (BsGAS) to small pilot plant testing using real flue gas at the Tiller plant at SINTEF (Norway) to engineering-scale demonstration at Technology Centre, Mongstad (Norway). Along the way, we also had some additional DOE funding to develop a novel emissions control technology for water-lean solvents and to evaluate the solvent using real flue gas at the National Carbon Capture Center (NCCC) at a coal-fired power plant in Alabama.

Under previous DOE projects, RTI established the NAS-based post-combustion CO_2 capture process at bench scale. Key performance attributes for NAS were to develop an optimized solvent formulation and determine solvent stability through detailed solvent degradation studies, using SINTEF's well-established solvent degradation test rig and procedure.

On the process side, key performance parameters were to establish a process design suitable for NAS and demonstrate the potential to achieve solvent regeneration heat duties ≤2.1 GJ/tonne-CO_2 at the bench scale. A pathway to a capture cost of 30/tonne-CO_2 was demonstrated in a detailed techno-economic assessment. Preliminary emissions studies and environmental, health, and safety (EH&S) assessments were completed and warranted the further development of the technology.

A more detailed timeline of the solvent development and ending TRLs at the end of each project is provided in Table 1.

Table 1: History of prior research on NAS technology

Year	Project	Tasks and key performance attributes	TRL at completion
2009-2010	RTI Internal R&D	• Proof of concept and feasibility of NAS	2
2010-2013	ARPA-E DE-AR0000093	• NAS screening to identify promising solvent formulations • Lab-scale evaluation of NAS process • Preliminary techno-economic analysis	3
2014–2016	NETL DE-FE0013865	▪ Finalize NAS formulation – Address evaporative losses and costs ▪ Develop critical process components ▪ Bench-scale testing within a process unit with major process components ▪ Show ⩽2.1 GJ/tonne-CO_2 using bench-scale system ▪ Detailed solvent degradation and preliminary emissions studies	4

		• Detailed technoeconomic and EH&S assessments	
2015-2018	NETL DE-FE0026466	▪ Large pilot-scale testing at Tiller plant, SINTEF ▪ Demonstration of integrated CO_2 capture process using real flue gas from coal and NG burners. ▪ 6-month long testing with stable water-balanced operations ▪ Evaluation of emissions and corrosion testing at NCCC	5
2018-2022	NETL DE-FE0031660	▪ Emissions control technology for NAS using flue gas from coal and NG burners ▪ Developed novel two-stage wash technology with amine emissions < 1 ppm ▪ Evaluated role of aerosols in amine emissions ▪ Updated TEA to include cost of emissions control on cost of CO_2 capture.	5
2018-2023	NETL DE-FE0031590	▪ Engineering scale demonstration of NAS at Technology Centre, Mongstad (Norway). ▪ Demonstrated 90-99% CO_2 capture from flue gas with CO_2 from 4% to 13.5% ▪ Demonstrated amine emissions < 1 ppm in the treated gas ▪ Demonstrated stable operations with water-balance ▪ Demonstrated stable operations with continuous long-term testing spanning ~500 hours ▪ Measured corrosion rates for carbon steel and stainless-steel coupons to show exceptionally low corrosion rates compared to aqueous solvents. Carbon steel shows excellent performance under cold (absorber side) conditions ▪ Demonstrated that the solvent can be sourced at commercial quantities. Testing required 60 metric tonnes of solvent for initial fill. ▪ Demonstrated ability to regenerate CO_2 at high pressures. Tests showed 95% capture while regenerating CO_2 at 4.2 bar, enough to eliminate the first stage of compression train. ▪ Demonstrated low reboiler temperatures. Some of the tests had 90% capture at reboiler temperatures as low as 95 C. ▪ Updated technoeconomic analysis to show lower cost of capture relative to DOE base case from DOE baseline report, rev 4a.	6
2021-2023	EERE DE-EE0009415	▪ Intensified water-lean solvent testing with cement flue gas ▪ Testing of intensified absorber systems and two-stage flash column, with NAS to reduce CAPEX costs	5

		▪ Integrated with cement plant flue gas at 1 TPD CO_2 capture scale. ▪ Evaluation of RTI's novel emissions control technology planned ▪ System design complete. Build in progress for testing in 2024 during BP2.	

2.2 Proposed Research to Mature the TRA System

The current project is focused on performing a FEED study for the integrated CO_2 capture plant to AACE Class 3 level (+/- 15% accuracy). Cost estimates at AACE Class 3 level will be used by CEMEX in their business case analysis to evaluate the commercial viability of the project. If the project economics are favorable, this will be followed by permitting, detailed engineering, procurement, and construction and finally operation of the integrated CO_2 capture plant. At that point, the project will reach TRL 7. Since the current project ends with the completion of the FEED study, the start and end TRLs for the project will be at TRL6.

