Recovery Act: High Temperature Syngas Cleanup Technology Scale-up and Demonstration Project

Final Scientific/Technical Report

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Abstract

Gasification is a technology for clean energy conversion of diverse feedstocks into a wide variety of useful products such as chemicals, fertilizers, fuels, electric power, and hydrogen. Existing technologies can be employed to clean the syngas from gasification processes to meet the demands of such applications, but they are expensive to build and operate and consume a significant fraction of overall parasitic energy requirements, thus lowering overall process efficiency. RTI International has developed a warm syngas desulfurization process (WDP) utilizing a transport-bed reactor design and a proprietary attrition-resistant, high-capacity solid sorbent with excellent performance replicated at lab, bench, and pilot scales. Results indicated that WDP technology can improve both efficiency and cost of gasification plants. The WDP technology achieved ~99.9% removal of total sulfur (as either H_2S or COS) from coal-derived syngas at temperatures as high as 600°C and over a wide range of pressures (20-80 bar, pressure independent performance) and sulfur concentrations. Based on the success of these tests, RTI negotiated a cooperative agreement with the U.S. Department of Energy for pre-commercial testing of this technology at Tampa Electric Company's Polk Power Station IGCC facility in Tampa, Florida. The project scope also included a sweet water-gas-shift process for hydrogen enrichment and an activated amine process for 90+% total carbon capture. Because the activated amine process provides some additional non-selective sulfur removal, the integration of these processes was expected to reduce overall sulfur in the syngas to sub-ppmv concentrations, suitable for most syngas applications. The overall objective of this project was to mitigate the technical risks associated with the scale up and integration of the WDP and carbon dioxide capture technologies, enabling subsequent commercial-scale demonstration. The warm syngas cleanup pre-commercial test unit was designed and constructed on schedule and under budget and was operated for approximately 1,500 total hours utilizing ~20% of the IGCC's total syngas as feed (~1.5 MM scfh of dry syngas). The WDP system reduced total sulfur levels to ~10 ppmv (~99.9% removal) from raw syngas that contained as high as 14,000 ppmv of total sulfur. The integration of WDP with the activated amine process enabled further reduction of total sulfur in the final treated syngas to the anticipated sub-ppmv concentrations (>99.99% removal), suitable for stringent syngas applications such as chemicals, fertilizers, and fuels. Techno-economic assessments by RTI and by third parties indicate potential for significant (up to 50%) capital and operating cost reductions for the entire syngas cleanup block when WDP technology is integrated with a broad spectrum of conventional and emerging carbon capture or acid gas removal technologies. This final scientific/technical report covers the pre-FEED, FEED, EPC, commissioning, and operation phases of this project, as well as system performance results. In addition, the report addresses other parallel-funded R&D efforts focused on development and testing of trace contaminant removal process (TCRP) sorbents, a direct sulfur recovery process (DSRP), and a novel sorbent for warm carbon dioxide capture, as well as pre-FEED, FEED, and techno-economic studies to consider the potential benefit for use of WDP for polygeneration of electric power and ammonia/urea fertilizers.

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I. Executive Summary

Gasification is a technology for clean energy conversion of diverse feedstocks into a wide variety of useful products such as chemicals, fertilizers, fuels, electric power, and hydrogen. Existing technologies can be employed to clean the syngas from gasification processes to meet the demands of such applications, but they are expensive to build and operate and consume a significant fraction of overall parasitic energy requirements, thus lowering overall process efficiency. RTI International has developed a warm syngas desulfurization process (WDP) utilizing a transport-bed reactor design and a proprietary attrition-resistant, high-capacity solid sorbent with excellent performance replicated at lab, bench, and pilot scales. Results indicated that WDP technology can improve both efficiency and cost of gasification plants. The WDP technology achieved ~99.9% removal of total sulfur (as either H_2S or COS) from coal-derived syngas at temperatures as high as 600°C and over a wide range of pressures (20-80 bar, pressure independent performance) and sulfur concentrations.

Based on the success of these tests, RTI negotiated a cooperative agreement with the U.S. Department of Energy for pre-commercial testing of this technology at Tampa Electric Company's Polk Power Station IGCC facility in Tampa, Florida. The project scope also included a sweet water-gas-shift process for hydrogen enrichment and an activated amine process for 90+% total carbon capture. Because the activated amine process provides additional non-selective sulfur removal, the integration of these processes was expected to reduce overall sulfur in the syngas to sub-ppmv levels suitable for most syngas applications. The overall objective of this project was to mitigate the technical risks associated with the scale up and integration of the WDP and carbon capture technologies, enabling subsequent commercial-scale demonstration. This project's Statement of Project Objectives is attached as Appendix A.

Some of the major accomplishments of this project included the following:

- The pre-commercial test unit was designed and built <u>on</u> schedule and <u>under</u> budget.
- >500,000 total labor hours were accrued with <u>no</u> injury other than a few minor first aids.
- The pre-commercial scale unit performed as expected for ~1,500 total syngas operating hours, duplicating previous performance at lab, bench, and pilot scales, and showing that the WDP technology can be scaled up with confidence.
- The WDP unit consistently reduced inlet total sulfur content from as much as 14,000 ppmv to ~10 ppmv (~99.9% total sulfur removal).
- Downstream clean syngas exiting the carbon capture block has consistently been < 0.5 ppmv (>99.99% total S removal), suitable for rigorous chemicals and fuels applications.
- Sorbent attrition rate has been lower than design expectations (good).
- Sorbent sulfur capacity has been steady - no sign of any significant deactivation.
- The WDP unit has successfully been operated both below and above its design rate.
- Significant learnings will benefit scale-up to a full-scale commercial demonstration unit.

- In addition to the above R&D achievements, this project also funded efforts that conducted beneficial R&D related to several peripheral technologies and/or processes:
  - Improvements were shown for trace contaminant removal process (TCRP) sorbents for Hg, As, Se, HCl, and NH_3 that can meet new EPA emissions limits.
  - Microreactor systems were built, installed, and tested to help demonstrate that WDP + TCRP + aMDEA® can clean syngas adequate for use with chemicals/fuels.
  - Improvements were identified in the lab that can improve scaled-up designs of RTI's direct sulfur recovery process (DSRP) technology.
  - Novel warm temperature carbon dioxide capture sorbents were developed that show promise for coupling with WDP to maintain high efficiency gains when carbon dioxide capture is also needed.
  - A series of pre-FEED and FEED studies, coupled with techno-economic analyses, showed that use of WDP + aMDEA® technologies could enable viable IGCC retrofit options for polygeneration of electric power and ammonia and/or urea.

In parallel with this project, a separate cooperative agreement (DE-FE0012066) was awarded to RTI by DOE that utilized Nexant to conduct a series of systems analyses to assess the benefits of RTI WDP technology for power generation with 90+% carbon capture and for chemicals and fuels applications (methanol production). This independent assessment revealed that use of WDP technology could enable substantial reductions in CAPEX (20%-50%) and in OPEX (up to 50+%) for the entire syngas cleanup block (WDP + WGS + LTGC + CC + SRU) compared to conventional technologies such as Selexol™ and Rectisol®, while also providing improvements in overall process efficiencies. This ability to simultaneously improve CAPEX, OPEX, and process efficiency illustrates why the RTI WDP technology is a game-changer technology.

A prolonged 5-month outage of the TEC host site gasifier in mid-2015, coupled with some reliability issues with auxiliary equipment and corrosion issues primarily with heat exchangers, prevented this project from reaching its original target of achieving several thousand operating hours on syngas (did achieve 1,500 hours), and also limited learnings related to system reliability and TCRP/microreactor testing. But because most other key performance objectives of this project were successfully achieved, a recommendation was made to DOE to provide for an extension of the pre-commercial testing of the warm syngas cleanup system at the TEC site. DOE approved a separate cooperative agreement (DE-FE0026622) which will enable the pre-commercial test unit to continue operating from October 1, 2015 until TEC's 2016 spring outage (planned for late April, 2016). The primary goals of this testing extension are to operate the warm gas desulfurization process, water gas shift, low-temperature gas cooling, and activated amine carbon capture units at the pre-commercial test site to achieve an additional ~3,000 hrs of syngas operation with a target of ~1,000 hrs of continuous operation of the full integrated systems. At the conclusion of this extended testing, it is anticipated that the WDP technology will then be ready for successful scale-up to a full commercial-scale demonstration plant.

II. Project Approach

In September 2010, RTI and the DOE/NETL signed a modified cooperative agreement to design, build, and operate a pre-commercial syngas cleaning system that would capture up to 90% of the CO_2 in the syngas slipstream, sequester up to 300,000 tons per year of this captured CO_2 in a deep saline aquifer (NOTE: in April, 2012 RTI, TEC, and DOE agreed to remove CO_2 sequestration from the scope of the project), and demonstrate the ability to reduce syngas contaminants to meet DOE's specifications for chemical production application. This pre-commercial syngas cleaning system was expected to process the equivalent of 30 to 50 MW_e of syngas and would be operated at Tampa Electric Company's (TEC) 250-MW_e integrated gasification combined cycle (IGCC) plant at Polk Power Station (PPS), located near Tampa, Florida.

RTI's warm syngas cleaning technology platform, which has been developed with funding from the U.S. Department of Energy (DOE), represents a key component in the syngas cleaning system in this project. The technology has been successfully demonstrated at pilot-scale at Eastman's Coal to Chemicals facility in Kingsport, Tennessee (USA) during >3,000 hours of parametric testing using coal-derived syngas at elevated temperatures >250°C (~ 500°F). During this project, this pre-commercial syngas cleaning system was used to complete key activities necessary for scale-up to subsequent commercial application of RTI's warm syngas cleaning technologies including demonstration of anticipated commercial performance, accumulating operating experience to establish reliability, availability, and maintenance (RAM) targets, startup, shutdown and operator training, and mitigation of design for a future commercial-scale system.

The selective sulfur removal possible with RTI's warm gas desulfurization process (WDP) enables effective integration with selective CO_2 capture technologies. Although RTI's WDP opens significant potential for emerging advanced CO_2 capture technologies, existing commercial CO_2 capture technologies also benefit from improvements in overall thermal efficiency and capital and operating costs.

The syngas cleaning system for this project consisted of the following units:

- Warm Gas Desulfurization Process (WDP) — this unit processes a syngas flow equivalent of approximately 50 MW_e of power (50 MW_e equivalent corresponds to about 1.5 MM scfh of syngas on dry basis) to produce a desulfurized syngas with a total sulfur (H_2S+COS) concentration of ~10 ppmv.
- Water Gas Shift (WGS) Reactor — this unit converts sufficient CO into CO_2 to enable 90% capture of the CO_2 in the syngas slipstream. This reactor uses conventional commercial sweet high-temperature shift catalyst technologies.
- Low Temperature Gas Cooling (LTGC) — this unit cools the syngas to ~110°F needed for the activated methyldiethanolamine (MDEA) carbon dioxide capture process and separates any condensed water.

- Activated MDEA Process — this unit employs a non-selective separation for the CO_2 and residual sulfur present in the WDP-treated syngas stream. Because of the selective sulfur removal by the upstream WDP unit, the CO_2 capture target of 90% CO_2 can be achieved with the added benefit that total sulfur concentration in the CO_2 product is < 100 ppmv. An additional advantage of the activated MDEA process is the non-selective sulfur removal from the WDP-treated syngas reduces sulfur in the final product syngas to sub-ppm concentrations, which are required for chemical production applications.

Figure 1 below shows the overall block flow diagram of the pre-commercial test unit within the existing syngas processing system at PPS. The pre-commercial test unit draws a slipstream of about 1.5 MM scfh of syngas (dry basis, about 2.0 MM scfh on a wet basis) from the discharge of the COS superheater before entering the COS hydrolysis reactor. The processed syngas is returned upstream of the humidification process before the combustion turbine. The slipstream of syngas for the pre-commercial unit is compressed from about 350 psig to about 400 psig prior to feeding WDP. This compression is used to compensate for the pressure drop across the test unit and minimizes the impact of returning the processed syngas stream to PPS's existing syngas processing system.

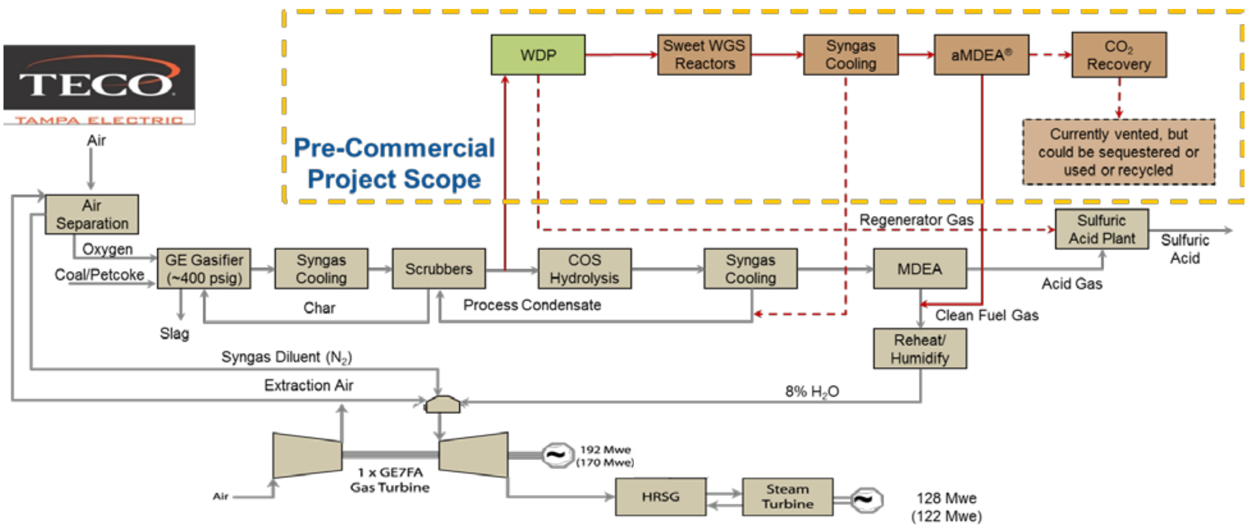


Figure 1. Overall Project Block Flow Diagram

The major original project goals are summarized in the table below:

Table 1. Project Goals

Technology	Size	Operation	Performance

WDP	~50 MW_e	5,000 to 8,000 hours	Total sulfur < 10 ppmv
CO_2 Removal	Up to 300,000 tons/year	5,000 to 8,000 hours	$\geq$90% carbon removal

III. Pre-Front End Engineering and Design (pre-FEED)

The engineering contractor selection was initiated by inviting multiple engineering companies to submit an intent-to-bid letter to RTI in late August, 2009. The following seven engineering companies expressed their interest to participate in the bid process.

- Jacobs
- KBR
- SNC Lavalin
- Shaw Group
- Pegasus TSI (formerly Mustang)
- Foster Wheeler
- Bechtel

After receiving the intent-to-bid letters, RTI negotiated and signed individual non-disclosure agreements (NDAs) with each of the above listed firms. The NDAs were finalized and signed by all parties by Sept. 4, 2009.

RTI developed a Request for Proposal (RFP) package that was used to allow the engineering firms to bid. The RFP package included:

- Subcontractor Information Form (including Representations & Certifications)
- Instructions to Subcontractors
- Project Background
- Scope of Work
- List of Minimum Deliverables
    - General/Project Management
    - Process
    - Control Systems
    - Process Safety
    - Mechanical
    - Piping
    - Civil/Structure
    - Electrical

- Technical Instructions
- Preliminary Process Flow Diagrams
- Preliminary Mass Balances
- Preliminary Equipment List
- Model Subcontract

The RFP package was reviewed by all project partners including DOE-NETL, TEC and Eastman before it was issued to engineering companies on Sept. 18, 2009.

Below is an overview of the selection criteria:

- Technical Capabilities (30%)
  Specific technical expertise will be advantageous to successfully develop a FEED package for the syngas clean-up technology. In the evaluation, RTI will consider to what extent the design approach demonstrates:
  - Experience in designing and building transport reactor systems
  - Experience in syngas processing
  - Experience in sulfur recovery
  - Experience in integration of new process technology into operating facilities in the power, chemical or refining sector
  - Experience in coal gasification and IGCC.
- Project Cost (30%)
  - The contract will be awarded on a cost reimbursement basis. RTI will evaluate the level of detail, competitiveness, and value provided by the estimated cost for the FEED package
- Project Implementation (30%)
  - RTI will evaluate to what extent the proposal demonstrates the capabilities, resources, and execution plan to successfully manage development of the FEED package on time and within budget.
- Other factors (10%):
  - Acceptance of subcontract terms

Once all the proposals were received by RTI, the project team reviewed the proposals utilizing the above criteria. Shaw Energy and Chemicals was selected to execute the pre-FEED package.

The initial scope for the pre-FEED package was to develop a process engineering package to support a factored cost estimate. The system was expected to process about 2 MM scfh (dry basis) of syngas and would be operated at Tampa Electric Company's (TEC's) 250-MW_e coal and petcoke fed integrated gasification combined cycle (IGCC) plant at Polk Power Station (PPS), located near Tampa, Florida.

The initial design package consisted of three test units to demonstrate RTI's warm syngas cleaning technologies at commercial operating conditions:

- Warm Gas Desulfurization Process (WDP) – this unit would process about 2 MM scfh of syngas on a dry basis and produce a desulfurized syngas with a total sulfur (H_2S + COS) concentration of ~10 ppmv.
- Trace Contaminant Removal Process (TCRP) – this unit would remove trace contaminants such as mercury, arsenic, and selenium from a desulfurized syngas slipstream of about 200,000 scfh, corresponding to approximately 5 MW_e of power equivalent.
- Direct Sulfur Recovery Process (DSRP) – this unit would be integrated with WDP to process a slipstream of the regeneration off-gas from the WDP unit to produce about 5 tons/day of sulfur.

The objective of the pre-FEED package was to develop a process design for WDP, TCRP, and DSRP and resolve open design issues and scale-up issues, and for Shaw to assist RTI to develop specific mitigation plans to address these issues.

The pre-FEED deliverables submitted by Shaw included the following:

- Process design narrative
- Process Flow Diagram
- Detailed Equipment List with sizes and specifications
- Material of Construction for equipment and piping
- Validate process simulation provided by RTI
- Heat and Material Balance for multiple design cases (design case, normal case, turndown case, alternative syngas composition)
- Preliminary plot plan
- Electrical area classification
- Hazardous area classification
- Preliminary P&IDs
- Interface diagrams with boundary limits for process and utility streams
- Emissions, waste stream summary and waste management strategy
- Raw materials, catalyst and chemicals summary
- Utility balance tables
- Utility specification and total usage
- Cost estimate (+/- 30%) Class IV Factored Cost Estimate

Shaw submitted the Pre-FEED design package with a corresponding cost estimate on October 15, 2010 (NOTE: the pre-FEED package was submitted to DOE in a previous topical report). The cost for the aforementioned scope was $90,829,503. However, between the pre-FEED and FEED phase of the project, the scope was changed to include carbon dioxide capture and sequestration. Between the pre-FEED and FEED phase of the project (i.e. fall of 2010), a modified preliminary process design package was developed to include the following unit operations:

- Warm Gas Desulfurization Process (WDP) – this unit would process about 2 MM scfh of syngas on dry basis and produce a desulfurized syngas with a total sulfur (H_2S + COS) concentration of ~10 ppmv.
- Water Gas Shift (WGS) – the design basis was to convert 90% of the CO in the syngas to CO_2.
- Carbon capture – aMDEA® system by BASF was the technology selected for carbon capture
- CO_2 Sequestration – the intent was to pressurize the CO_2 stream and to inject it underground at TEC's Polk Power Station.

The initial cost estimate exceeded the allocated budget for this project. Therefore, the plant was de-scoped to handle 1.5 MM scfh of syngas (dry basis). The results from this study were used to develop a Basis of Design document for the Front End Engineering Design (FEED) phase of the project.

IV. Front End Engineering and Design (FEED)

During this phase of the project, multiple activities were initiated. These activities included:

- FEED package development
- Finalize key teaming agreements
- Develop the air permit application
- Develop the Environment Assessment application
- Develop the Project Execution Plan
- Initiate the Risk Management Program

Below is a summary of the work for each activity mentioned above.

FEED Package Development

On October 15, 2010, a +/- 30% cost estimate of approximately $90 million (basis of the estimate was syngas flowrate 2.0 MM scfh dry basis) for the warm syngas cleaning system was developed by Shaw. Since this estimate did not include costs associated with water gas shift, cooling, acid gas separation, or compressing and drying of CO_2, it was decided to produce an estimate that include the additional scope. RTI and Shaw developed an Aspen model that combined the warm gas cleanup process and carbon capture/sequestration to develop process flow diagrams, heat and material balances, a sized equipment list, and a preliminary plot plan. These basic engineering documents were utilized to develop a cost estimate. The cost estimate was utilized to determine the scope (i.e. size of the plant) that would not exceed the authorized budget. During this exercise, it was determined that the plant should be sized to handle 1.5 MM scfh (dry basis).

RTI and Shaw developed a Basis of Design document and initiated FEED in February, 2011. The purpose of the FEED effort was to develop an engineering package sufficient to support at least a +/-20% cost estimate, a Level III resource loaded schedule, and overall project execution strategy. The engineering deliverables from the FEED efforts included the following:

- Aspen model of the warm gas cleanup, water gas shift, aMDEA® processes, and the utilities was developed
- Process flow diagram (PFD)
- Heat and material balance (HMB)
- Utility consumption and specification
- Catalyst and chemical summary
- Process description
- Control narrative
- Equipment list
- General arrangement
- Tie-in list
- Equipment datasheets
- Equipment quotes
- Material take-offs
    - Pipe
    - Electrical
    - DCS/Instrumentation
    - Civil
    - Structural
    - Architectural
- Operating guidelines
- HAZOP
- Health, Safety, & Environmental plan
- Fire protection philosophy
- Instrument list
- P&IDs
- Hazardous area classification
- Single line diagrams

During the FEED effort, the project team focused on developing an adsorber and regenerator design that would provide a solid circulation rate sufficient to capture both H_2S and COS from ~ 10,000 ppmv to ~10 ppmv. The design effort included a process design to determine reactor dimensions (i.e. height and diameter) and the circulation rate to satisfy a pressure balance. Additionally, the design included significant effort to produce a mechanical design robust enough to handle the pressure, temperature, and syngas composition without premature failure.

Additionally, a significant design effort between RTI, TEC, and Shaw was required to ensure tie-in to the Polk Power Station IGCC did not result in power production interruption. Areas of concern included tie-ins to the steam system (supply and return), syngas (supply and return), sulfuric acid plant, and cooling water (supply and return). Before the FEED effort was initiated, there were concerns about whether the gas turbine would handle the higher concentration of H_2 in the syngas stream returned to TEC. Therefore, TEC worked with GE and determined that burner modifications were not required for operations.

Finally, a HAZOP was conducted to identify potential hazards that could result in the loss of life, property, or negatively impact the environment. The HAZOP recommendations were documented and included as a portion of the FEED package.

Shaw submitted the FEED package on schedule and under budget in September, 2011. [NOTE: The FEED package was submitted to DOE as a separate report.]

In order to reduce the risk of being associated with only one engineering firm, RTI decided to issue the process package to solicit estimates, schedules, and execution plans from other engineering firms. The process package included a process description, process flow diagram, heat and material balance, process & instrumentation diagrams, equipment list, datasheets, plot plan, single line diagram, and control system philosophy. RTI approached Mustang Engineering out of Houston, Texas, Foster Wheeler out of Houston, Texas, AMEC Engineering out of Atlanta, Georgia, and Technip out of Los Angeles, California. Mustang and Foster Wheeler declined to participate; therefore, RTI worked with AMEC and Technip to develop a cost estimate and execution plan. At the time of this effort, each company had the following financial statistics:

- AMEC was a $4.5 billion dollar revenue company with over 27,000 employees world-wide.
- Technip was a company that had revenues in excess of $4 billion with over 25,000 employees.

Both AMEC and Technip have expertise working with emerging technologies in the power and chemical sectors.

In October, 2011 Shaw, AMEC, and Technip submitted their engineering packages, cost estimate, and execution plan to review. Below is a table outlining the costs for the project as proposed by each company.

Table 2. EPC Bid Estimates

Description	AMEC	Shaw	Technip
Direct Cost	$80,124,503	$88,160,616	$79,767,379
Indirect Cost	$16,238,221	$10,797,371	$12,442,917
Engineering	$ 5,950,000	$12,544,234	$ 9,527,000
Procurement	$ 850,000	$ 1,227,125	$ 1,734,000
Construction Man.	$ 2,023,689	$ 3,819,342	$ 3,098,500
Total	**$103,656,072**	**$116,548,688**	**$106,569,796**

NOTE: The costs above excluded freight, vendor representatives, first fills, spares, contingency, and escalation.

When evaluating the proposals by each company, RTI was interested in the overall execution strategy of each company. Shaw and Technip proposed an EPCM approach to executing the project while AMEC proposed an EPC approach where they intended to self-perform over 85% of the work. AMEC's execution strategy was more attractive since they understood their labor and productivity. Also, out of the three companies, AMEC was the only company willing to put money at risk to perform the job, which was an indication of the confidence they had with respect to their proposal. Finally, the schedule submitted by AMEC was more reasonable and fit the overall time line of the project.

To ensure the costs were reasonable, RTI evaluated the cost in major categories such as piping, equipment setting, civil, structural steel, instrumentation, electrical, engineering, procurement, and construction oversite. Figures 2-15 below show the evaluations that were performed to determine the reasonableness of the proposals. The blue lines and diamonds are derived from a cost database to show the low, average, and high normalized metrics from past first of a kind projects. Next, the red triangles were placed within each chart to show where AMEC, Shaw, and Technip fell based on their proposed estimates. Another consideration that was important to RTI was for each firm to recommend value engineering ideas that would drive down costs and improve upon the schedule. AMEC provided ideas that resulted in approximately $4 million in potential cost reductions.