Since this is a FEED study, the research efforts are focused on the design and integration of the capture plant and the key performance attributes that will be assessed during the FEED study are summarized in the table below:

Attribute	**Research Task**	**Project Task**
Integration of the CO_2 capture plant with the cement plant	o Develop project design basis definition to accurately capture plant details and incorporate them into integrated plant design. ▪ As part of the FEED study, evaluate different options for tie-in to plant utilities ▪ Evaluate options for cooling as water availability is limited. ▪ Permitting requirements review to initiate construction o Integration and Utilities Design o HAZOP review to eliminate high-risk, high-probability events in plant operations o Constructability review	2 4.2 4.3 4.5
AACE Class 3 level cost estimate	o Schedule and cost estimate ▪ Develop equipment datasheets and get vendor quotes for at least 70% of major equipment for cost-estimation	4.4
Commercial deployment	o Perform technoeconomic analysis (TEA) o Perform business case analysis (BCA) o Perform lifecycle analysis (LCA)	5.1 5.2 5.3

Successful execution of the FEED will provide information that will allow CEMEX to assess the technical and commercial viability of the CO_2 capture plant integrated with the cement plant, and thus move the technology closer to achieving the next TRL 7.

2.3 Potential Post-Project Maturation and Commercialization of the TRA System

Assuming the BCA based on the results from the FEED study indicates the technology to be commercially favorable, several steps are needed to advance the technology to the next TRL (TRL 7 - Full-scale, similar (prototypical) system demonstrated in relevant environment). These include:

(a) Identify a characterized injection well site for CO_2 sequestration
(b) Identify and develop agreements for CO_2 transportation to sequestration site.
(c) complete all local and state permitting, and NEPA review required to initiate construction,
(d) complete detailed engineering and develop datasheets that can be issued for construction
(e) secure all approvals needed to move to construction phase
(f) complete procurement and build for the capture plant

From a risk management perspective, steps (a) and (b) would be needed to secure a sequestration site before work can begin on steps (c) through (f). Steps (c) through (e) should take about 12-18 months. Step (f) could be 2-3 years, depending on time needed for long lead items.

RTI has entered into a licensing agreement with SLB to commercialize the NAS technology for post-combustion CO_2 capture applications. SLB recently partnered with Aker Carbon Capture (ACC) to establish a new joint venture named SLB Capturi (SLBC), focused on CO_2 capture activities. ACC brings extensive experience in CCUS, having successfully executed multiple projects. It built the TCM CO2 capture plant and recently completed a 400 TPD CO_2 capture facility at the Brevik site in Norway. Additionally, Aker also completed a CO_2 capture plant at Twence's waste-to-energy facility in Henglo, Netherlands. The joint development and commercialization agreement between RTI and SLB enable the two organizations to develop an effective technology package for end-to-end

As part of the solvent management strategy, RTI, in collaboration with SLBC, is working on two key initiatives: (a) developing a solvent reclamation process to remove heat-stable salts and degradation products, and (b) recovering amine from the acid wash. Currently, RTI uses an acid wash to control amine emissions from the NAS process. In its current configuration, the acid wash removes any residual amine from the treated gas by reacting the amine with the acid to form an amine-sulfate salt. This salt is typically treated as waste, and the lost amine must be replenished through the addition of makeup amine. However, this approach introduces operational inefficiencies in terms of chemical costs and waste handling.

Experimental work conducted by RTI has demonstrated that this amine can be successfully separated from the acid wash waste stream with a recovery rate of at least 95%. The process entails neutralizing the amine-sulfate salt to regenerate the parent amine, which then separates out as an organic phase due to its hydrophobic properties. The recovered organic amine can be recycled into the NAS solvent loop, creating a closed-loop process. By reducing the loss of amine and limiting the need for fresh chemical makeup, this recovery process offers significant cost savings. Experimental testing has demonstrated the technical feasibility and maturity of the amine recovery from acid wash waste stream technology, thereby eliminating significant implementation risks. The technology is planned for inclusion as part of the standard design package for subsequent projects.

RTI, in collaboration with its commercialization partner SLBC, is advancing the technology

toward commercial readiness. As part of this effort, RTI is collecting data on the atmospheric chemistry of the NAS amine and its degradation products. This data will be used to develop air quality dispersion models to better understand the fate and transport of emitted compounds, supporting future permitting activities. RTI and SLBC are also collaborating on further assessment of some degradation products, their classification and relative exposure in a commercial application.

Cemex is evaluating potential CO_2 sequestration sites where the formation reaches appropriate depth for supercritical CO2 phase. For Balcones plant, CEMEX has prepared a detailed roadmap to reduce the carbon footprint by 2030 through “traditional” levers like increased use of biomass-based alternative fuels, clinker factor reduction, energy efficiency improvements, among others. 60% of the cement plant CO_2 emissions come from process emissions from decarbonization of the limestone. CEMEX intends to use a combination of these traditional levers and CCUS technology such as the NAS technology to achieve net-zero operations by 2035.

N Environmental Justice Analysis

Carbon Capture Plant FEED Study for Cement Manufacturing

Topical Report:

ENVIRONMENTAL JUSTICE ANAL SIS

Contributors: Jak Tanthana, Sara Nienow and Vijay Gupta

WOR PERFORMED UNDER AGREEMENT
DE-FE0032220

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Background

This topical report presents the summary of environmental justice (EJ) considerations for project under DE-FE0032220 involving the front-end engineering design (FEED) study of RTI's Non aqueous solvent (NAS) CO_2 capture technology for CEMEX's cement manufacturing plant in Balcones, TX. This FEED study aims to implement the full-scale NAS CO_2 capture plant removing 2.4 million tons of CO_2 annually from the exhaust cement flue gas for sequestration. The sequestration site has not been finalized. Specific EJ questions to be addressed are based on Appendix D of the DE-FOA0002515.

Environmental Justice Analysis

1. How does the technology rely on limited resources such as coal, biomass, freshwater, land, and/or low-carbon energy? What is the relationship between the amount of resources used versus the amount of product formed?

   One of the process design challenges is the lack of raw water availability and its impact on cooling systems. The CEMEX Balcones Cement Plant is constrained to a raw water feed of 191 GPM from the CEMEX process water pond. An additional ~400 GPM of condensate from the Feed Direct Contact Cooler (DCC) is available for use as cooling water. The high summer design temperature also poses a challenge because the use of air or water cooling is limited by LMTD (log-mean temperature difference). Due to limited water availability, the NAS CO_2 capture plant utilizes a hybrid approach with 84% of the required cooling provided by the air-cooled heat exchangers and the remainder provided using the traditional water-cooled heat exchangers. This, however, leads to increase in land use to accommodate a fleet of air-cooled heat exchangers that are used in various part of the process. FEED study suggests that the total of 434 units of air-cooled heat exchangers will be required to sufficiently facilitate the cooling for the NAS capture plant. This translates to 4 acres of land required to install the heat exchangers while the rest of the process requires 10 acres.

2. If coal is used as a feedstock, where will it be mined and what are the associated near-term and legacy environmental impacts of the coal mining, including methane leakage?

   Coal is not used in the proposed CO_2 capture technology

3. How does the technology remediate legacy environmental impacts of the energy industry, including environmental impacts associated with the use of coal?

The NAS technology aims to remove CO_2 produced from the calcination of limestone along with the CO_2 generated from the use of various fuels such as petcoke, natural gas, biomass, and mixed industrial waste material feeding the furnaces.

4. If coal wastes are being remediated, what is the relationship between the amount of coal wastes used versus the amount of product formed?

   No coal wastes are being remediated in this project

5. What is the project's waste management strategy and what are the anticipated impacts of residual waste on local residents?

All water collected in the facility from the process and drains/blowdowns is routed to the Waste Water Treatment Package for treatment. The treated wastewater is then returned to the Service Water Tank for recycle back to the process or discharged to the water pond at Balcones site. The water pond is current used to accommodate the wastewater discharge from the cement production and has a sufficient capacity to receive the treated wastewater generated from the CO_2 capture plant.

6. To what extent does the technology provide ancillary environmental benefits, such as reductions in NOx and SOx emissions, particulate matter, or hazardous pollutants?

NOx - The NAS CO_2 capture plant requires a boiler package to provide energy for solvent regeneration. As a result, there is an additional NOx generated from the boiler package compared to the baseline NOx emission. The flue gas from this package boiler is routed to the inlet of capture plant to remove the CO_2. Based on NAS testing at TCM, the use of NAS technology does not lower the NOx level in the outgoing treated flue gas. Although the NO_2 reacts with NAS's amine, NO_2 only represents less than 2% of the NOx while the rest is NO. NO does not react to NAS or other chemicals presented in the NAS CO_2 capture plant.

SOx - DCC with caustic solution is used to remove SOx from the incoming flue gas. The technology has proved to the commercial setting that 90%+ of the SOx can be removed at-scale. Furthermore, a result from NAS testing at TCM shows that treated flue gas contained 33% less SOx than the absorber inlet. Although the cement flue gas at Balcones site does not contain SOx, the auxiliary natural gas boiler installed for NAS CO_2 capture plant generates a flue gas containing small amount of SOx that derives from H_2S in the natural gas. The NG burner flue gas is routed to the DCC inlet along with the cement flue gas from the cement plant. The SOx is removed through the use of caustic DCC as well as the NAS in the CO_2 capture plant. Overall, 90-93% SOx reduction can be expected.