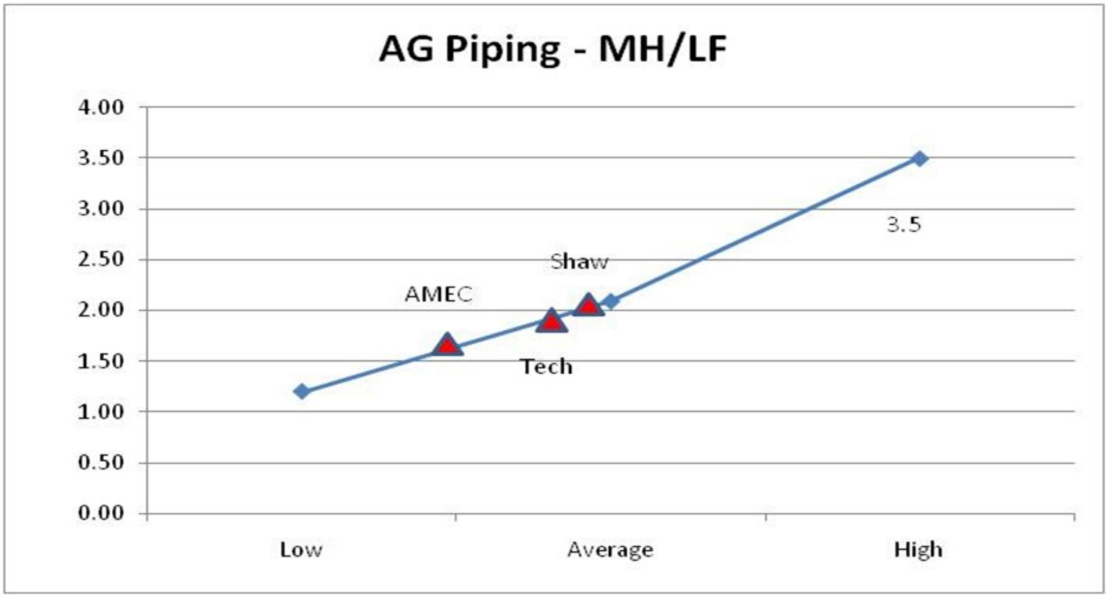


Figure 2. Piping Man-Hour Estimate Comparisons

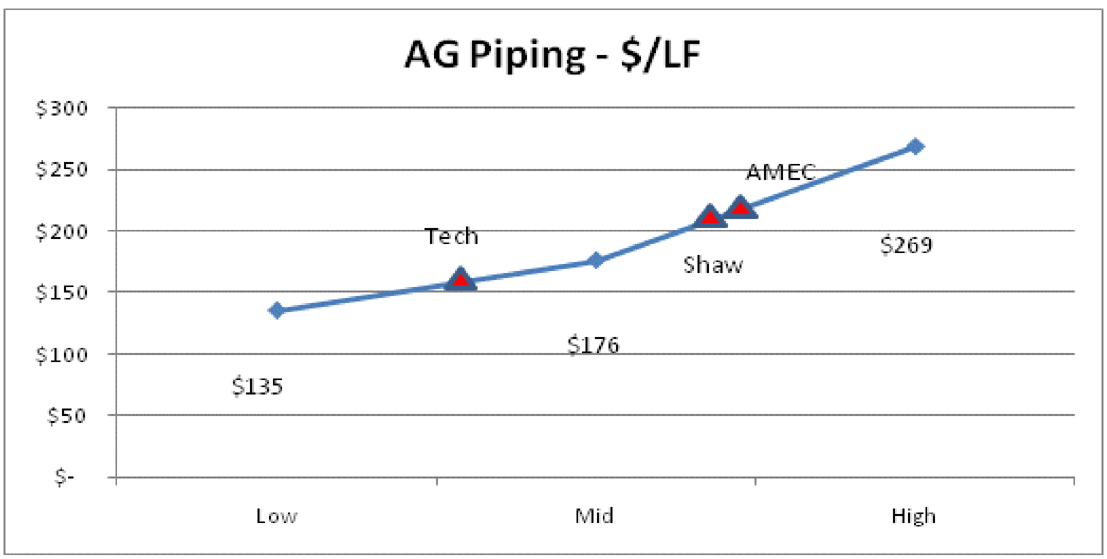


Figure 3. Piping Cost Estimate Comparisons

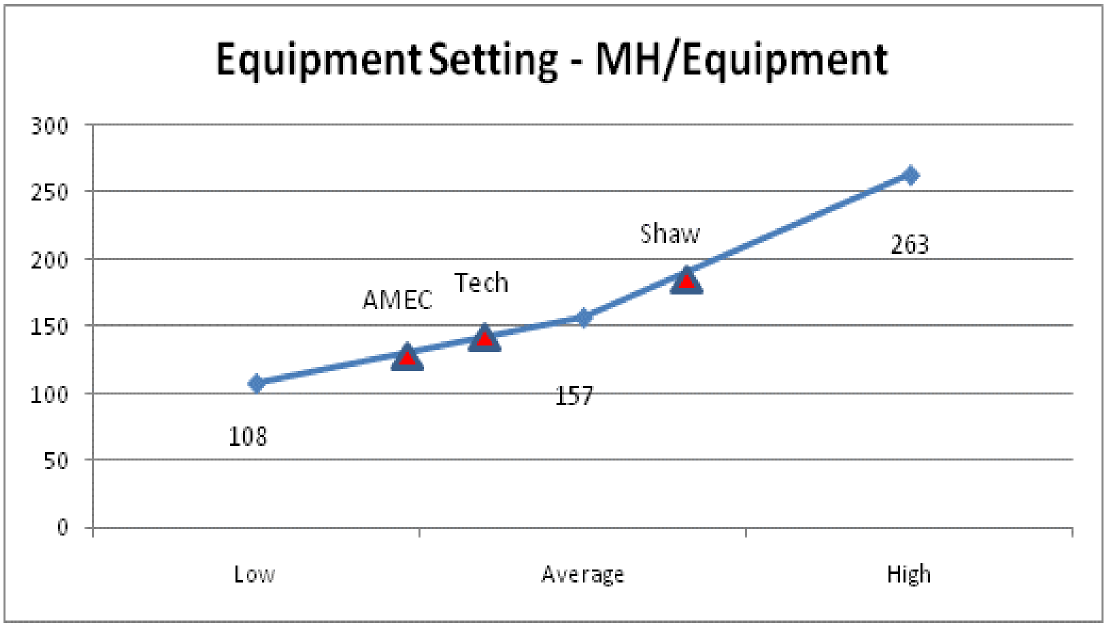


Figure 4. Equipment Setting Man-Hour Estimate Comparisons

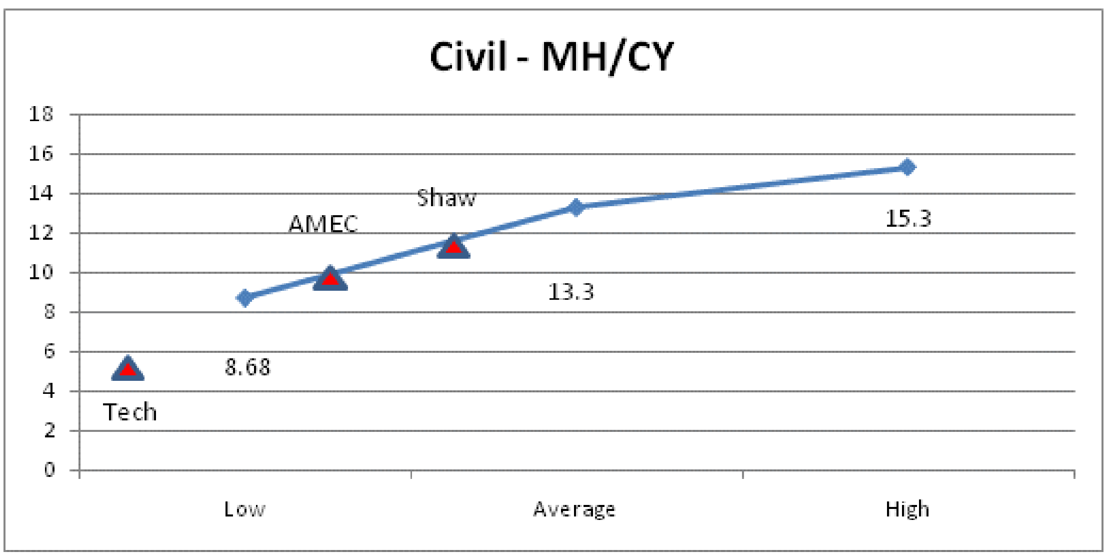


Figure 5. Civil/Concrete Man-Hour Estimate Comparisons

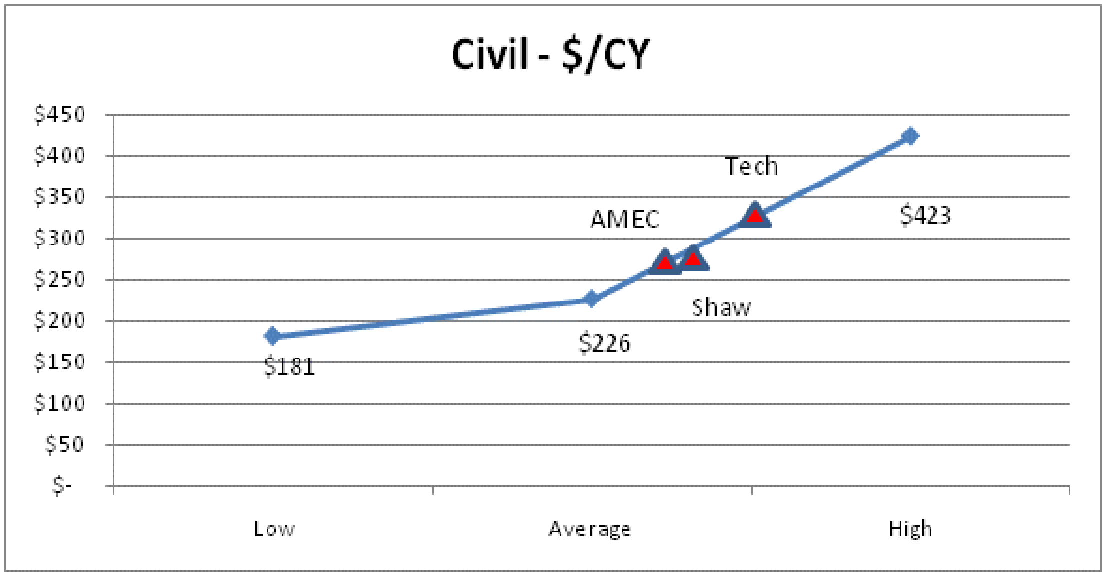


Figure 6. Civil/Concrete Cost Estimate Comparisons

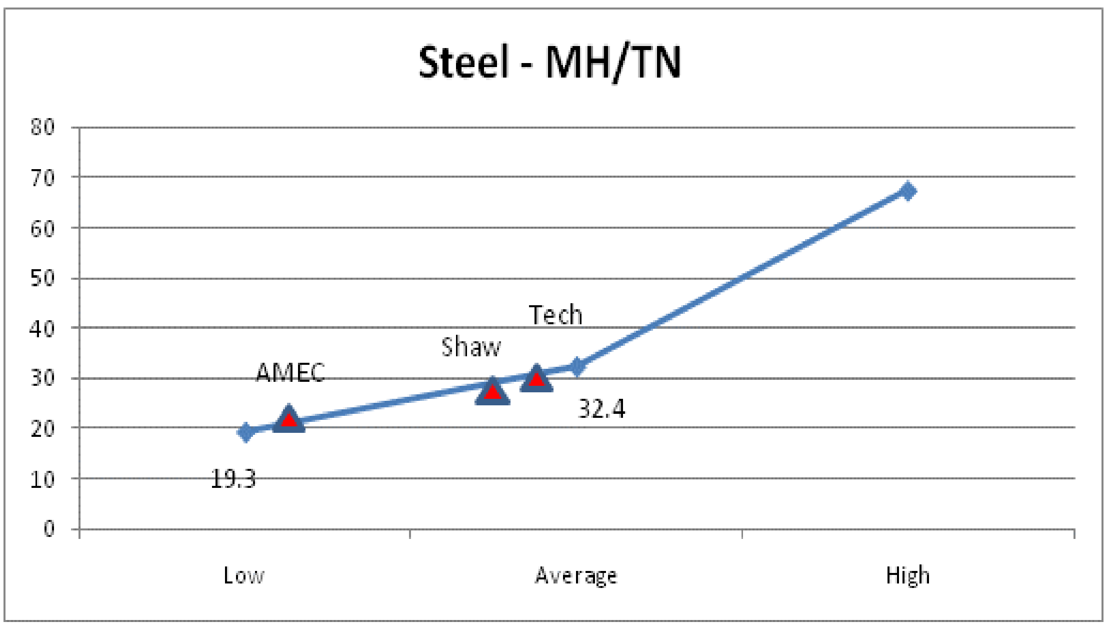


Figure 7. Steel Man-Hour Estimate Comparisons

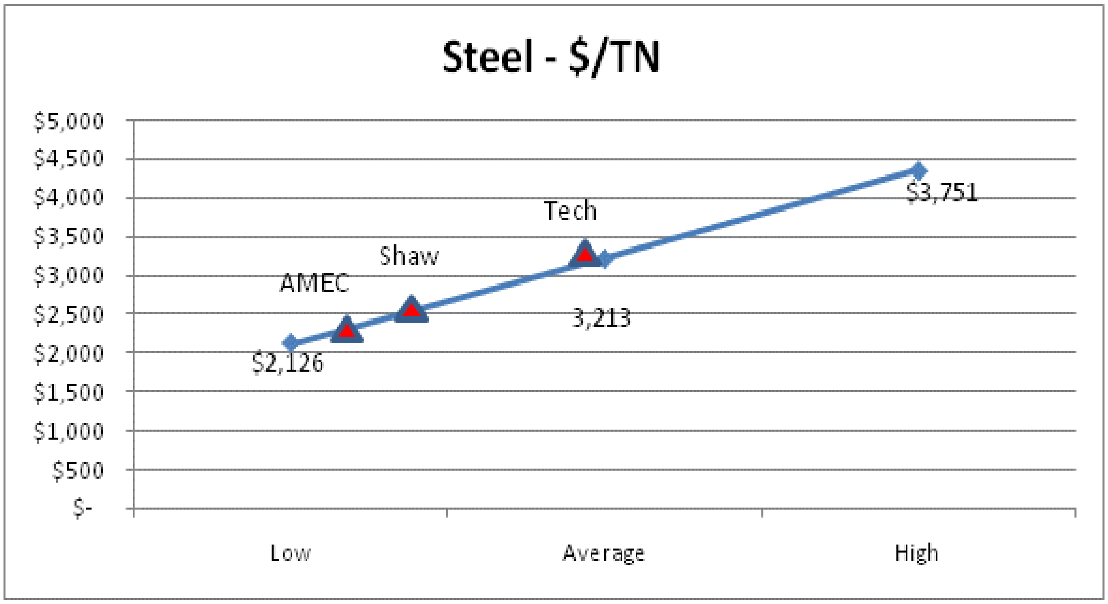


Figure 8. Steel Cost Estimate Comparisons

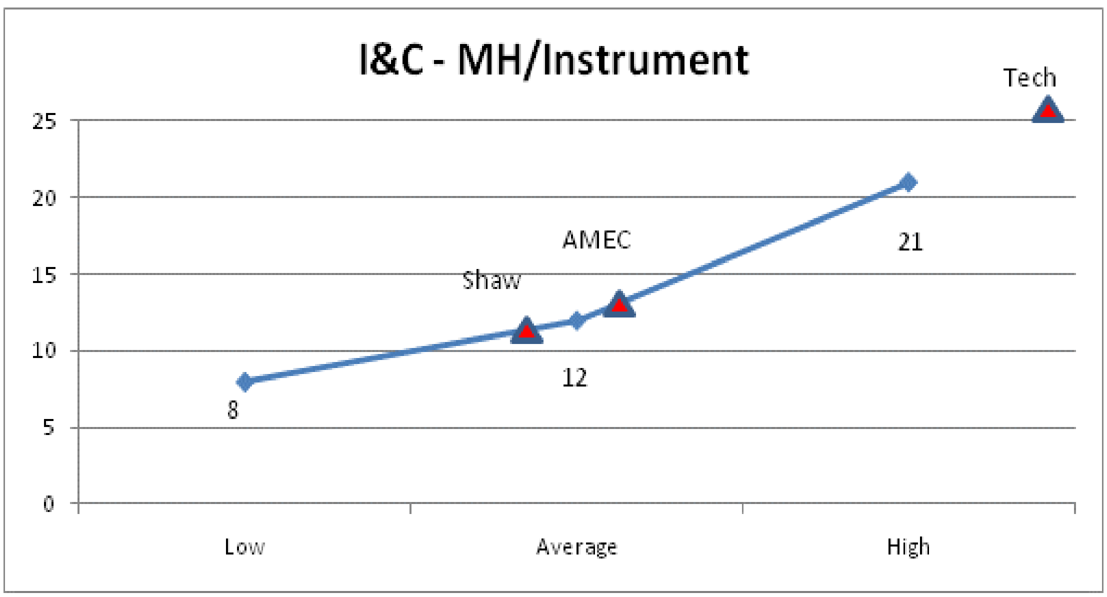


Figure 9. Instrumentation and Controls Man-Hour Estimate Comparisons

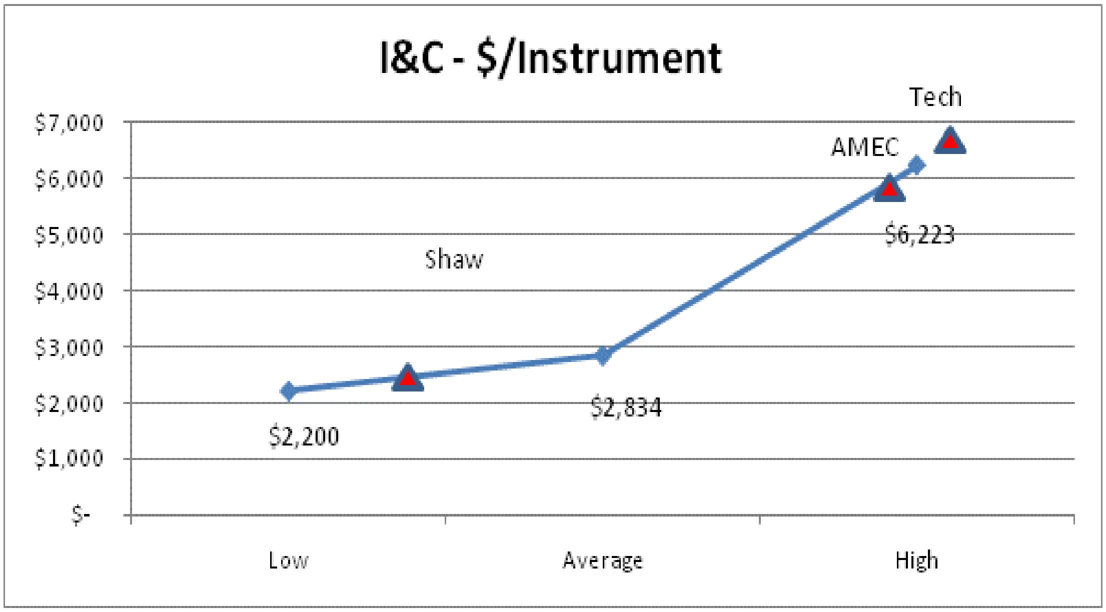


Figure 10. Instrumentation and Controls Cost Estimate Comparisons

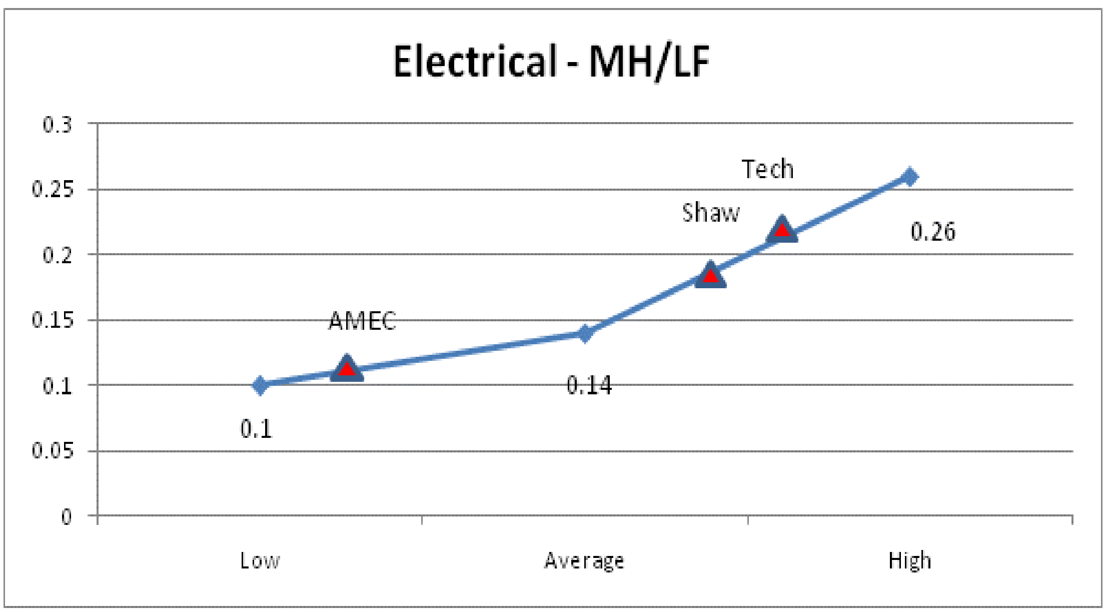


Figure 11. Electrical Man-Hour Estimate Comparisons

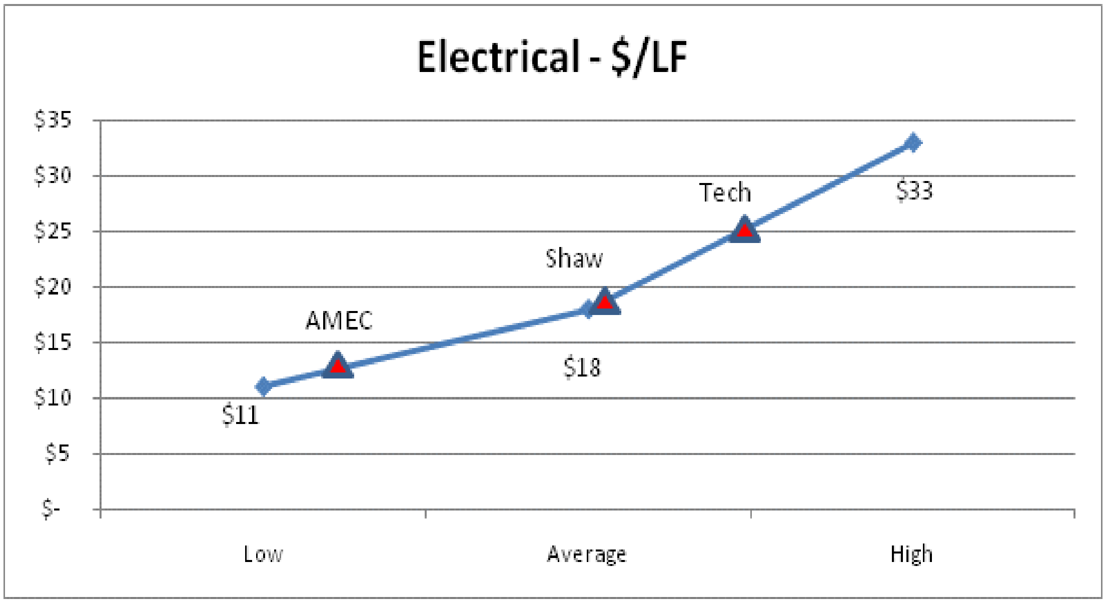


Figure 12. Electrical Cost Estimate Comparisons

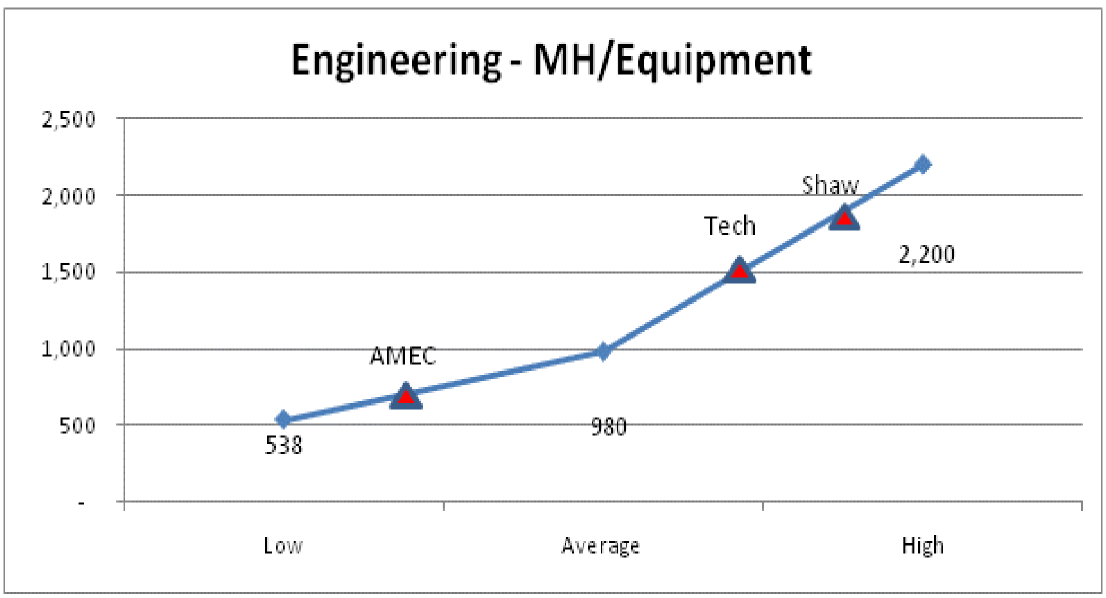


Figure 13. Engineering Man-Hour Estimate Comparisons

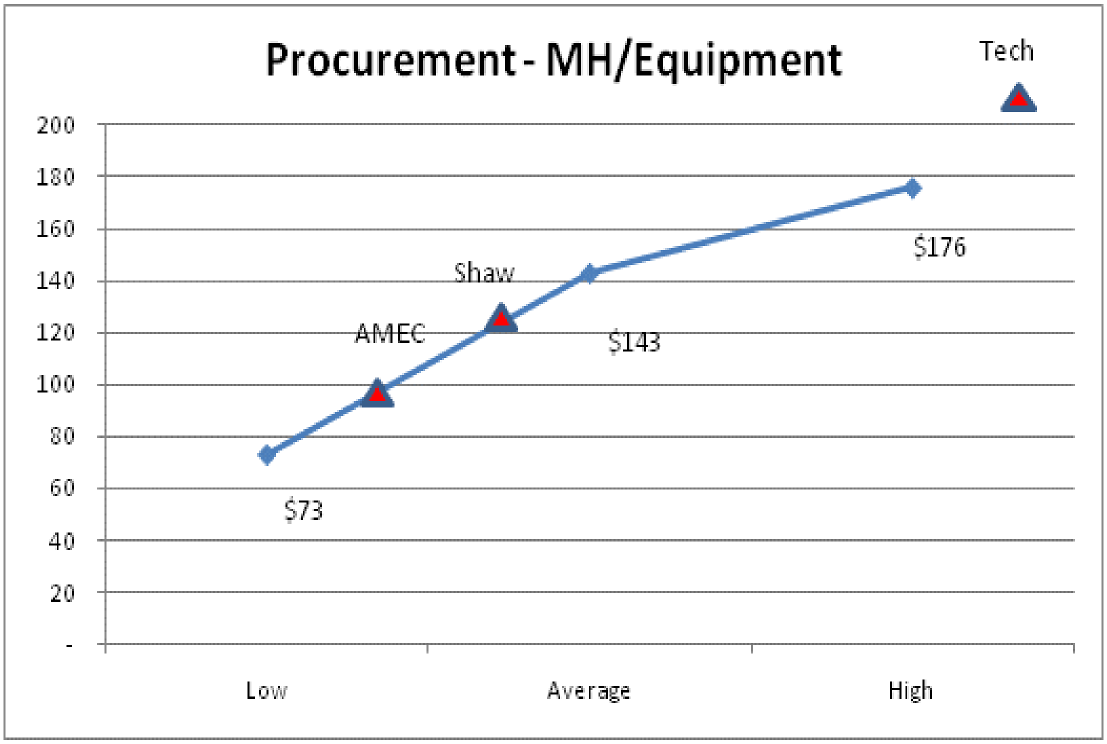


Figure 14. Procurement Man-Hour Estimate Comparisons

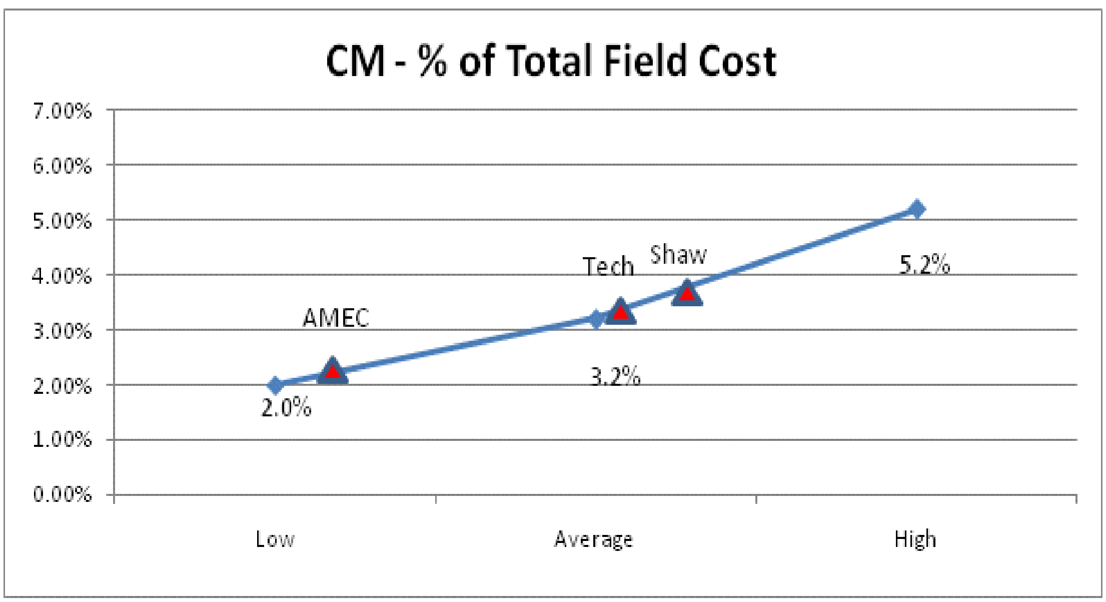


Figure 15. Construction Management Estimate Comparisons

Based on the results of this analysis, AMEC was selected as the EPC contractor for the project. Other considerations such as AMEC corporate culture, strong safety program, quality program, strong engineering and construction team, and good reputation with the emerging technology sectors made them a desirable choice to execute the warm syngas cleanup project. RTI selection basis was reviewed with DOE in November, 2011. DOE was in agreement with the selection of AMEC as providing the most value-added approach to executing the project, which allowed the project to move into the next phase.

From January, 2012 through July, 2012 the project scope changed significantly. During this time period, the CO_2 sequestration well was de-scoped from the project. The TEC well was issued a Class V UIC experimental permit in August, 2011; however, in December, 2011 EPA headquarters decided to reclassify the well as Class VI. The consequences of this decision are outlined below:

- Class VI designation transferred the primacy of the UIC permitting process to Federal EPA from FDEP. This would have resulted in schedule uncertainty since TEC would have to start the permitting process over and the Class VI permitting process was not well established during 2012.
- Class VI designation added additional requirements such as a 50 year monitoring period post-CO_2 injection and setting up a fund for financial assurance. These risks were not acceptable to TEC.
- The change in well class designation added cost uncertainty to the project, which was an unacceptable risk to both RTI and DOE.

TEC worked with EPA to get the well classification designated back to Class V based on the following arguments:

- Experimental Technology – TEC explained that the CO_2 injection well for the warm syngas cleanup project did not fall under Class VI regulations since it was a short term pre-commercial test project.
    - The project time frame was between 12 to 18 months
    - Small CO_2 volume – up to 300,000 tons
    - Primary long-term purpose of the well was for waste water injection.
- Class VI processing requirements conflicted with Warm Gas Cleanup project timeline.
- Class VI monitoring requirements exceeded the project timeline (i.e. exceeded the budget period).

However, EPA added extensive monitoring, verification, and accounting requirements (essentially mirroring Class VI MVA). These requirements added additional costs to the project and uncertainty to TEC beyond the project life. Therefore, RTI, DOE, and TEC decided to de-scope the CO_2 sequestration from the project. [NOTE: A significant amount of geologic site characterization data and sequestration modeling data was done for the intended CO_2 sequestration well and this data was submitted to DOE in a separate report as a contribution to cost share on the project.]

Based on the decision to remove CO_2 sequestration from the project, RTI worked with AMEC to update the cost estimate and schedule with the reduced scope. Once the cost estimate was updated, RTI submitted a continuation application seeking authorization to move into the next budget period, which would allow detailed engineering, procurement, and construction to start.

Teaming Agreements

As the prime sub-recipient to DOE for the 50 MW project, RTI had the responsibility to coordinate all essential contracts for successful execution of the project. The following list describes the contracts executed by RTI by company:

- BASF – in order to mitigate risk on the project, RTI decided to install a commercially available CO_2 capture technology. The BASF aMDEA® process was the technology of choice due to preferable capital and operating cost over other commercially available options. RTI signed a license agreement with BASF for the rights to use the aMDEA® technology and provide the project with an engineering package.
- Tampa Electric Company (TEC) – RTI signed an agreement with TEC to support the FEED effort and develop the air permit application and UIC well permit application. Finally, RTI signed a site access agreement with TEC to allow the construction and operation of the Warm Gas Cleanup process.
- Shaw – RTI signed an agreement with Shaw to execute the FEED package.
- AMEC – RTI negotiated and signed an agreement with AMEC to produce a shadow estimate and an EPC agreement.
- Technip – RTI negotiated and signed an agreement with Technip to produce a shadow estimate.
- CH2M Hill – RTI negotiated and signed an agreement with CH2M Hill to assist RTI as an owner's engineer.
- ECT – RTI signed an agreement with ECT to act as a consultant for Environmental Assessment. In order to execute this agreement a Three-Way NDA was required between ECT, RTI, and DOE/NETL.

Air Permit Application

In the state of Florida, an Air Permit is required to construct and operate a process plant. In order to construct and operate the Warm Gas Cleanup technology, TEC worked with RTI and Shaw to amend their air permit to account for the new emission points. The main items accounted for in the air permit application (see Appendix B) was the installation of a startup heater, a startup exhaust stack, and the routing of piping to TEC's flare. The air permit application was submitted in July, 2011. A signed permit was received in November, 2011 (see Appendix B). The state of Florida made the following regulatory classifications:

- The facility was not a major source of hazardous air pollutants (HAP).
- The facility operates units subject to the acid rain provisions of the Clean Air Act.
- The facility is a major stationary source in accordance with Rule 62-212.400, F.A.C. for the Prevention of Significant Deterioration (PSD) of Air Quality.
- The facility operates units subject to the New Source Performance Standards in part 60, Title 40 of the Code of Federal Regulations (CFR).

Environmental Assessment

The U.S. Department of Energy (DOE) provided $168.8 million of funding to RTI to design, procure, construct, commission, and operate a pre-commercial scale-up of RTI's Warm Gas Cleanup technology to remove sulfur constituents from syngas and capture CO_2. The funding was provided by the American Recovery and Reinvestment Act of 2009. In compliance with National Environmental Policy Act of 1969 (NEPA) (Title 42, Section 4321 et seq., United States Code) and DOE's NEPA implementing procedures (Chapter 10, Part 1021, Code of Federal Regulations), an Environmental Assessment (EA) was required to evaluate the potential environmental impacts of DOE's action to provide funding to RTI. The purpose of the EA was to provide DOE with information on the potential environmental consequences of the proposed project. The EA was required before funds to construct were released. DOE focused their attention on the following potential impacts:

- Air quality
- Geology and soils
- Water resources
- Socioeconomics
- Transportation
- Waste management
- Human health and safety

A signed Finding of No Significance (FONSI) from DOE was issued to RTI in October, 2011. Copies of the EA application and the signed FONSI can be found in Appendix C.

Project Execution Plan

During this phase of the project, a detailed project execution plan (PEP) was developed to ensure the scope was well documented and the appropriate roles and responsibilities were assigned. The PEP included information relating to project organization, execution strategy, communication management, project controls (i.e. change control, scope, schedule, and cost), environmental, health, and safety (EHS) management, procurement management, construction management, commissioning management, operating management, risk management, and closure management. The PEP included a detailed cost estimate, resource loaded schedule, work breakdown structure, and division of responsibility. Strict adherence to the PEP was critical to achieving the goals of the project. The PEP is included in Appendix D.

Risk Management Plan

During this phase, RTI initiated a detailed risk management program to help manage and mitigate risks encountered on this project. The risk management plan established the process for implementing proactive risk management as part of the overall project management. The purpose of the plan was to identify potential problems before they occurred. The Figure below summarizes the overall risk management program.

In March, 2011 RTI, TEC, Shaw, and CH2M Hill conducted a risk workshop to identify risks in the following areas – technical, health, safety, & environmental, operations, commercial/legal, project management, procurement, construction, cost, and quality. From that series of meetings, 132 risk items were identified and included in the risk register. The risks were assessed to determine the impact to the project. Additionally, mitigation plans to address each risk were developed. Ownership and due dates for the risk mitigation plans were assigned and included in the risk register. The project documented a total of 151 risk items. By the end of the project all but eight project risks were effectively mitigated and removed from the risk register. Table 3 below shows the final project statistics.

Table 3. Risk Management Process Statistics

					Risk Ranking		
Risk Category	**Total Count**	**Active**	**Retired**	**% Risk Retired**	**Monitor**	**Significant**	**Critical**
Technology	43	4	39	91%	4	0	0
Legal	18	1	17	94%	1	0	0
HSE	6	0	6	100%	0	0	0
Cost	2	0	2	100%	0	0	0
Procurement	24	0	24	100%	0	0	0
Operation	28	3	25	89%	3	0	0
Construction	20	0	20	100%	0	0	0
Project Management	9	0	9	100%	0	0	0
Quality	1	0	1	100%	0	0	0
Total	**151**	**8**	**143**	**95%**	**8**	**0**	**0**

Table 3 shows that none of the remaining risk items after construction were in the significant or critical category. The final remaining risks included items such as ARRA close out and reporting, unspared equipment preventing target availability, filters blinding over time, upset in process gas cooling (due to heat exchanger fouling) that prevents the removal of contaminants, and inability to determine erosion points.

The risk management plan was effective in identifying and mitigating a majority of the risks ahead of time, because:

- All safety targets were exceeded with no lost time accidents recorded.
- Quality targets were exceeded
- Project came in under budget
- Project came in on schedule

The risk management plan facilitated risk mitigation strategies to be developed with all stakeholders, effectively communicated to stakeholders the issues anticipated rather than risks incurred, and allowed the project to be proactive rather than reactive with respect to risk.

The detailed project risk register is shown in Appendix E.

Strategize	Identify	Assess	Respond	Monitor
Risk Strategy	Risk Identification	Risk Assessment	Risk Response Planning	Risk Monitoring
The process of deciding how to approach, plan and implement the risk management activities for a project or program.	The continuous process of risks inherent in a project or program.	The process of prioritizing and analyzing the likelihood and effect of risk upon the project or program objectives.	The process of identifying, evaluating, selecting and implementing action plans or techniques that will enhance opportunities and reduce threats to the project or program objectives.	The process of monitoring, updating and evaluating the effectiveness of risk response plans throughout the project or program life cycle.
• Evaluate Project Requirements • Review project objectives, success criteria, business strategy & scope • Identify, define & align all stakeholder expectations • Review project timeline & constraints • Create risk management plan for specific project/program	• Review project scope & plan documents • Determine risk identification techniques for specific task/phase • Determine participants required • Define sources & identify risks • Develop risk synopsis • Create risk register • Assign risk owners	• Define probability, manageability and impact criteria • Map risk data to project specific tasks and scope • Perform quantitative modeling, as required, of potential consequences (cost/schedule/HSE) • Determine risk ranking, priorities and treatment • Communicate major risks to stakeholders	• Evaluate major risk causes and effects • Develop risk response plan options • Evaluate risk response plans • Define risk triggers for the response plans • Assess secondary risks • Allocate responsibility and accountability • Implement and integrate risk response plans into project plans	• Review objectives, decisions & assumptions • Continuously review & update risk register • Define criteria and evaluate risk response plan effectiveness • Update risk response plans • Develop risk trend reports • Communicate status risks to stakeholders • Repeat Risk Management Proactive Actions

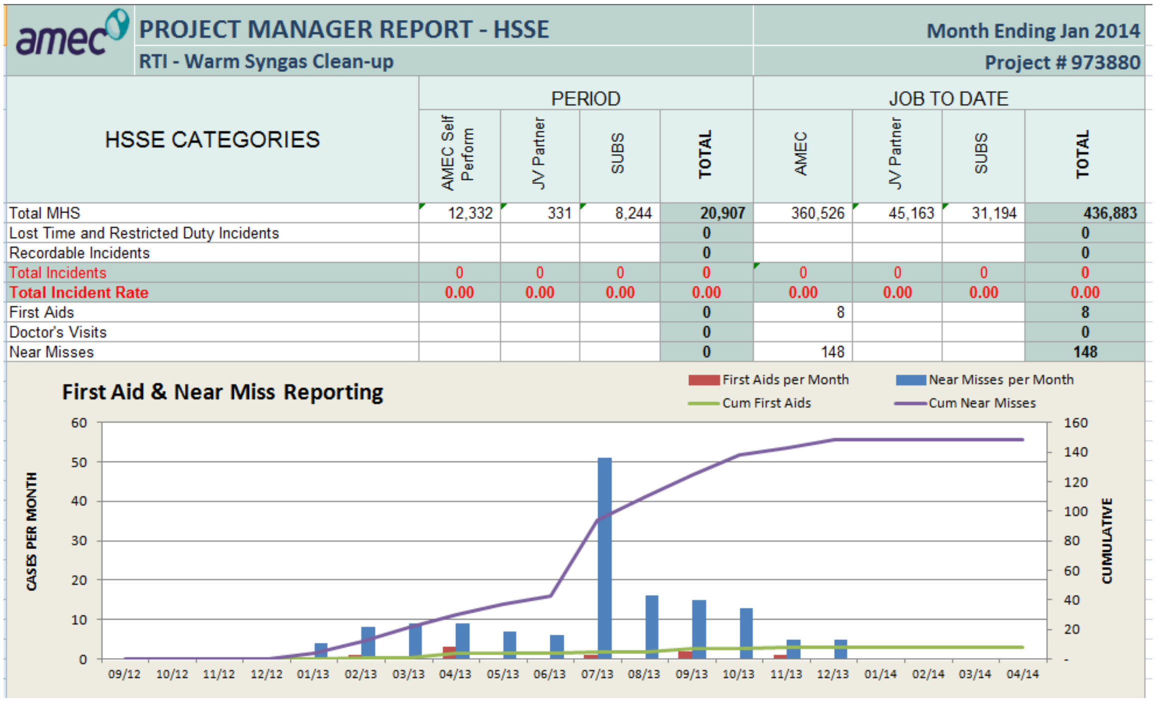
Table 4. Risk Management Program Summary

V. Engineering, Procurement, and Construction (EPC)

The EPC contract was structured, approved, and executed with a set of balanced incentives and penalties for safety, budget, schedule (including performance milestones), and quality. The maximum incentive was structured to achieve optimal results for each of these major factors and the lowest overall cost of construction (including incentive payments). The incentive/penalty structure of the EPC contract, coupled with rigorous project management and controls, resulted in mechanical completion of this project on schedule and under budget (by several million dollars), with no OSHA-recordable or lost-time accidents (and only eight total first-aid incidents) and < 1% required rework. Below is an overview of major activities during EPC.

Safety

During the construction phase of the project, AMEC's construction management team and field laborers had a high sense of awareness on safety. AMEC logged over 436,000 hours without a lost time accident or recordable incidents. This is due to the safety program implemented by AMEC to keep safety awareness in the minds of each person that comes onto site. The safety manager for AMEC did a good job performing audits on the job site. The table below shows the final safety statistics for the project. The safety metrics reported below in Figure 16 were a critical part of the project's success.



amec PROJECT MANAGER REPORT - HSSE								Month Ending Jan 2014
RTI - Warm Syngas Clean-up								Project # 973880
HSSE CATEGORIES	PERIOD				JOB TO DATE			
	AMEC Self Perform	JV Partner	SUBS	TOTAL	AMEC	JV Partner	SUBS	TOTAL
Total MHS	12,332	331	8,244	20,907	360,526	45,163	31,194	436,883
Lost Time and Restricted Duty Incidents				0				0
Recordable Incidents				0				0
Total Incidents	0	0	0	0	0	0	0	0
Total Incident Rate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
First Aids				0	8			8
Doctor's Visits				0				0
Near Misses				0	148			148

Figure 16. Project Construction Safety Metrics

Cost

An agreement to execute EPC between RTI and AMEC was signed in September, 2012. The contract structure between RTI and AMEC was a cost reimbursable with a fee at risk. The reimbursable cost contract value for engineering, procurement, and construction was $86,325,706. The final cost (i.e. reimbursable) for the EPC was $82,552,647, which was significantly under the original budget; therefore, AMEC received the maximum fee. The table below shows the cash spend during the time period of the EPC phase, which started in September, 2012 and ended with Mechanical Completion on January, 2014. Table 5 below shows the planned vs. actual cost.

Table 5. Planned vs. Actual EPC Costs and Earned Value

Year	Quarter	Planned Value	Cumulative Planned	Actual Value	Cumulative Actual	% Complete	Earned Value
2012	Q4	$ 4,483,280	$ 19,735,071	$ 4,194,486	$ 8,372,821	8.60%	$ 14,518,926
2013	Q1	$ 15,002,865	$ 34,737,936	$ 9,855,872	$ 18,228,693	20.60%	$ 34,777,891
	Q2	$ 28,628,648	$ 63,366,584	$ 20,038,851	$ 38,267,544	34.70%	$ 58,582,176
	Q3	$ 28,016,542	$ 91,383,126	$ 19,931,330	$ 58,198,874	45.30%	$ 76,477,596
	Q4	$ 17,464,483	$ 108,847,609	$ 21,079,454	$ 79,278,328	54.60%	$ 92,178,295
2014	Q1	$ 9,546,344	$ 118,393,953	$ 18,599,745	$ 97,878,073	64.40%	$ 108,723,117

The actual cost lagged the original baseline spend plan due to the following reasons:

- Schedule delay due to the reclassification of the deep injection well that was eventually de-scoped from the project,
- The project was under budget, and
- Delayed invoicing from contractors.

The lag in spending was not an issue for the project as the earned value exceeded the actual cost for each reporting period.

Schedule

Additionally, the project team did a good job managing the schedule throughout engineering, procurement, and construction phases of the project. RTI, AMEC, and TEC developed a resource loaded schedule in order to manage the project. This schedule had over 3,200 activities (NOTE: the resource loaded schedule was submitted to DOE each month for review). The project team updated the schedule on a weekly basis. This allowed the project management team to address and mitigate items that showed signs of slipping. This approach was successful in that the project achieved Mechanical Completion in January, 2014, which was on schedule. Figure 17 is a summary schedule that was derived from the resource loaded master schedule. From the summary schedule, it can be seen the project was able to achieve critical activities on schedule. This was due to the detailed planning and reporting throughout the life of the project.

Even though the project achieved schedule targets, a couple of items provided schedule challenges. These included:

- o DCS system was delayed due to an upgrade with the ABB system. TEC requested that the project use the same DCS system to facilitate seamless integration with their control system. At the time of the design, ABB initiated an upgrade to their control system, which caused challenges internally at ABB. The ABB design team was learning the new system at the same time as designing the control system. This learning curve resulted in a delay of the control system.

- Adsorber/Regenerator was delayed by several months due to poor management by the manufacturer. This required both RTI and AMEC to intervene and place full time oversight within the shop to prevent further schedule delay.

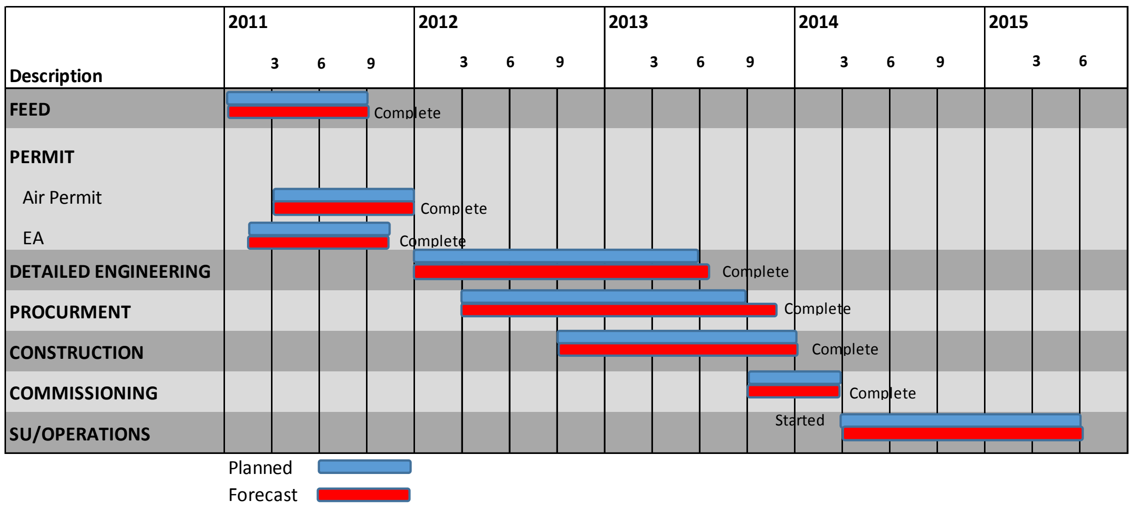


Figure 17. Summary Project Schedule

Quality

The quality on this job exceeded expectation in that the project experienced less than 1% rework. AMEC submitted their engineering, procurement, and construction quality plan to RTI, which was approved by RTI. RTI was responsible to audit the quality of the project. Below is a brief description of how RTI managed quality on the project:

- Engineering – RTI was integrally involved in the development of the process, which included the PFD/HMB, P&ID, and control narratives. Additionally, RTI reviewed the engineering specifications for all engineered equipment datasheets and control valves. RTI reviewed key process pipe design to ensure the design met process requirements. RTI conducted an audit with the AMEC audit team to ensure the design captured all the changes. The AMEC engineering team did an excellent job in ensuring engineering quality for the project.
- Procurement – RTI reviewed all the manufactured equipment purchase orders to ensure the specification met process requirements. Also, RTI and/or the owner's engineer participated in key shop visits to make sure the equipment was manufactured per engineering design.

- Construction – RTI was on site ensuring construction crews installed the plant per design. RTI, for example, reviewed concrete pour cards, ensured non-destructive examination was done per appropriate code, witnessed hydro tests, witnessed high-pot tests, and walked down each system with P&IDs.

EPC Project Success Factors

One of the key factors that led to the success of this first-of-a-kind project was the efforts made to ensure alignment of the project team. A list of actions taken to ensure this alignment from the beginning of the project included:

- The owner understood the EPC contractor's culture to make sure they were a good fit for a first-of-a-kind project.
- Since cost control was important, use of a cost-reimbursable fee-at-risk EPC contract was a better approach than lump-sum turnkey.
- The EPC contract was structured with balanced incentives and penalties for schedule, budget, safety, and quality. The maximum incentive was structured to achieve optimal results for each of these major factors.
- The commercial terms were clearly expressed and agreed upon with the contractor before the FEED estimate was produced.
- Each stakeholder's expectations were identified and documented since misalignment would be detrimental or at least delay/stall the project.
- All stakeholders were aware of the contracting strategy before negotiations with the EPC contractor began. This could have caused delays when/if one of the stakeholders took issue with the contract terms. The project execution plan was well-defined with a staged-gate process that had clear criteria for making go/no-go decisions.
- The scope was well defined and locked before moving forward with EPC.
- A detailed risk management program was instituted that was proactive rather than reactive with respect to dealing with risk.
- A resource-loaded schedule (at least to the fourth level) was developed with the project team.
- A detailed cost estimate prepared the EPC contractor was reviewed and approved based on the ability to adequately provide the resources required to complete the resource-loaded schedule in a timely and cost effective manner.

To maintain this strong alignment within the project team, effective coordination and communication were required. Key items that contributed to maintaining this coordination and communication were:

- Assembled teams that took into consideration "who" was best qualified to accomplish each task. This included using external experts to augment the project team's expertise where necessary.
- Developed and regularly audited a detailed project execution plan that included the following sub-plans: project control, legal/commercial, engineering, permit, safety, procurement, quality, construction, and commission.
- Selected an EPC contractor that had relevant experience. For this project AMEC was selected due to their experience in the emerging technology space, great safety record, high quality standard, self-perform execution strategy, and ability to work well with small companies.
- Required the master schedule be maintained and reviewed weekly with the project team by the owner. Only after approval in the weekly meeting were contractors allowed to modify/update the owner's matter schedule.
- Reported the project status and challenges regularly and frequently to the project stakeholders.
- Reviewed the risk register on a weekly basis with the project team.

One final element that proved important in this first-of-a-kind project was ensuring that the process design was also suitably designed to support startup of the process.

VI. Commissioning

RTI was responsible for the commissioning phase of the project. RTI assembled a team of engineers, operators, and maintenance personnel from AMEC, RTI, and TEC to help with the commissioning of the process. Commissioning started in the fall of 2013 as portions or blocks of the construction were turned over and ended in March of 2014. Below is a list of commissioning activities completed. The commissioning activities included:

- Verified the process was installed per drawings by comparing the as-built P&IDs with the actual installed equipment during system walk downs
- Verified that punch-list items were completed by construction
- Witnessed hydro-tests
- Reviewed and signed turnover books
- Witnessed Meggar tests
- Functionally checked all instrumentation loops
- Bumped motors
- Started equipment and tuned loops with inert fluids
- Transitioned to hot startup

VII. Operations

Operations officially started in April, 2014. RTI was responsible for organizing the operations team and overseeing the day-to-day operations. The RTI operations team was comprised of engineers and chemists from RTI, operators from TEC, and engineers and maintenance support from AMEC. The initial objective for the operations phase of this project was to achieve up to 5,000 or more hours of syngas operations in order to determine the performance of the RTI-3 sorbent and begin validating RAM assumptions.

At the close of this project in September, 2015, approximately 1,500 hours of total syngas operation were achieved on the RTI-3 sorbent. This was less than the targeted hours of operation. The primary reason for this shortfall was the unavailability of syngas from TEC when the 50 MW pre-commercial unit was available for operation. Based on TEC's historical performance, they achieve an average availability of > 70%. However, TEC's available during the last year of operation for this project (2015) was very poor. Due to problems in restarting after their annual spring outage, TEC was unable to supply syngas to the 50 MW pre-commercial unit from early March 2015 to the last day in July 2015. The extension of TEC's outage past the planned schedule resulted in the loss of about 2,400 hours of syngas availability for operation of the 50-MW warm syngas cleanup pre-commercial unit. Other TEC unplanned outages during the operation phase of this project decreased potential operating time by about another 1,000 hours.

In spite of the challenges in accumulating total operating hours, the operational phase of this project has been very successful in its primary goal of reducing the technical risk associated with commercial deployment of WDP. These success include:

- The demonstration that commercially available knowledge and operating expertise for transport reactor systems from fluid catalytic crackers can be effectively leveraged for WDP and essentially eliminate technical risks associated with commercial deployment of WDP.
- Stable and continuous desulfurization can be achieved in just two reactors using near commercial scale equipment.
- The use of diesel to assist in lighting of the regeneration reaction can be successfully and reliably accomplished at near commercial-scale.
- The desulfurization sorbent, RTI-3, has consistently demonstrated the ability to remove over 99.9% of the both the H_2S and COS from syngas even after the abuse from repeated startups, operations and forced

shutdowns. The 50-MW WDP testing has also demonstrated that attrition resistance of the sorbent actually improves with use and that sorbent losses of substantially below the design of 1% of sorbent inventory per day have been achieved. Sorbent capacity was also demonstrated to be stable, showing no significant loss in sulfur capacity across the 1,500 hours of completed operations.

- Stable, continuous desulfurization of syngas with an availability of > 80% for WDP and a total of about 1,500 hours of operation.
- The aMDEA® system when coupled with WDP is able to enable highly selective removal of both the sulfur and CO_2 achieving greater than 99.99% sulfur removal and 98% CO_2 removal.
- Coupling of the WDP, WGS, and aMDEA® can effectively generate a H_2-rich syngas stream.

Below is a discussion of the operational phase of the project, which includes a discussion of safety, operation summary, management of change, and performance analysis.

Operation Safety

As the project transitioned to operations, RTI instituted a safety management program that attempted to ensure safety procedures were rigorously implemented. Table 6 below shows the final safety metrics for the operation and maintenance phase of this project.

Table 6. Project Operations and Maintenance Safety Metrics

Month	Total Man-hours	Cumulative Hours	Lost Time	Total Incidents	First Aids
APR, 2014	4,750	4,750	0	0	0
MAY, 2014	5,741	10,491	0	0	0
JUN, 2014	6,457	16,948	0	0	0
JUL, 2014	5,643	22,591	0	0	0
AUG, 2014	7,021	29,612	0	0	0
SEP, 2014	7,037	36,649	0	0	0
OCT, 2014	0	36,649	0	0	0
NOV, 2014	7,669	44,318	0	0	0
DEC, 2014	6,699	51,017	0	0	0
JAN, 2015	7,960	58,977	0	0	0
FEB, 2015	8,905	67,882	0	0	0
MAR, 2015	11,015	78,897	0	0	0
APR, 2015	1,400	80,297	0	0	0

MAY, 2015	7,680	87,977	0	0	0
JUN, 2015	6,953	94,930	0	0	0
JUL, 2015	7,422	102,352	0	0	0
AUG, 2015	6,499	108,851	0	0	0
SEP, 2015	6,573	115,424	0	0	0

Over 115,000 total operations and maintenance hours were logged without any lost time accidents or first aid incidents. There were, however, six near misses reported through the operations period. These included:

- Batteries were found dead in some of the personal gas monitors. This issue was addressed during the shift turnover meetings to ensure a heightened awareness of this issue.
- Personnel were identified in the process area without gloves when performing work that requires hand protection. This issue was addressed during the shift turnover meetings to ensure a heightened awareness of this issue.
- Dust masks were not worn when handling sorbent. Each employee was trained on the hazards of dust exposure. Additionally, each employee was fit tested for a respirator.
- System was not adequately vented before maintenance attempted to break into a system. The line procedures were reviewed and additional training provided to the operations team.
- Syngas leak from E-110 flange. This gasket was replaced.
- Air compressor oil fire happened while air compressor vendor was on site tuning the compressor. It was determined that the oil coalescer was not properly grounded. Modifications were made to the filter to provide proper grounding to prevent this incident from occurring again.

Operation Summary

The operations phase of this project extended from April, 2014 through September, 2015. The overall plan for operation was to start RTI's WDP system, achieve stable operation and sequentially tie in the activated amine (aMDEA®) process for CO_2 capture system and finally the water gas shift (WGS) system and then continue to operate for between 3,000 and 5,000 hours. At the end of this project, the total operating times were 1,500 hours for the WDP system, 370 hours for WDP and aMDEA® systems, and 35 hours for the WDP, WGS, and aMDEA® systems.

As mentioned previously, the lower than average availability of syngas from TEC's gasifier during the operations phase of this project severely reduced the potential operating time for the 50 MW pre-commercial unit. The other factor affecting the ability to operate was the availability of the 50 MW pre-commercial system. Because the 50 MW pre-commercial unit was both a first-of-a-kind unit and a newly constructed unit, the plan was for availability to start relatively low and steadily increase to achieve a goal of over 90%.