PM - A separate test of DCC to remove iron PM-laden flue gas was performed on a commercial project for NAS technology. The result shows a 61% reduction of the PM concentration of 6.05 to 2.31 mg/m^3, demonstrating the effectiveness of DCC to remove PM from the flue gas.

7. If the project involves a carbon capture retrofit technology, what are the potential co-benefits of the carbon capture technology (e.g., reduction of other hazardous air pollutants or reduction of other negative environmental impacts commonly associated with existing natural gas power plants or industrial processes)?

The potential co-benefits of using NAS technology are described in responses to question 6.

8. How is the project incorporating a plan to ensure community and stakeholder input and engagement from underserved communities, which include persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality?

This question is not applicable.

O Workforce Readiness Plan

WORKFORCE READINESS PLAN
Recipient Name: RTI International, CEMEX, Inc., Schlumberger (SLB), and KBR, Inc.
PI Name: Dr. Vijay Gupta, RTI International
Award Number: DE-FE003220
Project Title: Carbon Capture Plant FEED Study for Cement Manufacturing Technology

Availability and accessibility of training programs:

Cemex: The Balcones project will build upon Cemex's existing workforce development, educational, and career programs to provide the skills training, certification, and education required for the project and to help community members access future clean energy jobs. Training requirements will be reviewed by Cemex and any necessary training on this topic will be developed and implemented as appropriate. Cemex runs several training and professional development programs for its employees, including a 24-hour onboarding training for new staff, and providing 40 hours of training per year per employee to upskill, reskill, and raise climate action awareness.

Cemex University is an award-winning continuous learning program with in-person and online courses available across diverse platforms, devices, and locations. Employees can access more than 150 courses within seven different academies and four leadership development programs, such as the Health & Safety Academy, Cement Operations Academy, Digital Academy and Sustainability Academy. Cemex University has reached more than 24,000 employees, with an average 90% learner satisfaction rate. In 2023, Cemex University saw over 18,000 active learners and more than 70,000 course completions. Furthermore, Cemex has collaborations with LinkedIn Learning and the University of Phoenix to offer additional courses and certifications.

RTI: As the developer of the carbon capture solvent, RTI International has a material safety data sheet complying with OSHA requirements. This sheet classifies the hazards associated with this specific chemical, provides precautionary statements on use and storage, and contains first aid measures that should be taken in the event of accidental exposure. If this project progresses to the demonstration stage, RTI International, along with other project partners, will engage with facility staff, local fire departments, first responders, and emergency management personnel to review emergency response protocols. Emergency response agencies will be encouraged to review their equipment and personal protective gear resources considering the potential need to respond to an emergency at the Balcones facility. RTI is creating more detailed environmental health and safety information for the NAS solvent.

As presented below, SLB will train plant operators on the equipment, equipment-specific safety issues, and equipment maintenance. The people hired to operate the plant may come from Cemex's existing workforce or be sourced from similar industries or educational institutes.

Carbon capture plants may be staffed by people from other industries that use similar technologies like chemical and gas processing plants. Based on analysis of the industrial gas manufacturing industry, specific occupations with transferable skills could include, but is not limited to, the following:

Table 1: Select Occupations with Potentially Transferable Skills for Carbon Capture

Occupation	Standard Occupational Classification (SIC) Code	Current Employment in San Antonio/New Braunfels MSA	Employment Location Quotient
General and Operations Managers	11-1021	32,030	1.27
Maintenance and Operations Supervisors	49-1011	5,060	1.19
Transportation, Storage, and Distribution Managers	11-3071	1,660	1.16
Engineers (Chemical*, Electrical)	17-2071	740	0.55
Plant and System Operators, All Other	51-8099	180	1.65
Chemical Technicians	19-4031	210	0.51
Electrical and Electronic Engineering Technologists and Technicians	17-3023	880	1.26
Occupational Health and Safety Specialist	19-5011	1,070	1.22
Other Production Occupations	51-9199	670	0.38
Other Installation, Maintenance, and Repair Occupations	49-99099	1,390	1.10
Material Moving Workers, All Other	53-7199	140	0.79

*Number of chemical engineers at the MSA level is suppressed.

In general, these occupations are well represented in the San Antonio New Braunfels metropolitan statistical area (MSA) as indicated by the high location quotients for these occupations in Table 1. Widescale adoption of carbon capture technology may require training additional workers or entail greater employee and wage competition between industries in which workers have similar skill sets. Training for chemical technicians, other production workers, and material moving workers requires either a high school or associate degree and on-the-job training, whereas the chemical and electrical engineering positions would require bachelor's degrees.

Ongoing or planned collaborations with education and training providers: Describe plans and approaches to access the necessary training for the workforce needed to commercialize/deploy the technology. This includes coordination with educational institutions such as community colleges, technical schools, and universities, company-led in-house training, union training, etc. Please identify any institutions with which working relationships exist.