As one of the primary goals for this project was to reduce the risk associated with operation of a commercial system, the knowledge gained during the optimization of the pre-commercial unit's availability was critical. Although our intention was to demonstrate achieving this goal through accumulating operational hours with high availability, the actual result was more the accumulation of knowledge from finding the solutions to achieving higher availability. One of the most trying challenges of this learning process was the lessons that were associated with the selection of materials of construction, particularly related to heat exchangers, which only became apparent after accumulation of sufficient operating time. Another challenge was related to the selection of vendors of commercially-available equipment and learnings regarding the reliability of their equipment in field use. Interestingly, the actual WDP adsorber and regenerator (the true first-of-a-kind design and equipment portion of the pre-commercial unit) had relatively few reliability and availability problems, which is very encouraging. The consequence of these challenges is that although the number of issues decreased as more operating experience was gained and these challenges were addressed one-by-one, the time required for fixing issues reduced potential operating time. A list of the major challenges and solutions for the key systems with which we had struggles is provided in Table 7 below. The implementation of the solutions described in this table has not only successfully resulted in increased system availability, it has also identified solutions to many of the technical risks associated with future commercial deployment of this technology. Other more minor changes that have been implemented were effectively collected through management of change documentation described in the next section.

A key observation about the operational challenges described in Table 7 is that all of these systems are auxiliary systems to RTI's WDP. Furthermore, some of these systems were specifically required to permit integration of the 50 MW_e pre-commercial unit into TEC's existing IGCC system and might not be necessary in future commercial WDP units. The absence of major operational challenges associated with critical components in RTI's WDP reactor system and sorbent is one of the crowning achievements of this project.

Table 7. A List of Operational Challenges and Solutions Associated with Key Systems in the 50 MW_e Pre-Commercial Unit

System	Operational Challenge	Solution
DCS control system	A newly released version of control software, for which even the vendor's operation support was inadequately trained, was applied to a first-of-a-kind unit	A team of experts, chosen by demonstrated ability with the new software to get the programming done and expertise with the actual control hardware, was assembled to troubleshoot and fix the original control system provided by the vendor. This team's leader was also persuaded to remain with the project and lead the modification and improvement of the control system during operation.
Syngas Compressor (C-150)	Effectively starting and maintaining continuous operation	The solution comprised working with the compressor vendor to ensure proper interfacing of utilities and the compressor, modification and tuning of the control logic for both nitrogen and syngas operation, additional training of the operators on compressor start up; operation; and maintenance, and modification of operational procedures for the compressor.
Air compressor (C-120)	Effectively starting, maintaining continuous operation, and achieving the design flow rate of air	The solution consisted of working with the compressor manufacturer to optimize the control logic, set up of the subsystems equipment, and tuning of key operational parameters. In addition, the system was equipped with an inter-stage chiller to generate a significantly drier product air stream.
Regeneration off gas compressor (C-121)	Larger than anticipated pressure drops and competition with the air compressor system limited the actual compressor output.	Working with the compressor vendor, no long-term equipment solution short of replacing the compressor could be identified. Operational modifications were successfully enacted that enabled startup and normal operation of the regenerator effectively using C-121 and making the most of its operational constraints in the 50 MW pre-commercial unit.
Filter elements	Mechanical failure of the filter elements allowed the transfer of sorbent material into downstream systems	The vendor was able to link the failure of the filter elements to a specific set of filter elements in their production process. A new set and replacement set of filters were manufactured without this defect. In addition, plugs, which effectively blind off a filter upon failure of the filter element, were installed in all the new filters.
Activated amine system	The decision to proactively commission this system and	The full pre-cleaning process had to be fully repeated to permit startup of the activated amine unit after sitting idle for a number of months.

	complete the required pre-cleaning steps in December 2013 and January 2014 and eventually attempt to start the unit in December 2014 were ineffective. The operation and maintenance of the continuous anti-foaming addition system did not meet the necessary addition rate causing operational upsets.	Modifications of the continuous anti-foaming agent addition system were made to address the technical challenges of the low flow rate and the challenging physical properties of the anti-foaming agent, which included high viscosity and poor solubility in the amine solution. These were effectively linked with target changes in multiple operating variables. The operators and engineers were also trained to recognize and effectively respond to these target changes. Finally, an emergency dosing system for the anti-foaming agent was also installed to permit rapid recovery from failure or reduced flow of the continuous addition system.
Heat exchangers for cooling of regeneration off gas (E-120 and E-121)	A combination of high temperature, corrosion associated with high moisture in the humid air intake, and exchanger design based on thin tubes resulted in premature failure of these heat exchangers	New heat exchangers were built based on a new design with thicker exchanger tubes. In addition, an inter-stage cooler was installed on the air compressor to significantly reduce the water concentration in the product air.
Syngas interchanger (E-110)	Corrosion of the heat exchanger tubes significantly reduced the tube thickness near the outlet of the hot and dirty (high sulfur) syngas which resulted in mechanical failure of this exchanger.	This exchanger was rebuilt with new exchanger tubes based on a different material of construction. This material selection was vetted with multiple experts and actual operation data for similar tubes successfully used for heating the dirty syngas after the syngas interchanger in an existing unit at TEC.

Prior to this testing at pre-commercial scale, many design aspects of the transport reactor design for operation of RTI's WDP were based on the ability to effectively leverage commercial knowledge of the transport reactor systems used for commercial fluid catalytic crackers (FCCs). This commercial knowledge consisted of design knowledge pertaining to the sizing and layout for the adsorber and regenerator transport reactors, the standpipes, and cyclones. This design knowledge also included materials of construction relating to the pressure vessel, refractory and insulation. The successful operation of the WDP system has shown that commercial knowledge for transport reactor systems can be effectively leveraged. The breadth of commercial knowledge on transport reactor systems and sizes of operating commercial units significantly reduces the technical risk associated with design and operation of a future commercial WDP unit.

Finally, the RTI-3 sorbent has demonstrated an extremely robust performance in spite of the harsh and demanding conditions to which it was subjected during startup, operation, and forced shutdown of the system throughout the operational phase of this project. One of the key technical features of the WDP to be demonstrated in this project was the light off of the regeneration reaction with diesel. Although simulated testing was performed in the laboratory, the 50 MW pre-commercial testing was the first opportunity where actual diesel was used to light off the regeneration reaction. No detectable impact on sorbent performance has been identified that is linked with the use of diesel for lighting off the regeneration reaction. In addition, the attrition losses for the commercially produced sorbent have been substantially better than the design expectations, which will significantly reduce OPEX costs associated for the sorbent replacement and make this technology even more attractive economically.

A list of specific issues and actions taken on a weekly and quarterly basis during operations from April, 2014 through September, 2015 are attached in Appendix F.

Management of Change

For the operations of the project, RTI implemented a management of change (MOC) program to track changes to the process. Table 8 outlines the tracked changes made to the process. These changes included hardware changes in the field and/or software changes in the DCS and ESD. During the operation period, 55 MOC's were implemented.

Table 8. Management of Change Process – Approved Changes

ID	Description
1	Change PV-540 fail safe position
2	Relocate minimum flow recirculation line
3	Add 2 inch line from P-508 to P-501
4	Add 4 inch check valve to line AML1-5J10
5	Add nitrogen purge to line USY7-1D)5
6	Change fail safe position for XV-552, FV-565, PV-570

7	Move pressure tap for PDV590 and 593
8	Change logic for MOV-514 A/B and 515
9	Change FC-501 permissive value
10	Add linear purge line
11	Add fuel oil recirculation line to calibrate fuel oil pump
12	Modify syngas purge line to reduce nitrogen flow
13	Revise minimum flow ESD on FV-501
14	Remove latching solenoid from FV-501
15	Add 10 second delay to DP across LV-567
16	Changed the differential pressure trip point from 0 psid to -5 psid
17	Add manual block valve on SO2 line to sulfuric acid plant
18	Add bypass control valve FCV-578B in parallel to FCV-578A
19	Add “OR” block in DCS logic for “either/or” C-121 or C-130 permissive
20	Modified the sorbent sampling system
21	Changed fuel oil pipe size
22	C-120 Start/Stop logic change to “Enable” and “Stop” in DCS
23	Added continuous bypass around the REV-111 foot valve
24	Logic enhancement for PV-570 to filter out Pall filter system back-pulses
25	Logic enhancement to the fuel oil air controller FIC-510
26	Reset the low trip in ESD-103 to -10 psid
27	Remove DCS interlock 1-USY-FIC-501P
28	Change DP across 1TSY-MOV-566 from 15 psid to 5 psid
29	Rescale the DCS analog output range to 0-100
30	Change the range on 1USY-PDT-509 to -50 to 325 psid
31	ESD logic modified to remove the permissive that C-150 must be running to open 1TSY-MOV-566
32	Modify C-120 trip logic to slowly close FV-510
33	Utilize ROG recycle gas to cool regenerator off gas
34	Change logic in fines removal system to prevent both lock valves from opening at the same time
35	Adjust the interlocks in ESD so that USY-FV-501 can only operate when USY-MOV-514A/B are proven closed
36	Nitrogen low flow interlock bypass switch added, which enables operations to prevent nitrogen valves from overriding their current position during a low flow condition
37	Changed C-150 trip logic and enable logic
38	Move ESD interlocks to DCS slowly close SAH-FV-510 to prevent C-120 shutdown
39	Operating HTDP Regen System w/o C-121 ROG Recycle Compressor
40	Add insert into bottom nozzle of REV-120 to direct nitrogen fluidization
41	Replace shell and tube heat exchanger E-120 & E-121 with pipe in pipe exchanger
42	Air nozzles 1BH & 1BJ on REV-120 changed from air injection to spare fuel nozzles
43	Move LH-121 SO2 vent line from D-113 to SO2 Stack
44	Emergency N2 supply from D-920 tied to Regen air header to FV-521 and FV-524
45	Add chiller to C-120 inter-stage cooler to remove 95% of water from air
46	USY-PV-547 and HTR-PV-524 interlock changes to prevent accidental operation
47	TSY-XV-552, ESD-401 increase time open to 120 minutes
48	Modifications and additions to PDT’s on Adsorber/Regenerator Vessels
49	Logic added to allow automatic selection of pressure transmitter used in Flare Pressure Controller
50	E-121 heat exchanger ROG Temp Controller 1SMPTIC507 to adequately control the temperature in HE, two TT are used in high select controller configuration
51	USY-LV-567 add 10 sec delay to level USY-PDT-567 low level trip
52	Added Amine Adsorber syngas inlet & outlet valves pressure differential interlock between TSY-XV-568 inlet valve and TSY-XV-582 outlet valve
53	Modify AML-LI-577 Low-Low-Level Trip

54	Logic changes for process condensate system to allow D-110, D-130, D-152, and D-510 to drain to CSY-P-500 and then through CYS-FV-516 out to the TEC process condensate header. Condensate sources no longer drain to package 610 waste water system and the CRR header
55	MPN-XV-561 and MPN-XV-564 low HPN header trip logic changes

Process Sampling and Analytical Methods

To properly control the pre-commercial warm syngas cleaning process units and understand their performance, it was critical to have rapid and accurate data analysis of key process streams. This was accomplished by installing a purged and pressurized process analytical shelter at the project site to house various process analyzers, such as process gas chromatographs, that were used for analysis of process streams. Process sample probes were installed at appropriate process locations and the sampled gas were conditioned and transported via tubing to the process analytical equipment shelter where these sample streams were analyzed at a specified frequency. Analytical results were uploaded to the project data collection system and DCS control system for access by the operators and engineers and for process control. Periodically, solid sorbent samples were manually taken and then analyzed for sulfur loading with equipment located in the TEC's analytical laboratory. Amine solution samples were also periodically collected and analyzed for amine concentration and foaming levels to assist in the operation of the aMDEA® system. A detailed description of the various process sampling and analytical methods is attached in Appendix G.

Performance Analysis

If the original operating plans had been implemented, performance data would have been available for the fully integrated 50 MW_e pre-commercial unit. Unfortunately, this type of performance data is not available for this project because TEC's extended outage from March 2015 to July 2015 prohibited operation of the 50 MW_e pre-commercial unit when solutions to over 90% of the operational challenges had been effectively implemented and fully integrated operation was planned. Consequently, the performance data described in this section pulls together the best available performance data from the entire operating phase. This performance data has been organized by system in the following sections.

i. WDP [Area 100]

The primary performance data for WDP was taken from operation during January 2015. This period was selected because it represents the longest period of continuous operation and it achieved an availability for the entire WDP block of about 84% for about a month. The one upset that occurred during this timeframe was the loss of regeneration reaction requiring the regeneration reaction to be restarted with diesel combustion. This was also the first time WDP operation was intentionally stopped. The system was shut down because of suspicions that the regenerator filters were damaged and sorbent was being allowed to pass through the filter. The analysis of the regenerator filter after this shutdown showed that no filter element had failed and that all the filter plugs were intact and operational. Thus, there was no technical reason the run could not have continued well past this intentional shutdown.

For reactors, one of the most effective means of demonstrating stable operation is by the temperature profile across the reactor. Figures 18 and 19 show the temperature profiles for the WDP adsorber and regenerator during operation in January 2015. Figures 18 and 19 show that except for early January, when the system was down because of loss of reaction in the regenerator, the temperature profiles in the reactor were stable both as a function of time and position in the reactor. In addition, Figures 18 and 19 show that stable operation of the adsorber and regenerator was achieved soon after the startup sequence was completed. The stability and rapid startup for WDP demonstrated at this pre-commercial scale, which uses the same equipment that will be used in a commercial system, implies that the same performance can also be achieved in a commercial system.

As the primary function of WDP is sulfur removal, Figure 20 shows the sulfur removal for both H_2S and COS. These results demonstrate that the RTI-3 sorbent selectively and consistently removes ~ 99.9% of both H_2S and COS from the syngas. The consistency of the temperature and the sulfur removal profiles shows that sorbent is able to repetitively be used to remove H_2S and COS from syngas followed by regeneration to remove this sulfur as SO_2 with no visible deactivation of the sorbent. In addition, it demonstrates that by maintaining a stable set of operating conditions, stable sorbent circulation allows simultaneous and continuous sulfur removal and regeneration of the sorbent in just two reactor vessels. As one of the key means of deactivation of the sorbent is through the formation of sulfates, several samples of sorbent taken from WDP were analyzed. The results from this analysis are shown in Table 9. These results show no evidence of sorbent deactivation via sulfate formation.

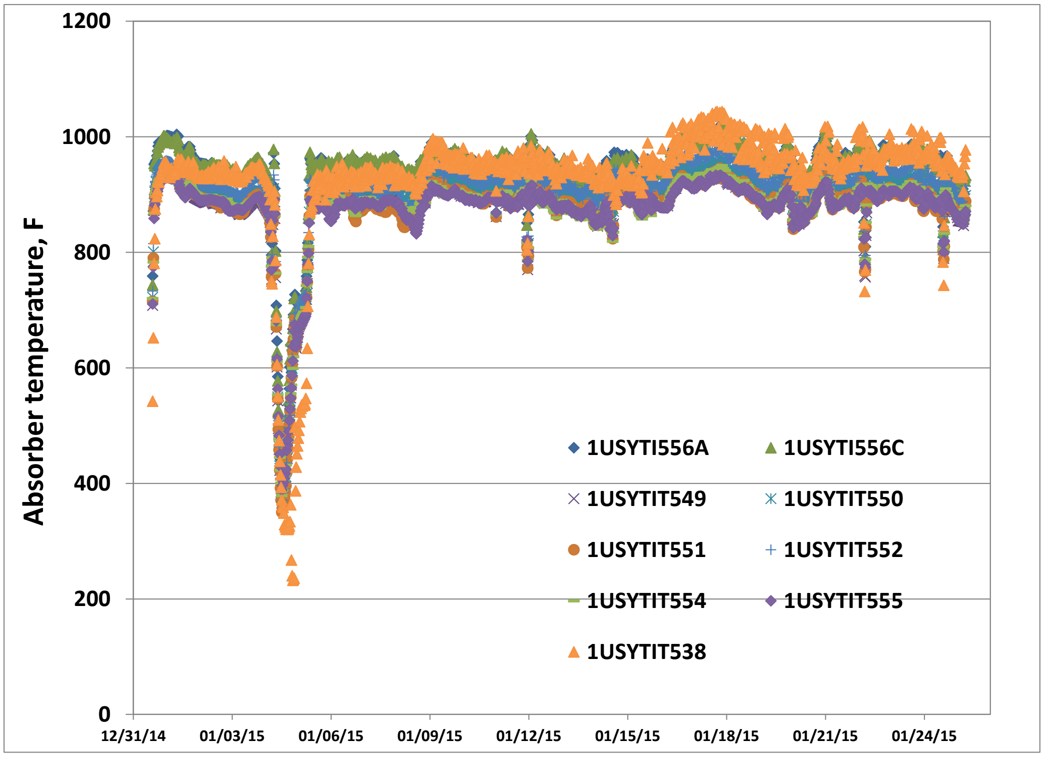


Figure 18. Temperature Profiles in the Adsorber for January 2015

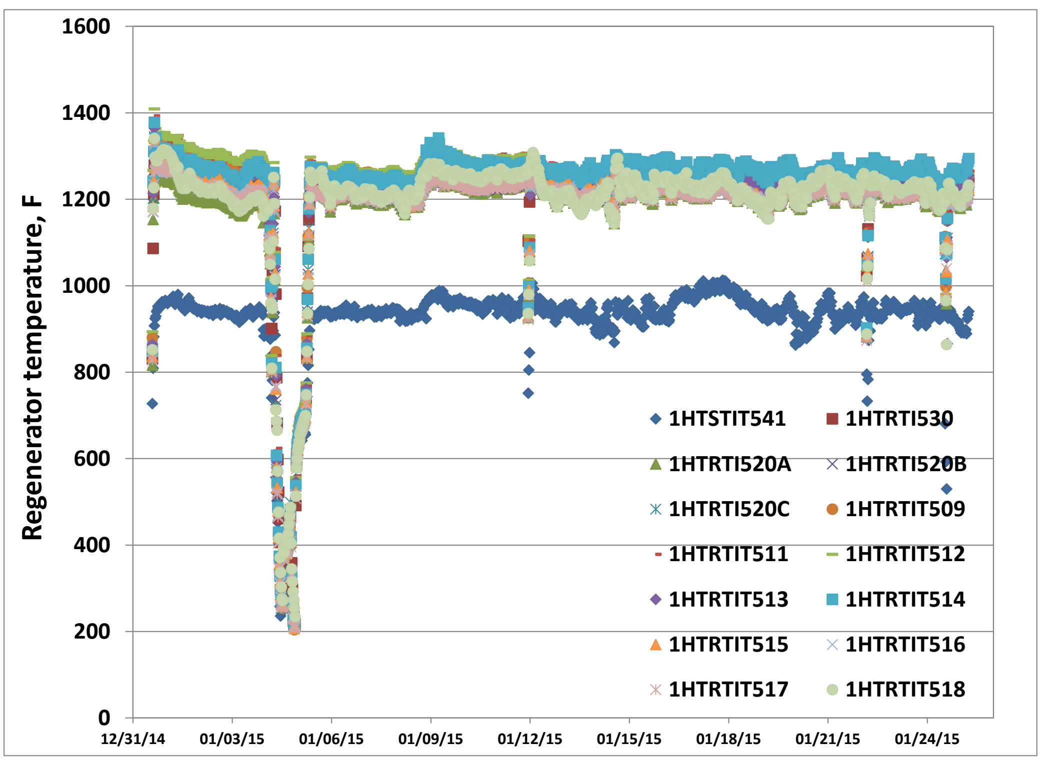


Figure 19. Temperature Profiles in the Regenerator for January 2015

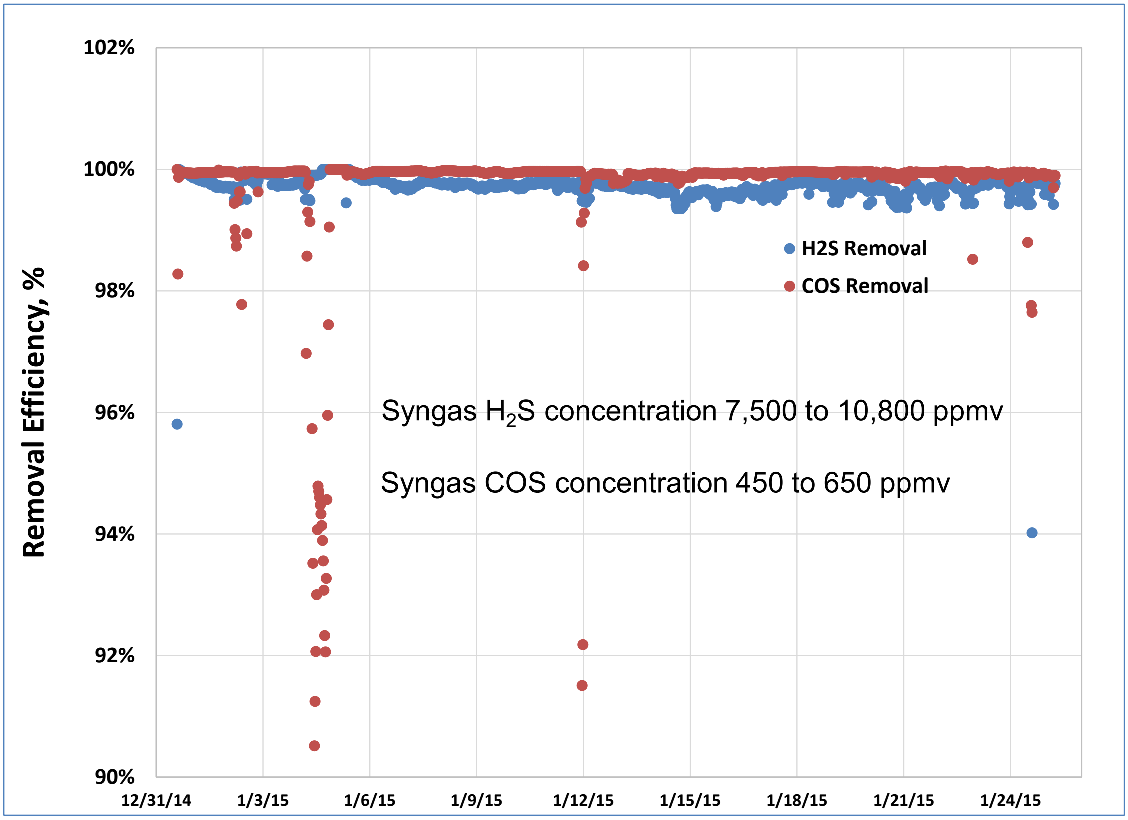


Figure 20. Sulfur Removal Efficiency of the WDP Unit and RTI-3 Sorbent

Table 9. Sulfate Analysis for Sorbent Samples Removed in January 2015

Analysis	Method	Fresh	Adsorber		Regenerator	
			A	B	A	B
Sulfate	XRF	None	None	None	None	None
Sulfate (wt%)	IC	None	0.02	0.01	0.13	0.13

In addition to being analyzed for sulfate, these samples were also analyzed to provide information about changes in the physical size and attrition resistance. The results from this analysis are shown in Table 10. The results in Table 10 for particle size distribution show that the particle size distribution in both the adsorber and regenerator are consistent and essentially identical to the particle size of the fresh sorbent. Although a consistent particle size distribution between the adsorber and regenerator is anticipated due to the continuous transfer of sorbent between the adsorber and regenerator, the similarity with the fresh sorbent sample indicates that a minimal amount of fines have been generated prior to the removal of these sorbent samples from the system. The attrition analysis also indicates that the sorbent becomes significantly more attrition resistant as it is used.