Cemex: In addition to the training through Cemex University and other platforms that are mentioned above, current training offerings include 77 different topics ranging from training on specific types of equipment to leadership development. Some of these courses are offered by in-house staff, whereas others are provided by external vendors such as Airgas, Dale Carnegie, and Exxon Mobil. In the past, the New Braunfels Fire Department has provided training on fire extinguisher use and safety. Furthermore, Cemex is working to develop relationships with:

- BLR environmental, which provides environmental, health and safety training, and
- Texas State Technical College, which offers electrical and mechanical training.

Cemex prioritizes recruiting their workforce from local colleges, including HBCUs (e.g., Prairie View A&M and Texas Southern University) and Hispanic-serving institutions (e.g., University of Houston and Texas A&M). The company runs an Intern Development Program for all lines of business and all plants and a 12-month rotational Talent Development Program, which recruits local college students and recent college graduates. The Cemex Foundation also makes donations to the Concrete Industry Management Program at Texas State University to build the next generation of workers in the cement and concrete industries.

As depicted in Table 2, Cemex Balcones partners with the New Braunfels Independent School District Education Foundation and the Greater New Braunfels Economic Development Foundation to support schools, offer local scholarships, and participate in career fairs at Canyon High School and New Braunfels High School. Across these partnerships, Cemex is committed to advancing equity through workforce development by providing opportunities to workers who face systematic barriers to employment. For example, Cemex partners with the local Chamber of Commerce and Family Life Center to meet the communities' basic needs.

Table 2: Cemex Engagement with Local Educational Institutions

Educational Institution	Nature of Cemex Engagement
New Braunfels Independent School District	Apprenticeships, expand recruitment
Texas State Technical College	Scholarships, training partnerships
Canyon High School	Recruitment
New Braunfels High School	Recruitment

SLB: As the entity tasked with designing and constructing carbon capture and sequestration technology, SLB shall provide an overall introductory training program for personnel involved in the Carbon Capture Plant. The personnel will be introduced to the main equipment, operation, and maintenance and the control systems emphasizing safety. Relevant suppliers may also be involved in conducting training on specific equipment packages or services.

The proposed training provided by SLB will include a Pre-learning/E-learning, introductory training for all staff, and either operation or maintenance training depending on employee role prior to commissioning start-up. Practical training, involving hands-on experience, may be carried out in smaller groups during the commissioning phase and plant start-up. Total training time will be approximately 4-8 hours for a general Cemex worker and up to 1 or 2 weeks for operating supervisors/control room operators.

Identify any necessary certificates, certifications or other educational attainment involved in this technology/activity.

Cemex: Under the normal operation for CCS, approximately four or five new jobs per shift would be needed, or up to 15 total new jobs. New positions for each shift would consist of two operators in the control room, one operating supervisor/team lead in the plant itself, one maintenance operator and one laboratory specialist. For other maintenance work, it is assumed that existing Cemex

operators can be trained in maintaining some of the equipment in the plant. Especially for the common types of equipment / utility systems etc.

The general nature of these jobs can be characterized in the following ways:

- An operating supervisor should possess a bachelor's or master's degree or have 4-6 years of equivalent experience in chemical engineering, process engineering, and a comparable combination of education and experience. Other preferred education and experience includes 5-10 years' experience in industrial gasses, natural gas processing and/or CO2 capture projects and have experience as an engineer or testing in a cement facility, chemical processing, gas, oil, or air separation plan.
- Control room operators should have a bachelor's degree in petroleum, power, chemical, mechanical, electrical, environmental, or instrumentation engineering and at least 3 years of experience in a processing plan. Other preferred skills and experience include an understanding of control room operation, technical and soft skills, experience working in similar chemical processes, and self-starting.
- Maintenance technicians do not have to be college graduates but should have technologist training or equivalent.
- Lab specialists do not require any specific certifications or experience, although training in the following areas would be advantageous: Carbon Capture, Utilization, and Storage (CCUS) training, climate change and energy transition courses, safety and risk management training, technical skills in laboratory practices, and regulatory compliance and environmental policy.

Identify any Economically Distressed Communities or state or federal designated Opportunity Zones or other geographically defined empowerment zones where this activity may occur.

The front-end engineering design (FEED) study is being conducted for Cemex's Balcones Cement Plant in New Braunfels, Texas. The facility is in U.S. Census Tract 48091310802, within Comal County. According to the Department of Energy's Working Justice40 Disadvantaged Communities database, the census tract is not designated as disadvantaged, nor does it share a border with any disadvantaged tracts. However, 150 out of 372 Census tracts in the broader project area meet the Climate and Economic Justice Screening Tool's definition of a disadvantaged community (see Table 3), representing 33% of the broader project area's (30 mi. radius) population. Thirty-one of these tracts exceed the threshold for only one category of burden, while 119 exceed the threshold for two or more categories of burden.