Table 10. Attrition Analysis of Sorbent Samples from January 2015

	Fresh	Adsorber		Regenerator	
		A	B	A	B
Particle Size (µm)					
d 10	41.9	39.2	40.7	42.3	38.1
d 50	72.9	69.2	69.6	73.4	66.2
d 90	111.3	108.0	105.5	111.8	102.0
Attrition (wt%)	3.20				0.32

One feature about the operation during January 2015 that has not been mentioned is that once stable operating conditions were achieved, no efforts were made to optimize performance. In some of the operating runs after TEC's extended outage in which the best operating conditions were applied, effluent sulfur concentrations from the WDP could be consistently maintained at 5 to 20 ppmv. In addition, the daily collection of sorbent fines in the filters was < 0.25% of the sorbent inventory in the system, which is significantly less than the design of about 1 % of sorbent inventory loss per day.

ii. WGS [Area 400]

The operation data during which all three systems (WDP, WGS, and aMDEA®) were in operation is from the first week in March 2015. During this period, a small slipstream was used to start up the reaction in the catalyst beds in the WGS system. Once the temperature and syngas and steam flow rates had been adjusted, the flow rate of syngas and steam were rapidly increased to take about 66% of the syngas through the WGS system. Because the steam concentration in the actual TEC syngas arriving to the 50 MW pre-commercial unit is lower than the original design conditions, the steam system did not have the capacity to provide sufficient extra steam to process the full syngas stream.

Figures 21, 22, and 23 show the inlet and outlet H_2, CO, and CO_2 concentration profiles, respectively. Because the full inlet concentration of the syngas is not measured just upstream of the WGS system, the inlet syngas for WDP was provided instead. The profiles in Figures 21, 22, and 23 all show the typical trends in H_2, CO and CO_2 concentration that are characteristic of the concentration changes resulting from the water gas shift reaction, namely an increase in H_2 and CO_2 and a decrease in CO. The interesting feature of Figures 21, 22, and 23 is that a small amount of water gas shift is observed across WDP indicating that RTI-3 does have some water gas shift activity. The subsequent changes in concentration show an increasing amount of water gas shift reaction. Based on the concentrations of CO, the total amount of CO conversion was about 80% even with about 33 % of the syngas bypassing the WGS system. Based on these results, the CO conversion of the whole syngas stream would be sufficient to allow > 90% CO_2 capture by the aMDEA® system.

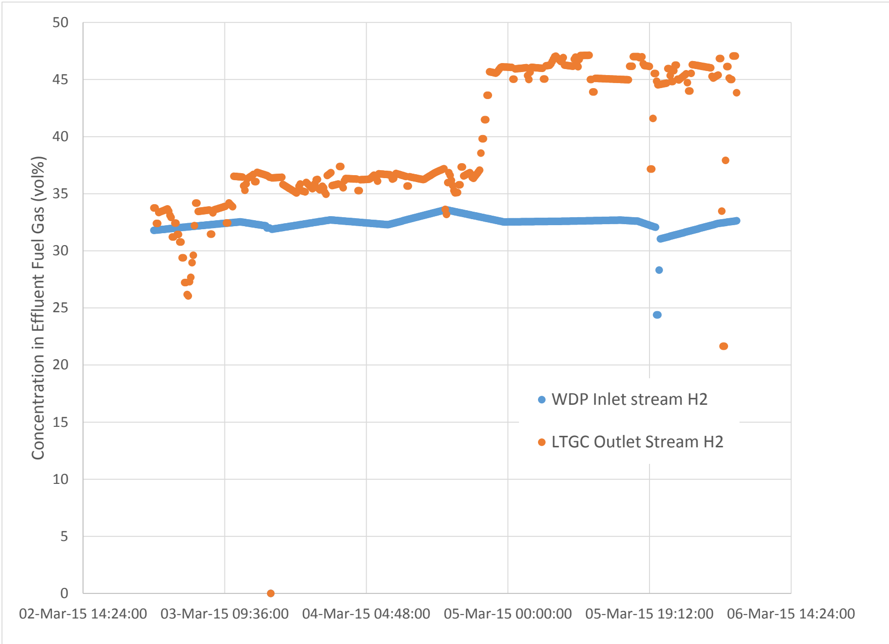


Figure 21. H_2 Concentration Change between WGS Inlet and Outlet in Jan 2015

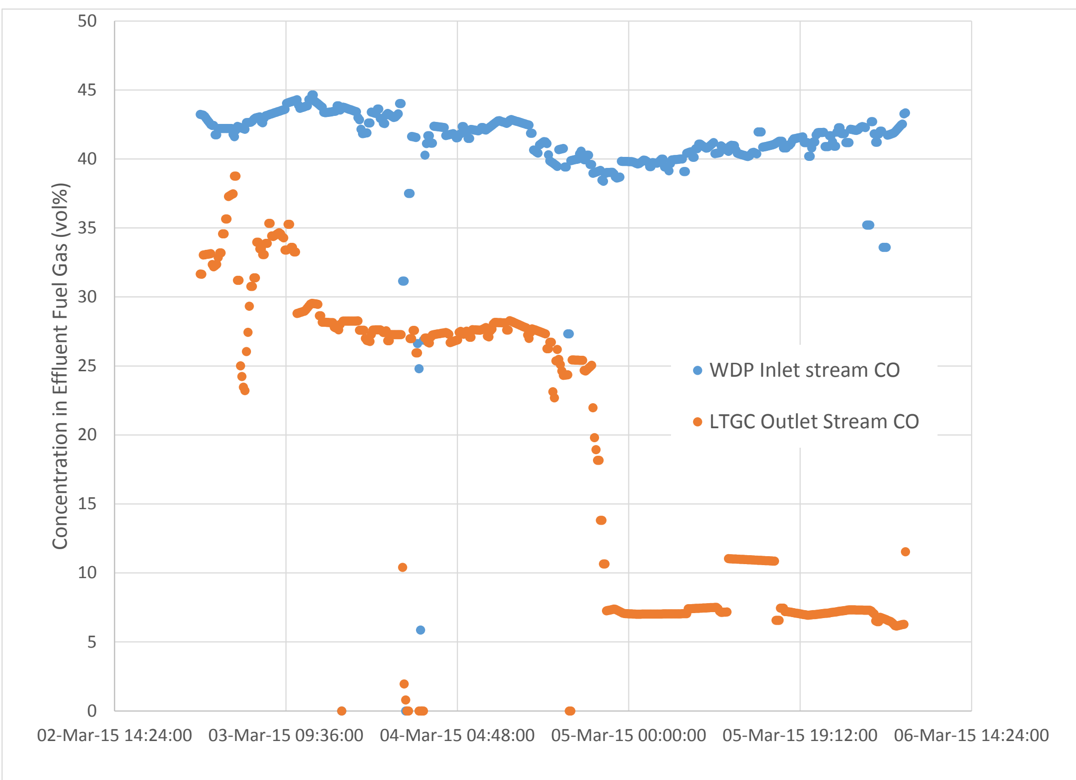


Figure 22. CO Concentration Change between WGS Inlet and Outlet in Jan 2015

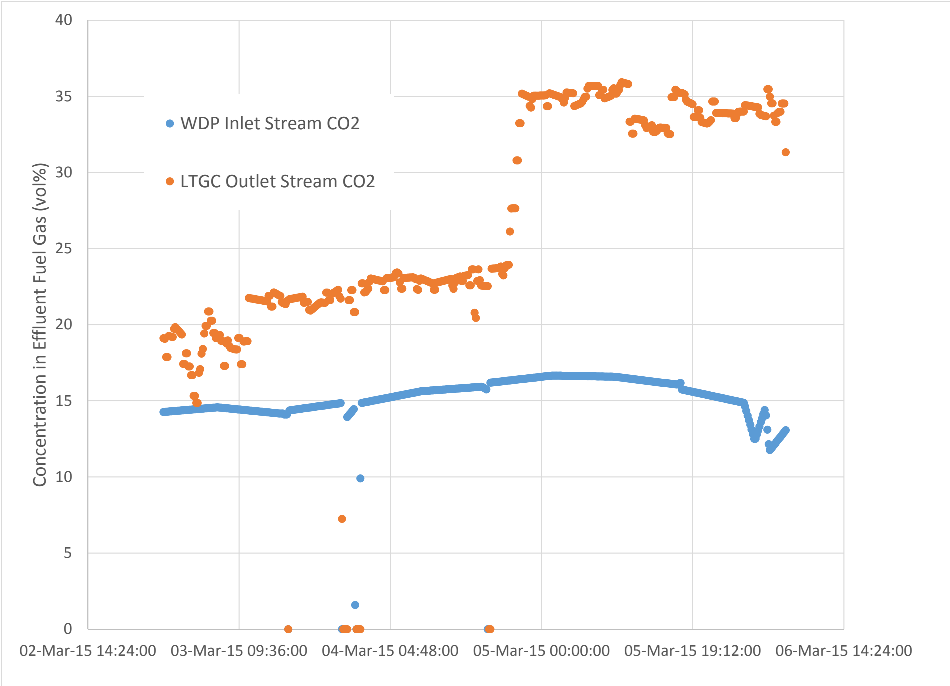


Figure 23. CO_2 Concentration Change between WGS Inlet and Outlet in Jan 2015

iii. aMDEA® [Area 500]

The first set of operational data for the aMDEA® system was also taken from January 2015. Although the aMDEA® system was not started until January 21, it operated until the WDP was shut down on January 25 because of suspected problems with the regenerator filter. During this operational window, the aMDEA® system operated for about 100 hours processing the product gas from WDP (Area 100). A comparison of the CO_2 concentration in the feed gas and product syngas from the aMDEA® system is shown in Figure 24. Based on this data, the aMDEA® process was able to remove over 98% of the CO_2 in the feed gas.

Initially, a single process gas chromatograph was used to measure the sulfur concentration in the feed syngas to the 50 MW pre-commercial unit as well as the sulfur in the inlet and outlet streams for the aMDEA® process. The typical sulfur concentrations in the feed syngas were about 10,000 ppmv and 600 ppmv for H_2S and COS, respectively. By contrast, the sulfur in the inlet and outlet to the aMDEA® system were either low ppm to sub-ppm for both H_2S and COS. Because surfaces are noted to retain sulfur species, any retained sulfur from measuring the feed syngas would bleed off during measurement of sulfur in the streams with the extremely low sulfur concentration. This causes a bias in the results that was not representative of the actual gas samples. After identifying this issue, a separate gas chromatograph was acquired for measurement of the gas composition for the feed syngas. Although this solution eventually fixed the problem, the data from this run in January 2015 could only be used to qualitatively indicate that the aMDEA® system was removing a significant portion of the H_2S and COS. The primary indication of this was the presence of H_2S and COS in the CO_2 byproduct stream. Analysis of this stream showed the H_2S concentration to be < 70 ppmv and COS concentration to be in the ppbv range.

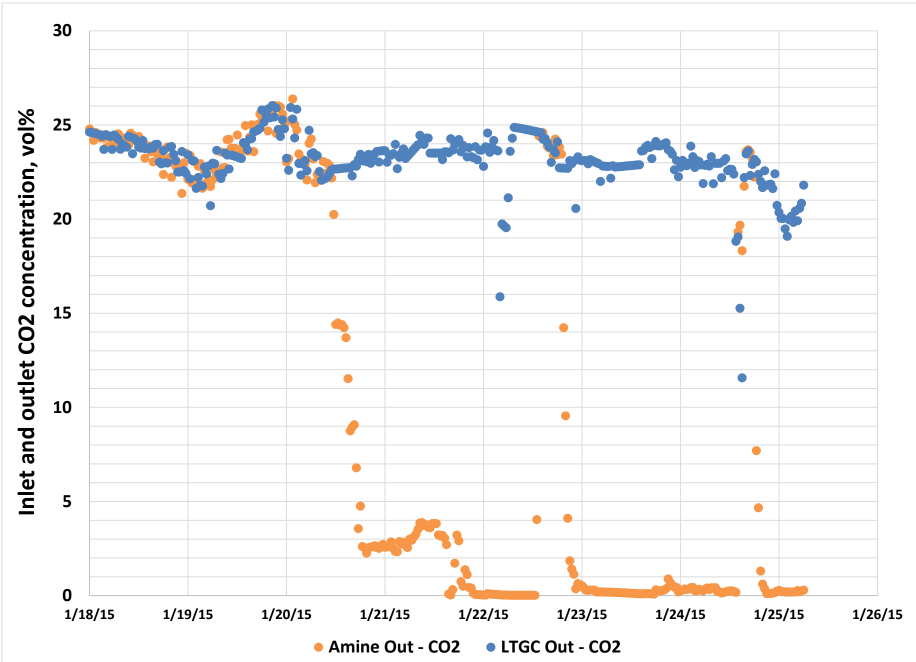


Figure 24. Carbon Dioxide Removal by the aMDEA® System in Jan 2015

The second set of operational data was collected during March 2015 when all three systems (WDP, WGS, and aMDEA®) were in operation. Prior to starting the WGS system, both WDP and aMDEA® were operating with the specific operating parameter for aMDEA® set for non-WGS operation. The WGS system was started by taking a small slipstream of syngas through the WGS reactors and bypassing a majority of the syngas around WGS directly to LTGC. After the conditions in WGS had stabilized, the amount of syngas being bypassed around WGS was rapidly reduced until about only 33% was being bypassed. When the conditions in WGS had stabilized at the higher syngas flow, the aMDEA® circulation rates were increased towards the conditions recommended for the shifted syngas. The inlet and outlet CO_2 concentrations for this operational period are provided in Figure 25. The CO_2 profiles in Figure 25 show the aMDEA® system was able to consistently remove almost all the CO_2. With the amine circulation rates set for the lower CO_2 concentrations of the unshifted syngas, the aMDEA® did require some time to achieve maximum CO_2 capture after the WGS system was started. When the WGS system began processing about 70% of the syngas stream, the aMDEA® system was still able to remove a significant amount of the CO_2 and increasing the amine circulation rates effectively managed to get back to > 98% CO_2 removal.

Unfortunately, the plans for installing the additional GC to solve the sulfur measurement issues in the feed and effluent stream to the aMDEA® system were scheduled for after TEC's planned outage which began after this run was completed. The qualitative results from sulfur analysis continued to confirm that the aMDEA® system does remove additional sulfur from the syngas.

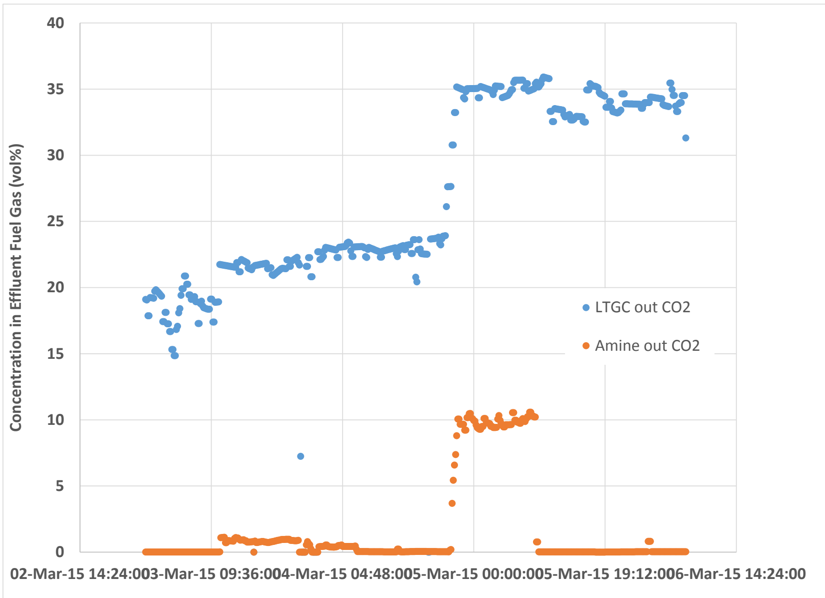


Figure 25. Carbon Dioxide Removal by the aMDEA® System in March 2015

VIII. Trace Contaminant Removal Process (TCRP) Development and Testing

Gasification systems convert feedstocks such as coal, petroleum coke, natural gas, biofuel, and municipal waste to syngas that can effectively be used to produce electricity or value-added chemicals in a very efficient and environmentally friendly process. Challenges faced when utilizing gasification-produced syngas for both power and chemical production include the presence of contaminants in the feedstock that survive the high temperatures and pressures of the gasification step and are therefore present for any downstream syngas utilization processes. The presence of these contaminants can be problematic for syngas utilization because they can attack vital metal components in advanced gas turbine systems used to produce power and can also poison expensive catalyst materials used to produce high-value chemicals. In addition, if contaminants survive the utilization step then they may be released to the environment and potentially trigger regulatory issues. For these reasons, control systems designed to reduce syngas contaminants to acceptable levels for both downstream conversion processes and to control emissions is crucial for gasification systems to be a viable alternative to conventional power generation and to be used in chemical production.

Syngas can be relatively free of contaminants if derived from clean feedstocks such as refined natural gas, but it also can contain a myriad of contaminants that vary widely in their concentrations if derived from coal, petroleum coke, or municipal waste. In the case of coal-derived syngas, results from previous research has led to a fairly good understanding of the contaminant species and expected concentrations for the major contaminants including sulfur, nitrogen, and chlorine. For the minor contaminants, those present at trace-level concentrations (commonly referred to as trace contaminants) such as mercury, arsenic, and selenium, much less is known about the species type and their concentrations at any specified gas cleaning condition. To overcome this lack of knowledge, researchers have relied on thermodynamic equilibrium calculations to predict chemical species and coal feedstock analyses to predict concentrations for the design of trace contaminant control systems. Conventional trace contaminant removal approaches have relied primarily on the use of physical absorption solvents that require refrigerated temperatures and thus lower process efficiencies.

RTI's approach to trace contaminant removal is based on the interaction of the gaseous contaminants with fixed beds of disposable sorbent materials at warm temperatures above 400°F and pressures above 600 psig. This system, known as the warm syngas trace contaminant removal process (TCRP), has been developed in the laboratory using simulated syngas, has been tested on-stream using actual coal-based syngas at Eastman Chemical Company's gasification facility in Kingsport, TN, and is currently being pre-commercially tested along with RTI's warm temperature desulfurization process (WDP) at Tampa Electric Company's Polk Power Station located in Tampa, Florida. These two processes (WDP and TCRP), when combined, comprise RTI's warm syngas cleanup package capable of producing ultra-clean syngas suited for either power or chemical conversion.

The report attached as Appendix H describes the following activities related to TCRP development and testing associated with this project:

- The construction of a test skid for use in slip-stream testing of the treated syngas leaving the WDP in the pre-commercial test unit at TEC's IGCC plant site.
- The installation of three microreactor systems and their associated analytical systems to test the impact of WDP plus activated amine plus TCRP treated syngas on the deactivation rate of commercial catalysts used for conversion of syngas to Fischer-Tropsch fuels (both iron-based and cobalt-based catalysts) and for conversion of syngas to methanol.

- Baseline testing of these microreactor systems when exposed to simulated syngas generated from commercially available high-purity compressed gas mixtures for a nominal 500 hours to determine the syngas conversion rate under ideal conditions.
- Procedures used for slip-stream testing with actual WDP/amine/TCRP-treated syngas from the gasification facility at TEC.
- Third party independent testing by AECOM's environmental services division (formally URS Corp.) based in Austin TX for trace components in the feed and effluent syngas for the pre-commercial unit and TCRP test skid.
- Descriptions of laboratory-scale developmental efforts for new improved warm-temperature sorbents for Hg, As, and Se that had been proven in the lab to be capable of meeting new EPA emissions limits for each of these trace contaminants. These improved sorbent materials are being used in the TCRP test skid at the warm syngas cleanup pre-commercial test unit at TEC.
- A laboratory program evaluating hydrogen chloride tolerance of RTI's desulfurization sorbent, RTI-3, and developing critical design data for removal systems for HCl and NH_3.