Table 3: Climate and Economic Justice Screening Tool Categories and Affected Population within 30-mile Radius

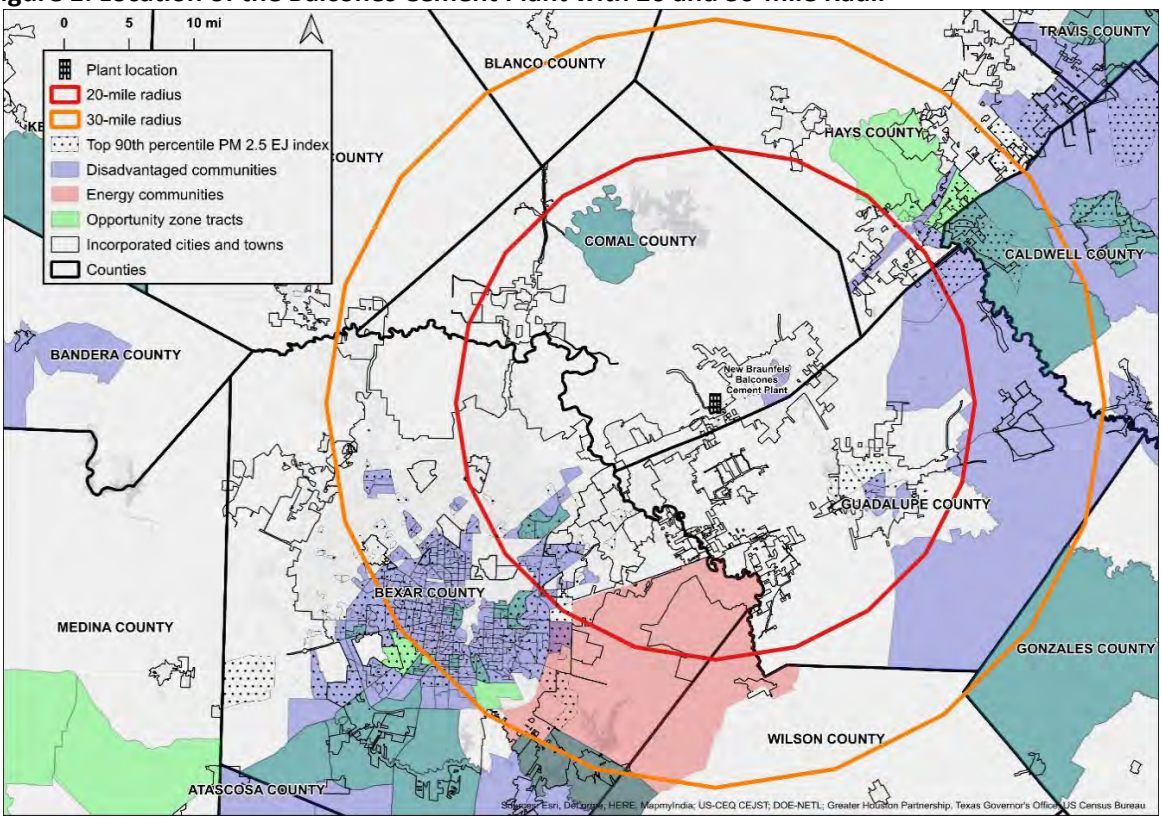
CEJST Category	Criteria Description	Affected Population	Share of Total Population	Number of Disadvantaged Tracts
All	Meet criteria threshold for at least one factor	618,858	33%	150
Wastewater	Underground storage tanks, wastewater discharge	47,323	3%	14
Workforce Development	Linguistic isolation, poverty, unemployment, education	358,057	19%	88
Climate Change	Agriculture, building or population loss, disaster risk	116,889	6%	31
Energy	Energy cost, PM 2.5 in air	62,328	3%	16
Transportation	Diesel exposure, transportation barriers, traffic	183,397	10%	48
Housing	Underinvestment, housing cost, lack of amenities, lead paint	244,029	13%	66
Legacy Pollution	Abandoned mines, hazardous waste, superfund sites	242,486	13%	59
Health	Asthma, diabetes, health disease, life expectancy	437,325	24%	110

There are no federally recognized American Indian tribes for whom the proposed project may have implications. The nearest Texas Opportunity Zone is approximately 14 miles from the plant, and individuals from this Opportunity Zone are within commuting distance from the plant.[1]

The 20 and 30-mile radii around the plant are depicted in Figure 1, along with energy communities[1], disadvantaged communities, and opportunity zone areas. The 30-mile radius represents the commuting area for 75% of facility employees.

[1] Energy communities are areas with high concentration of coal-dependent jobs.

Figure 1: Location of the Balcones Cement Plant with 20 and 30-mile Radii



Source: DOE Working Justice40 Disadvantaged Communities, 2023.

Within the project area (30 mi. radius), 32% of the population is low income.[2] The project area is also above the national average for the Hispanic population, unemployment, and adults without a high school diploma. New jobs created by this project will potentially be filled by people within this area. Additional project work is being performed at KBR's offices in Wilmington, DE, Cemex's corporate offices in Houston, TX, RTI International's headquarters in Research Triangle Park, NC, and SLB's facility in Houston, TX.

[2] This statement is based on the dataset and definition for "low-income" used by the Climate & Economic Justice Screening Tool (CEJST): https://screeningtool.geoplatform.gov/en/methodology#low-income

P Economic Revitalization and Job Creation Outcome Analysis

ECONOMIC REVITALIZATION AND JOB CREATION OUTCOMES ANALYSIS
Recipient Name: RTI International, CEMEX, Inc., Schlumberger (SLB), and KBR, Inc.
PI Name: Dr. Vijay Gupta, RTI International
Award Number: DE-FE0032220
Project Title: Carbon Capture Plant FEED Study for Cement Manufacturing Technology

Apart from job creation, how will the project and/or the associated technology development and deployment support economic revitalization?

Cement has a sizable carbon footprint because CO_2 is directly released during the production process. Efforts to decarbonize existing cement plants may extend the life of these facilities and avoid job losses. In addition to sequestering carbon, NAS technology reduces the amounts of SO_2 and particulate matter in air emissions. These reductions may be necessary in the future to keep Comal County in attainment with federal air quality standards. When an area is designated as a "nonattainment" area this negatively impacts businesses that want to locate or expand a business in that area.[1]

Whereas job creation is a significant aspect, CO_2 capture technology can potentially revitalize the economy beyond that through the fostering innovation and technology leadership of the US. Investing in CO_2 capture research and development can spur innovation in various fields like materials science, engineering, and chemical processing. This can lead to the creation of new technologies and industries, positioning the US as a leader in innovative solutions in multiple disciplines. The development of more efficient and cost-effective CO_2 capture technologies also can attract international investment and partnerships, further boosting the economy. Investments in CO_2 capture infrastructure can create new opportunities for sustainable development and green jobs, attracting talent and investment in environmentally conscious industries.

How many jobs could potentially be created by the project and/or associated remediated, number of jobs created per unit of emissions mitigated, and/or another appropriate metric.

The project team's preliminary estimates for job creation during the installation of the CO_2 capture unit to the Balcones plant shows that it would create more than 300 construction jobs during the 18 to 22-month duration for construction. The jobs would include direct crafts and associated supervision to carry out the construction and commissioning of the added CO_2 capture unit.

Under the normal operation, approximately 4 or 5 new jobs per shift would be needed, or up to 15 total new jobs. New positions for each shift would consist of 2 operators in the control room, 1 operating supervisor/team lead in the plant itself, 1 maintenance operator and 1 laboratory specialist. For other maintenance work, it is assumed that existing Cemex operators can be trained in maintaining some of the equipment in the plant. Especially for the common types of equipment / utility systems etc.

What will be the nature of the created jobs, including the extent to which they will include clean energy jobs?

[1] For more information about how nonattainment status can affect industrial projects see Nonattainment New Source Review Basic Information at https://www.epa.gov/nsr/nonattainment-nsr-basic-information

The general nature of these jobs can be characterized in the following ways:

- An operating supervisor should possess a bachelor's or master's degree or have 4-6 years of equivalent experience in chemical engineering, process engineering, and a comparable combination of education and experience. Other preferred education and experience includes 5-10 years' experience in industrial gasses, natural gas processing and/or CO2 capture projects and have experience as an engineer or testing in a cement facility, chemical processing, gas, oil, or air separation plan.
- Control room operators should have a bachelor's degree in petroleum, power, chemical, mechanical, electrical, environmental, or instrumentation engineering and at least 3 years of experience in a processing plan. Other preferred skills and experience include an understanding of control room operation, technical and soft skills, experience working in similar chemical processes, and self-starting.
- Maintenance technicians do not have to be college graduates but should have technologist training or equivalent.
- Lab specialists do not require any specific certifications or experience, although training in the following areas would be advantageous: Carbon Capture, Utilization, and Storage (CCUS) training, climate change and energy transition courses, safety and risk management training, technical skills in laboratory practices, and regulatory compliance and environmental policy.

All created construction and operation jobs can be classified as clean energy jobs, given their direct role in the construction and operation of the CCS facility.

To what extent will the created jobs be at the prevailing wage?