Because of the extended outage of the TEC IGCC unit that occurred from March through July of 2015, actual plant syngas was not available to complete the TCRP and microreactor testing. Since only a portion of the planned gas-phase sample collection campaign was completed under this Cooperative Agreement DE-FE0000489 due to the unavailability of syngas, the syngas production and sampling campaign will be continued under a separate new Cooperative Agreement DE-FE-0026622. To adequately capture the breadth of work completed on this project and the continued testing campaign in the next cooperative agreement, the reporting under this new agreement will provide a comprehensive description of the work completed under both projects.

The test efforts aimed at HCl showed that the sulfur capacity of the RTI-3 desulfurization sorbent used in WDP can be diminished somewhat over time if HCl above a threshold limit concentration is present in the inlet syngas. However, a suitable sorbent was found and demonstrated (in the lab) to remove HCl at high temperatures to levels substantially below the threshold limit. Thus this sorbent can protect the RTI-3 sorbent and WDP process when using coals or other feedstocks that contain high levels of chlorides.

Tests of newly identified sorbents for ammonia removal from warm syngas showed potential for commercial application, particularly when located downstream of WDP because high sulfur levels in the syngas have been indicated to lower the ammonia adsorption capacity of the sorbents.

IX. Direct Sulfur Recovery Process (DSRP) Development

In previous work, RTI has developed a new process for the direct recovery of elemental sulfur from SO_2 in N_2 that is generated during the oxidative regeneration of metal oxide-based solid sorbents like RTI-3. Because the original development work on RTI's Direct Sulfur Recovery Process (DSRP) focused on tailgas streams with 2 to 5 vol% of SO_2 more typical of a fixed-bed system, one of the primary goals of this work was to identify and optimize the operating conditions necessary for treating a tailgas stream with the higher SO_2 concentrations typically generated by RTI's WDP and enable process design and modeling of a potential future pre-commercial scale unit.

One of the key challenges in the original DSRP testing was that condensation of the elemental sulfur in the product gas severely limited the operational time possible for the DSRP reactor. In the reactor system used in this work, the elemental sulfur in the product gas was reduced to H_2S in a second reactor before final treatment and release of the effluent gas. With this reactor system, there was no condensation of elemental sulfur, which allowed the DSRP reactor to be run continuously for long periods of time, and provided a DSRP product stream that could be analyzed for SO_2, H_2S, COS, and elemental sulfur.

This new reactor system was extremely successful. Data from parametric testing with this reactor system enabled more detailed evaluation of the temperature effect of the light-off behavior of the SO_2 to elemental sulfur reaction, the selectively between elemental sulfur, H_2S, and COS based on the reducing gas composition and excess reducing gas supplied, and the impact of operating at higher SO_2 concentrations in the feed gas stream. This information was been very helpful in the design of DSRP systems for techno-economic analyses. Because of other higher priorities of the overall warm syngas cleanup pre-commercial scale-up program and a decision not to pursue further scale-up testing of the DSRP technology as part of the project, further DSRP testing work was discontinued. However, the learnings from this testing will be useful for any future DSRP development effort.

The report of this DSRP development effort is attached in Appendix I.

X. Novel Carbon Dioxide Sorbent Development and Testing

In addition to removing contaminants from syngas, applications such as power production, hydrogen production or syngas utilization also require removal of all or most of the CO_2 present in syngas. A high-temperature CO_2 removal process will have to be realized to seamlessly integrate with the rest of the high-temperature processes being developed under this project. To date, no feasible high-temperature CO_2 removal process from syngas has been conceptualized. RTI has identified a series of solid sorbent materials based on magnesium–alkali mixed salts that have very promising CO_2 capture properties for CO_2 removal from warm syngas. RTI has proposed a warm, sorbent-based CO_2 capture process based on this novel sorbent. The objective of this development effort was to optimize the sorbent formulation for syngas application, transform it to fluidizable form, optimize the CO_2 capture process and demonstrate feasibility under realistic conditions.

Reverse-Temperature Swing Adsorption Process and Sorbent Development

Contrary to typical applications of sorbent based CO_2 capture, the novel process design initially proposed included a multi-stage, reverse-temperature swing fluidized-bed process (RTI-RTSA). The sorbent upon adsorption of CO_2 at a certain temperature and pressure undergoes regeneration at a slightly lower temperature to enable utilizing the heat of adsorption and water-gas-shift to sustain the heat required during sorbent regeneration. As a result, no additional heat is required to sustain sorbent regeneration while the main energy penalties associated with regeneration are low-pressure steam for stripping and the subsequent CO_2 compression to pipeline pressures. In order to achieve this heat utilization, by overcoming the thermodynamic limitation of operating the regeneration at a lower temperature, regeneration will have to operate at a much lower CO_2 partial pressure than the adsorber and hence at a lower operating pressure than the adsorption step. As a result, the reverse-temperature swing process is also complimented with a pressure-swing process. Due to the high heat exchange requirements and need to control the bed temperature precisely, use of fluidized beds for the adsorption and regeneration step was proposed. These process requirements laid the groundwork for the development of a fluidizable sorbent.

Table 11. Test Conditions for CO_2 Sorbent Screening for RTSA Process

Adsorption
Temperature: 450˚C
Total Pressure: 300 psig
P_{CO2}: 150 psia
P_{H2O}: 45 psia
Regeneration
Temperature: 450˚C
Total Pressure: 300 psig
P_{CO2}: 0 psia
P_{H2O}: 45 psia

Sorbent development efforts in this project were focused around MgO based sorbents and built upon previous work where MgO sorbents were developed for CO_2 capture from exhaust gas at mild temperatures. The MgO sorbents of special interest are promoted using alkali salt metals to enhance sorbent activity and regenerability under warm conditions. Sorbents evaluated in this study used a basic magnesium carbonate precursor as an MgO source. The alkali metal promoters tested were sourced as either carbonates or nitrates. Although several sorbents with high CO_2 activity were synthesized, most of the sorbents suffered with either steep or steady deactivation over 150 cycles. Extensive sorbent characterization was performed to identify the following three primary reasons for sorbent deactivation:

1. MgO crystal growth
2. Segregation of MgO and alkali salts
3. Loss in surface area

The above inferences indicate that the key to developing an active and stable sorbent is to avoid the sorbent sintering to control MgO particle growth and to improve homogeneity of MgO and alkali salts. The approach used to counteract the particle growth was to pre-sinter the sorbent material prior to CO_2 capture testing. In essence, we tried to mimic the particle growth occurring during the CO_2 capture process, prior to the sorbent performance testing. One of the method to achieve this was to increase the calcination temperature used for the sorbent activation (sorbent ageing). Hence, effect of calcination temperature on MgO crystallite size and CO_2 capture activity was studied. The sorbents were tested for 150 adsorption-desorption cycles to compare its performance against the deactivating sorbent. Figure 26 presents the results of this test. As can be seen from the plot, the pre-sintered sorbent exhibited a similar initial activity as the previous sorbent. However, the deactivation was observed for only the first 15-20 cycles followed by a stable performance with a sorption capacity of about 15 wt% for the next 130 adsorption-desorption cycles.

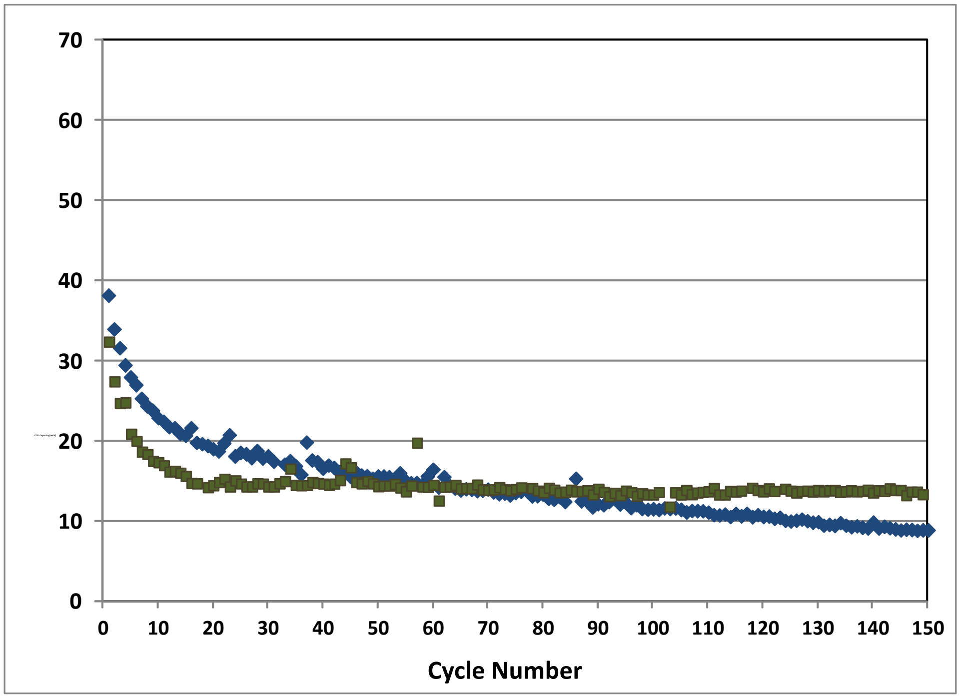


Figure 26. Performance Testing of $MgO/Na_2CO_3/NaNO_3$ based Sorbent with Mg:Na-3.75:1

Techno-economic Evaluation of the Reverse-Temperature Swing Adsorption Process

A preliminary technical assessment of this proposed process was performed by Noblis prior to the start of this project and the results from this study showed that RTI's proposed sorbent-based CO_2 capture process could improve the net electrical efficiency of an IGCC facility by approximately 1.9 efficiency points compared to a baseline case using Selexol™ as the CO_2 capture process. A detailed techno-economic evaluation was conducted under this project and the summary is shown in Table 12. Consistent with the preliminary technical assessment, an improvement in energy efficiency of 1.6 % points was observed when using RTI's reverse temperature swing adsorption process. However, the cost of electricity was estimated at 113.7 $/MWh compared to 105.6 $/MWh for comparative "DOE Case 2" (CO_2 removal in a dual stage Selexol™ process).

Table 12. Comparison of Energy Efficiency and Cost of Electricity for Baseline Cases and RTI's RTSA Process

	DOE Case 1	DOE Case 2	RTI-RTSA
Energy Efficiency, %	39.0	32.6	34.2
Cost of Electricity, $/MWh	**76.3**	**105.6**	**113.7**
Increase in COE, %	**-**	**38.4%**	**49.0%**

Even with improved energy efficiency, higher cost of electricity for RTI's RTSA process was observed and was due to high capital cost associated with the process, almost twice the cost of a dual-stage Selexol™ process. One of the main capital cost contributors was the re-pressurization system required to feed sorbent from the low-pressure regenerator to the high-pressure adsorber while maintaining the temperature of sorbent in excess of 450°C. Additionally, no practical way of transferring the high quality (at 450°C) heat of adsorption and water-gas-shift to sustain the heat demand of the regeneration step was identified. Due to these reasons it was decided that the RTSA process is not economically feasible at this stage.

Techno-economic Evaluation of the Temperature Swing Adsorption Process

An alternate process arrangement similar to the classical temperature swing adsorption process (RTI-TSA), utilizing RTI's MgO-based sorbent, was explored. Such a process is conceptually similar to conventional gas-liquid absorption processes where the absorber and regenerator operate at approximately the same pressure while the regenerator operates at a higher temperature. Since the adsorption in this proposed process takes place at a temperature of 450°C, the heat of adsorption and reaction heat generated by the water-gas-shift reaction can be recovered as medium- to high- pressure steam and converted to electricity. In the regenerator, the heat of desorption (endothermic) can be supplied, either directly or directly, by firing natural gas. Such a process arrangement is equivalent to burning natural gas to raise medium- to high- pressure steam to in turn produce electricity. Firing of natural gas in the regenerator can be carried out either a) direct firing using enriched oxygen (95 vol%) which allows for the capture of combustion product CO_2 at a high purity, or b) indirect heating using combustion flue gas in which case the combustion product stream will not be mixed with the capture stream to avoid dilution with nitrogen from air. Although economics and process operation may favor the use of air for indirect natural gas firing, the issue of CO_2 emissions associated with natural gas combustion may demand the use of enriched oxygen for direct natural gas firing. Also, the combusted gas stream from the natural gas (NG) reformer presents an attractive alternative for stripping steam in the regenerator. However, one of the advantages associated with using air as oxidant is that nitrogen in the air helps limit the high temperatures (< 2200°C) in the NG reformer. Using enriched oxygen as oxidant instead of air posed a problem with controlling the high temperatures in the NG reformer. Hence, a portion of pure CO_2 stream exiting the regenerator was recycled to serve as heat sink.

Detailed techno-economic evaluation of the RTI-TSA process was conducted and the results are summarized in Table 13. The energy efficiency of RTI-TSA process was 3.1 % points better than "DOE Case 2" and 1.5 % points better than RTI-RTSA process. The estimated cost of electricity for the RTI-TSA process was 100.6 $/MWh and equivalent to 31.8% increase in cost of electricity compared to 38.4% increase in cost of electricity observed for “DOE Case 2”.

Table 13. Comparison of Energy Efficiency and Cost of Electricity for Baseline Cases and RTI’s TSA Process

	DOE Case 1	DOE Case 2	RTI-RTSA	RTI-TSA
Energy Efficiency, %	39.0	32.6	34.2	35.7
Cost of Electricity, $/MWh	**76.3**	**105.6**	**113.7**	**100.6**
Increase in COE, %	**-**	**38.4%**	**49.0%**	**31.8%**

Development of Sorbent for Temperature Swing Adsorption Process

The most promising sorbent developed for the RTSA process was tested for a classical TSA process using testing conditions described in Table 14. The initial CO_2 loading under temperature swing adsorption process conditions was 18 wt%. However after 20 cycles, CO_2 capacity dropped to 8 wt%. Although the sorbent working capacity stabilized, it had to overcome two challenges. The sorbent working capacity needs to be stable but also higher (>15 wt%) and the sorbent needs to be fluidizable to be used in the fluidized bed adsorption and regeneration reactors.

Table 14. Test Conditions for CO_2 Sorbent Screening for RTI-TSA Process

Adsorption
Temperature: 350-450°C
Total Pressure: 400 psig
P_{CO2}: 350 psia
P_{H2O}: 50 psia
Regeneration
Temperature: 550°C
Total Pressure: 400 psig
P_{CO2}: 350 psia
P_{H2O}: 50 psia

Need for a supported sorbent was proposed to transform the unsupported sorbent to fluidizable form. Support candidates were selected from commercially available materials (like Al_2O_3 and SiO_2) that met certain physical and thermal stability criteria. In order to improve the stability of the sorbent the thermal stability of the active components of the sorbents had to be improved. In general, the growth of crystal size at high temperatures is a common problem under relatively harsh conditions. Several in-house developed approaches were explored for making a stable CO_2 sorbent based on the consideration of functionality and chemical interaction among the components: active phase MgO, promoters, and fluidizable supports (SiO_2 or Al_2O_3). Figure shows the change in CO_2 loading capacity for three sorbent materials: unsupported baseline sorbent (13580-64A), and supported sorbents (13580-66A and 13580-70A). Sorbent material 13580-70A was found to be more stable over 9 cycles than sorbent 13580-66A. Optimized process conditions for the best sorbent material, 13580-70A, in warm syngas application were also identified.

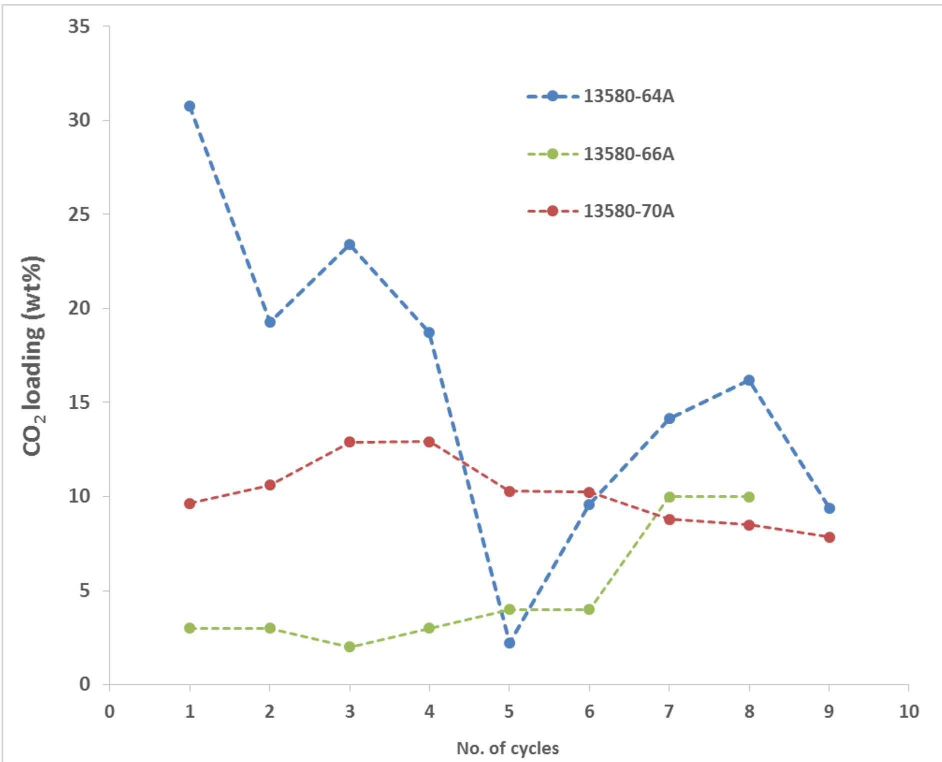


Figure 27. Stability of Unsupported and Supported Sorbents using MgO, Promoter and Support Composition Obtained from Optimization Effort

XI. Ammonia/Urea Integration

Pre-FEED Study

The integration of RTI's WDP technology for sulfur removal with RTI's warm syngas TCRP technologies offers options to achieve syngas cleanup to very low contaminant levels at costs substantially below that of conventional processes, thus expanding the application of RTI's warm gas cleanup technologies beyond clean power generation to applications such as chemicals, fertilizers, fuels, and hydrogen. Successful use of RTI's warm gas cleanup technologies in these industrial applications will demonstrate the technologies' reliability and economic advantage when needed to support lower cost, ultra-clean coal power generation projects with carbon capture.

To help understand the potential value of these integrated syngas cleanup technologies for poly-generation and/or stand-alone chemicals/fertilizers/hydrogen production, a study (approximately pre-FEED level) was conducted to develop a techno-economic assessment of these options using ammonia and urea production as the study basis. Two scales of these processes were considered. The overall study and techno-economic analyses were conducted utilizing information provided by an established technology supplier for ammonia and urea plants with process integration assistance from AMEC Kamtech Inc., the EPC contractor for the warm syngas pre-commercial testing project at TEC.

An established technology supplier was contracted to provide a feasibility study for the following ammonia and urea plants for potential integration with the TEC Polk IGCC site:

- A 300 short-tons per day ammonia process and its associated equivalent-scale urea process (sized at 520 short-tons per day to use all 300 short-tons per day of ammonia production and approximately a third of all captured CO_2). This scale is sized to utilize all of the hydrogen produced from the warm syngas pre-commercial test project at TEC and thus evaluate a case involving polygeneration.
- A 1500 short-tons per day ammonia process and its associated equivalent-scale urea process (sized at 2600 short-tons per day to use all 1500 short-tons per day of ammonia production and approximately a third of all captured CO_2). This scale is sized to utilize all of the hydrogen produced from scale-up of the warm syngas cleanup technologies to treat all of the raw syngas produced from the gasifier at TEC and thus evaluate a case involving a standalone fertilizer production process as retrofit for the Polk IGCC facility.

The contracted feasibility study was to include a design basis, process and technology descriptions, process flow diagram, heat and material balance (major streams only), feed material requirements and specifications, utilities specifications and consumption, overall space requirement, and budgetary capital cost estimate for each of the above study options.

AMEC Kamtech Inc. was contracted to provide a feasibility study for integration of each of the above ammonia and urea plant options into the existing TEC Polk IGCC site. This feasibility study addressed the needs to meet feed specifications and consumption, utility specifications and consumption, and any integration requirements for installation of the proposed ammonia/urea plant options at the TEC Polk site.

- For the 300 short-tons per day ammonia case (and corresponding urea plant case) this included any required modifications to the existing TEC plant equipment and to the warm syngas cleanup technologies equipment installed as part of this overall project.
- For the 1500 short-tons per day ammonia case (and corresponding urea plant case) this included addition of a new or expanded full-scale warm syngas cleanup technology system, conversion of the existing TEC syngas turbine to natural gas firing, and any process equipment modifications required to integrate the ammonia and/or urea plants with the existing TEC Polk site.
- As part of this feasibility study, AMEC Kamtech Inc. also reviewed the feasibility study deliverables from the ammonia/urea technology provider and suggested modifications to any assumptions made therein with regard to construction labor costs and productivity and commodity piping, steel, electrical costs, etc. in order to reflect AMEC's more accurate knowledge of local site costs/values for such items.

Techno-economic Analyses for Integration of Ammonia/Urea Plants

Data from the feasibility studies described above were used by RTI, with input and review from TEC, to conduct techno-economic analyses for the various proposed ammonia and urea integration cases. The techno-economic analyses were focused at determining the viability of such options for retrofit of an IGCC site such as the TEC Polk plant for cases involving polygeneration and/or complete retrofit.