During the construction phase of the project, subcontractors would be responsible for ensuring that they comply with the Davis Bacon Act and pay laborers no less than the locally prevailing wages and fringe benefits for corresponding work on similar projects in the area. As the lead grant recipient, RTI International will contract with an experienced third party well versed in prevailing wage work to determine proper application of the required rates and feeds and ensure compliance by construction subcontractors.

The plant employees approximately 171 individuals and 95 are members of the Local Teamsters 657. The union sets wages with the company through a Collective Bargaining Agreement. For workers who are not union members, Cemex define wage rates based on market benchmarks which include: information on job boards, compensation surveys, recruiters/headhunter input, and prevailing wages.

To what extent will the created jobs be located in power plant and coal communities that are economically distressed and/or have been harmed by the adverse environmental impacts of the energy industry?

Construction and operational jobs are at the Cemex facility in Comal County, TX. The U.S. Department of Energy has not determined that Comal County is a designated energy community. However, nearby Bexar

County, which is within commuting distance from the Cemex plant, is eligible for the Qualifying Advanced Energy Project Credit (48 C) Program, which is designed for communities that have been negatively impacted by the closure of either a coal-fired power plant or a coal mine.[2]

As presented in the Workforce Readiness Plan, 150 out of 372 Census tracts in a 30-mile radius around the project site meet the Climate and Economic Justice Screening Tool's definition of a disadvantaged community, representing 33% of the area's population. If this project is constructed, local communities will benefit from better air quality and workforce development opportunities offered by the project.

What recruitment strategies will be used for: a) workers from the local community, and b) individuals who belong to groups that are historically underserved or underrepresented?

Cemex recruitment strategies include broad-based strategies such as utilizing hiring banners and billboards throughout the community and participating in various career fairs and hiring events, such as the Texas State Technical College Career Fair, Indeed Hiring Event, and numerous other local high school, college and community-oriented career fairs. Additionally, we offer a Referral Bonus program to our employees who successfully refer candidates for hire. Furthermore, Cemex maintains partnerships with Orion HirePurpose® and Society of Women Engineers whose recruitment strategies are geared towards underserved populations such as women, persons with disabilities, veterans/military, and disparate race/ethnicity groups. Recruitment at Historically Black Colleges and Universities (HBCUs) such as Prairie View A&M and Texas Southern University and Hispanic-Serving Institutions (HSIs) such as University of Houston and Texas A&M also expands the candidate pool to ensure opportunities are granted for underrepresented race/ethnicity groups. Cemex also recently participated in a Juneteenth HBCU Career Fair and MLK Parade in Houston, distributing recruitment information. Events such as these attract candidates throughout the Southwest that have experiences that qualify them for jobs specific to our Balcones operations.

KBR will post positions in the local area, so the community is aware of the available positions. We will establish a relationship with the local unemployment offices. KBR prides it's self on being one of the most diverse companies in the world. It strives to hire the most qualified candidates, and pulls from a diverse candidate pool, by posting the positions in various locations such as indeed, LinkedIn, and through HBU's. Non-union construction contractors will recruit local craftsmen through local advertising, word of mouth, and temporary hiring agencies. Union contractors will deploy craftsmen through the associated Union Hall.

Will the skills possessed by the existing labor force be adequate for the created jobs, or will training be required for those workers?

Even though the project is near San Antonio, there is expected to be some difficulty hiring craft workers for the construction portion of the project based on current labor surveys published from Alpha Resources (10/4/24) considering the size of the job. A craft per diem (50% of workers x $96/day) is expected to attract some of the workers who live outside of the region.

[2] https://arcgis.netl.doe.gov/portal/apps/experiencebuilder/experience/?data_id=dataSource_4-1888c6ff8c5-layer-4%3A3388&id=a44704679a4f44a5aac122324eb00914&page=home

Carbon capture operations initially may be staffed by people from other industries that use similar technologies such as chemical and gas processing plants or through upskilling existing workers. Based on analysis of the existing industrial gas manufacturing industry, many needed occupations are well represented in the San Antonio New Braunfels metropolitan statistical area (MSA). According to Workforce Solutions Alamo, the local workforce development board, the region has an unemployment rate of 3.9% with more than 54,000 people actively looking for work.[3] The oil and gas extraction industry is expected to be one of the top ten fastest growing industries between 2022 and 2023 and the local workforce development board has identified this sector as one that will require targeted assistance.[4]Training for chemical technicians, other production workers, and material moving workers requires either a high school or associate degree and on-the-job training, whereas the chemical and electrical engineering positions would require bachelor's degrees. Several construction occupations such as carpenters and first-line supervisors on construction also are considered in-demand occupations and may require training support from the local workforce development board.

[3] Bexar County Jobs and Unemployment Claims

[4]https://www.workforcesolutionsalamo.org/about/board-plan/