At the conclusion of the techno-economic analyses, the results were shared in a detailed briefing to the DOE Project Manager at NETL and in a topical report to DOE (the topical report is attached as Appendix K and is summarized below).

Because of its similarity to the TEC Polk 1 design and a desire to model retrofit of a single-train IGCC without carbon capture, the GE radiant-cooled gasifier cases from the following DOE baseline studies were used as the foundation for the Base Case IGCC techno-economic analysis in the topical report:

- "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity", DOE/NETL-2010/1397 (used Case 1 from this report, modified for 311-MW single-train IGCC).
- "Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases", DOE/NETL-341082312 (used Case 1 update to provide updated costs for the reference case).

The DOE baseline Case 1 study, selected from the above reports to serve as reference model for the IGCC in this report, was for a dual-train 622-MW IGCC but the desired model was for a single-train IGCC (such as for TEC Polk 1). However, the DOE study assumed two parallel trains all the way through except for the final combined cycle steam turbine, so it was relatively straightforward to modify the case for a single-train 311-MW IGCC by creating dual steam turbines and breaking out the capital and operating costs for each parallel single train. For purposes of this study, the construction/operation timeline and economic assumptions used in the DOE baseline studies were also used for these techno-economic analyses, except for assuming a 30-yr life for the Base Case IGCC. A gasification plant availability of 80% was assumed for single-train operation. For the retrofit cases where CO_2 was captured, no additional cost for sequestration or revenue generation for utilization of the captured CO_2 was assumed.

As in the DOE baseline studies, it was assumed here that the Base Case IGCC was constructed during the period of 2004-2007 and started up in 2007, and would operate through 2036. However, for each of the retrofit option cases in this report, it was further assumed that in 2014 a decision would be made to retrofit the IGCC to either a 20% polygen ammonia or urea plant or to a full retrofit conversion to an ammonia or urea plant. The 20% polygen retrofit cases assumed it would take 2 years to construct the ammonia or urea facility with polygen startup in 2016, while the full retrofit cases would take 3 years to construct and would start up in 2017. During the construction of the ammonia/urea plants, it was assumed that the IGCC plant would continue to operate as much as possible. After retrofit conversion, it was assumed that natural gas would be used to fire the syngas turbine in place of any lost syngas now sent to the ammonia or urea plants (any required retrofits to allow natural gas firing of the syngas turbine were included in the techno-economic analyses), so that 311 MW of electric power were co-produced in all cases. The economic timeframes for all of these study options were chosen to start in 2014 and to end at the end of 2036. The depreciated value for the Base Case IGCC plant in the year 2014 was used as the IGCC asset value starting point for each of the Base Case IGCC and retrofit cases.

For purposes of these techno-economic analyses, an established global technology supplier with extensive ammonia and urea plant licensing and retrofit experience was contracted to provide a feasibility study for the various scale ammonia and urea plants for potential integration with the Base Case IGCC (using the TEC Polk 1 IGCC and RTI demonstration facility as a basis). AMEC Kamtech, Inc. (who designed and constructed the RTI demonstration facility at the TEC Polk 1 site) was then contracted to provide a feasibility study for integration of each of the ammonia and urea plant options into a facility such as the existing TEC Polk IGCC site. For the 20% syngas retrofit cases (300 stpd ammonia case and corresponding 520 stpd urea plant case), this included any required modifications to existing TEC plant equipment (including additional purified nitrogen for feed to the ammonia facility) and to the RTI 50-MW_e warm syngas cleanup pre-commercial test facility (including a pressure swing adsorber (PSA) for final H_2 enrichment). For the full 100% syngas retrofit cases (1500 stpd ammonia case and corresponding 2600 stpd urea plant case), this included addition of a new or expanded full-scale RTI WDP and aMDEA® carbon capture system, conversion of the existing syngas turbine to natural gas firing, and any equipment modifications required to integrate the ammonia/urea plants with the IGCC plant site.

For the techno-economic analyses for this study, the following option cases were modeled:

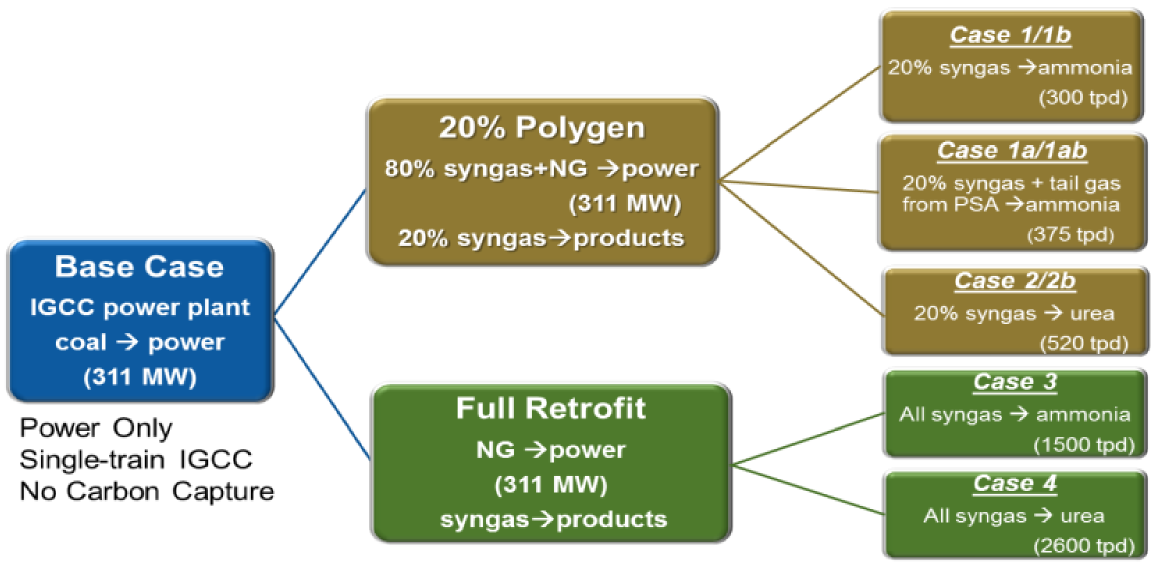


Figure 28. Techno-economic Case Studies for Ammonia/Urea Integration

A brief description of each of these cases is as follows:

- Base Case: single-train 311-MW IGCC, no water-gas-shift (WGS) or carbon capture
- Case 1: 20% syngas polygen retrofit to a 300 stpd ammonia facility (full capital with no DOE funding support); hydrogen further enriched by PSA to ammonia specifications
- Case 1a: same as Case 1 but with alternative technology to enrich the H_2, eliminate the need to send PSA tailgas to the syngas turbine, and thus produce 375 stpd ammonia
- Case 1b: same as Case 1 but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA® carbon capture (similar to DOE-funded 50-MW_e pre-commercial test plant at TEC)

- Case 1ab: same as Case 1a but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA® carbon capture (similar to DOE-funded 50-MW_e pre-commercial test plant at TEC)
- Case 2: same as Case 1 except all the ammonia is used to make 520 stpd granulated urea
- Case 2b: same as Case 1b except all the ammonia is used to make 520 stpd granulated urea
- Case 3: 100% syngas retrofit to a 1500 stpd ammonia facility including a new full-scale warm syngas cleanup plant
- Case 4: same as Case 3 except all the ammonia is used to make 2600 stpd granulated urea

Techno-economic analyses for each of these cases were performed by RTI using the DOE baseline IGCC data and costs, feasibility study data and costs provided by the established global ammonia/urea technology licensor, and IGCC integration study data and costs provided by AMEC Kamtech, Inc. For the Base Case stand-alone IGCC, power prices were set at a level ($64.10/MWh) to achieve a 15% after-tax IRR. This power price was then carried forward into all the other study cases. Illinois # 6 coal ($68.60/ton) was used as the feedstock. Natural gas costs were assumed to be $3.50/MBtu and ammonia and urea prices ($500/ton and $400/ton, respectively) were based upon average U.S. prices for the 2012-2013 timeframe. Table 15 summarizes the techno-economic analyses results.

Table 15. Summary of Techno-economic Results for Ammonia/Urea Options

	Base Case IGCC (100% syngas to power)	Case 1 (20% syngas to NH3; 80% to power)	Case 1a (20% syngas to NH3; 80% to power)	Case 1b (20% syngas to NH3; 80% to power)	Case 1ab (20% syngas to NH3; 80% to power)	Case 2 (20% syngas to Urea; 80% to power)	Case 2b (20% syngas to Urea; 80% to power)	Case 3 (100% syngas to NH3; NG to power)	Case 4 (100% syngas to Urea; NG to power)
Input Fuels:	Coal	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG
Products:									
Electricity, MW	311	311	311	311	311	311	311	311	311
Co-Product		Ammonia	Ammonia	Ammonia	Ammonia	Urea	Urea	Ammonia	Urea
Co-production Capacity, tpd		300	375 (extra H2 recovery)	300	375 (extra H2 recovery)	520	520	1500	2600
Capital Costs:									
2007 IGCC Capex, $M	$697	$697	$697	$697	$697	$697	$697	$697	$697
2014 IGCC Asset Value, $M	$383	$383	$383	$383	$383	$383	$383	$383	$383
Polygen Retrofit Block Capex, $M		$177	$189	$86 (plus federal support)	$98 (plus federal support)	$297	$206 (plus federal support)	$505	$837
After-tax IRRs:	**15.0%**	**14.2%**	**16.9%**	**19.3%**	**21.9%**	**13.6%**	**17.5%**	**22.6%**	**22.2%**

The above results indicated that full retrofit Cases 3 and 4 would generate a significantly higher after-tax IRR than the Base Case stand-alone IGCC. 20% syngas retrofit Cases 1 and 2 produce after-tax IRRs that are reasonably good, but are slightly lower than for the Base Case stand-alone IGCC. Interpolation between Cases 1 and 3 and between Cases 2 and 4 would suggest that any IGCC polygen retrofit to ammonia or urea that utilizes at least 25-30% of the IGCC's syngas should result in an after-tax IRR greater than that of the Base Case stand-alone IGCC. If the warm syngas cleanup block (WDP + WGS + aMDEA® for carbon capture) were to be supported with federal funding as in Cases 1b, 1ab, and 2b, then the after-tax IRRs for the 20% syngas retrofit cases would then be higher than the IRR for the Base Case stand-alone IGCC. However, if alternative technology to conventional PSA could be developed and/or utilized to enrich the hydrogen in the syngas, avoid sending PSA tailgas to the syngas turbine, and use the additional hydrogen to make additional ammonia, then the after-tax IRR of all modeled retrofit cases would be improved by several percent (as indicated in Cases 1a and 1ab) and would make the 20% syngas retrofit cases more attractive on an after-tax IRR basis than the stand-alone IGCC Base Case, without need for any federal support. It was recommended that the development and/or utilization of such an alternative to PSA should be considered as part of any future R&D efforts focused on polygen retrofits of IGCCs.

Pre-FEED Follow-up Design and Site Optimization Study

Task 5.4 of the Statement of Project Objectives for this project stated that if the techno-economic analyses from the ammonia pre-FEED studies indicated that one or more of the ammonia/urea integration options at TEC was a valid candidate for commercial consideration, and if sufficient project funds were available, RTI would prepare a subtask plan and a budget for a follow-up study and submit it for DOE review and consideration for partial or complete inclusion in this project. The objective of this work would be to conduct a more detailed study (approximately FEED-level) of the selected ammonia and/or urea integration option(s) from the pre-FEED study to determine its commercial viability. If determined to be commercially viable, this could help lead to the commercial deployment of advanced ultra-clean gasification projects in the U.S. (starting at the TEC Polk site) and around the globe for polygeneration and industrial applications that include CO_2 re-use.

Based on the results of the pre-FEED study, it was agreed by RTI and DOE to proceed with a FEED-level study on Case 1 of the pre-FEED study to utilize the enriched hydrogen stream from the 50-MW_e warm syngas cleanup pre-commercial test unit for the coproduction of ammonia. As part of this effort, AMEC Kamtech Inc. was commissioned to conduct a follow-up study to consider various sub-options for the coproduction of ammonia prior to locking scope for the FEED study. The following sub-option case studies were considered:

Table 16. Pre-FEED Follow-up Optimization Case Studies

	Case 1	Case 2	Case 3	Case 1A	Case 2A	Case 3A
Nitrogen Purification	Standalone Nitrogen Plant	Standalone Nitrogen Plant	Standalone Nitrogen Plant	Existing DGAN + Deoxo Catalyst + Molecular Sieve	Existing DGAN + Deoxo Catalyst + Molecular Sieve	Existing DGAN + Deoxo Catalyst + Molecular Sieve
Hydrogen Purification	WDP + CC + PSA	WDP + LTS + CC + PSA	WDP + LTS + CC + Methanation	WDP + CC + PSA	WDP + LTS + CC + PSA	WDP + LTS + CC + Methanation
Estimated Ammonia Production, stpd	344	363	384	338	357	379

WDP = warm desulfurization process;
LTS = low temp. shift;
CC = carbon dioxide capture (aMDEA);
PSA = pressure swing adsorption

After AMEC's analysis, it was determined that Cases 3 and 3A offered the best overall value, having the lowest capital costs per annual ton of ammonia, the lowest cost of production per ton of ammonia, and the maximum daily production of ammonia. After joint discussions with RTI, TEC, and DOE, it was decided to pursue Case 3A for the FEED study. Case 3A would provide the required nitrogen for ammonia production from further purification and compression of existing DGAN nitrogen (contains about 2.5% oxygen) from the existing TEC IGCC air separation plant. It would also purify the enriched hydrogen stream from the existing 50-MW_e pre-commercial test unit via addition of an additional low-temperature water gas shift stage and a methanation unit. This strategy, coupled with use of a hydrogen membrane on the ammonia process recycle loop would enable maximum daily production of approximately 380 standard tons per day.

Ammonia FEED Study

Once the design basis for the FEED study was selected (based on Case 3A as described above), AMEC worked with TEC, RTI, and an established global ammonia technology provider to develop the FEED study and a +/- 10% budget estimate for addition of ammonia coproduction to TEC's IGCC facility and the existing 50-MW_e warm syngas cleanup pre-commercial test facility. The FEED study is attached in Appendix L.

During the FEED study, AMEC developed heat and material balances (HMBs), process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), a 3-D model, and equipment specifications for the outside battery limits (OSBL) process and subcontracted the established ammonia technology provider for the inside battery limits (ISBL) ammonia process HMB, PFDs, P&IDs, general layouts, and equipment specifications. AMEC obtained vendor quotes for all equipment and developed preliminary engineering and associated material quantity take-offs to generate a +/-10% capital cost estimate (CAPEX). The estimated project budget CAPEX is $98.9 million based on 2015 costs with no escalation factor and consists of the following primary project components:

Table 17. Major Component Costs of Ammonia FEED Study Estimate

Project Component	Description	Estimated CAPEX (US$ millions)
OSBL Plant	WGCU LTS, Methanation, DGAN	$50.6
ISBL Plant	Ammonia Plant	$48.3
Total Estimated Costs		**$98.9**

The preliminary project schedule for EPC completion was estimated to be 36 months following project funding.

XII. Conclusions

Even though this project did not meet one of its key original goals, the goal of achieving 5000+ syngas operation hours, it was highly successful overall and did demonstrate at a pre-commercial 50-MW_e scale that the RTI WDP process and associated RTI-3 sorbent can remove ~99.9% of total sulfur from syngas at temperatures as high as 600°C in a low-cost, small-footprint transport reactor system design with acceptably low sorbent attrition rate and with stable sorbent sulfur capacity. The project also demonstrated that when WDP is coupled with a downstream carbon capture process such as aMDEA®, the combined processes can reduce total sulfur in the syngas by >99.99%, achieving sub-ppm levels of total sulfur as needed for many chemical and fuel conversion applications of syngas and for ultra-clean IGCC power generation. The project would likely have met, or come close to meeting, its goal of 5000+ syngas operating hours had it not been for a prolonged 5-month outage of the host site TEC IGCC system that provided syngas to the 50-MW_e pre-commercial test unit.

Some of the major accomplishments of this project included the following:

- The pre-commercial test unit was designed and constructed on schedule and under budget.
- >500,000 total labor hours for construction and operations occurred with no injury other than a few minor first aids.
- The pre-commercial scale unit has performed as expected, duplicating previous performance at lab, bench, and pilot scales, and showing that the WDP technology scales up with predictable performance (i.e., can scale the system up with confidence).
- The WDP unit has consistently been able to reduce inlet total sulfur content from as much as 14,000 ppmv to ~10 ppmv (~99.9% total sulfur removal).
- Downstream clean syngas exiting the carbon capture block has consistently been < 0.5 ppmv (>99.99% total sulfur removal), suitable for rigorous chemicals and fuels applications (with use of an appropriate guard bed).
- Sorbent attrition rate has been in line with design expectations (in fact has been lower than design) and improves over time as the sorbent is used.
- Sorbent sulfur capacity has been steady - no sign of any significant deactivation.
- The WDP unit has successfully been operated both below and above its design rate.
- Significant learnings have occurred which will benefit scale-up to a full-scale commercial demonstration unit, such as appropriate materials of construction to reduce or eliminate corrosion issues, auxiliary equipment reliability, equipment sparing and preventative maintenance policies, and potential for WDP design improvements.
- In addition to the above R&D achievements related directly to the WDP technology, this project also funded efforts that conducted beneficial R&D related to several peripheral technologies and/or processes, including:
    - Improvements to RTI TCRP technologies, including development of warm syngas cleanup technologies for Hg, As, Se, HCl, and NH_3 that can meet new stricter EPA emissions requirements and can provide protection for RTI-3 sorbent and for downstream syngas conversion catalysts.
    - Microreactor systems were built and installed and baseline tested to help demonstrate that WDP + TCRP + aMDEA® can adequately clean syngas for use with chemicals and fuels applications.
    - Improvements were identified, and demonstrated in the lab, that can improve scaled-up designs of RTI's DSRP technology.
    - Novel warm-temperature carbon dioxide capture sorbents were developed and tested that showed promise for coupling with WDP and TCRP to maintain the high efficiency gains from these warm syngas cleanup technologies when carbon dioxide capture is also needed.

Although a reverse-temperature swing adsorption approach for use of these sorbents was found to be too expensive, a more classical temperature swing adsorption approach was found to hold more promise.

- A series of pre-FEED and FEED studies, coupled with techno-economic analyses, showed that use of WDP + aMDEA® technologies could enable viable retrofit options for polygeneration of electric power and ammonia or urea at existing IGCC sites or for full retrofit conversion of existing IGCCs to ammonia or urea production, coupled with conversion of the existing syngas turbines to co-fire or re-fire with natural gas.

In parallel with this project, a separate cooperative agreement was awarded to RTI by DOE-NETL (DE-FE0012066) that utilized Nexant to conduct a series of systems and techno-economic analyses to assess the benefits of the RTI WDP technology for power generation with 90+% carbon capture and for chemicals and fuels applications (conversion of syngas to methanol). This independent project and assessment revealed that the use of WDP technology could enable substantial reductions in CAPEX (20-50%) and in OPEX (up to 50+%) for the entire syngas cleanup block (WDP + WGS + LTGC + CC + SRU) compared to conventional technologies such as Selexol™ and Rectisol®, while also providing improvements in overall process efficiencies. This ability to simultaneously improve CAPEX, OPEX, and process efficiency, without trading one improvement area off versus another, illustrates why RTI WDP is a game-changer technology.

The prolonged outage of the TEC host site gasifier, coupled with some reliability issues with auxiliary equipment and corrosion issues primarily with heat exchangers, prevented this project from reaching its original target of achieving several thousand operating hours on syngas (did achieve 1,500 hours), and also limited the information and learnings related to RAM analysis and related to the TCRP and microreactor testing. Because most of the other key performance objectives of this project had been successfully achieved, a recommendation was made to DOE to provide for an extension of the pre-commercial testing of the warm syngas cleanup system at the TEC site. DOE did approve a separate cooperative agreement (DE-FE0026622) which will enable the pre-commercial test unit to continue operating from October 1, 2015 until TEC's 2016 spring outage (planned for late April, 2016). The primary goals of this testing extension are to operate the warm gas desulfurization process, water gas shift, low-temperature gas cooling, and activated amine carbon capture units at the TEC pre-commercial test site to achieve an additional ~3,000 hrs of syngas operation with a target of ~1,000 hrs of continuous operation of the full integrated systems. At the conclusion of this extended testing, it is anticipated that the WDP technology will then be ready for successful scale-up to a full commercial-scale demonstration plant. At the conclusion of this extended testing, more complete data can be reported related to issues such as RAM analysis and microreactor testing.

XIII. List of Acronyms and Abbreviations

Al_2O_3 - alumina
aMDEA® - activated methyldiethanolamine (registered absorbent of BASF)
As – arsenic
BEC – bare erected cost
BFD – block flow diagram
BFW – boiler feed water
Btu – British thermal unit
CAPEX – capital cost
CC – carbon (or carbon dioxide) capture
CFR – Code of Federal Regulations
CM – construction management
CO – carbon monoxide
CO_2 – carbon dioxide
COS – carbonyl sulfide
CY – cubic yards (of concrete)
DCS – distributed control system
DOE – U.S. Department of Energy
DSRP – direct sulfur recovery process
EA – Environmental Assessment (part of NEPA)
EPA – U.S. Environmental Protection Agency
EPC – engineering, procurement, and construction
FCC – fluidized catalytic cracker
FDEP – Florida Department of Environmental Protection
FEED – front-end engineering and design
FONSI – Finding of No Significance (part of NEPA)
H_2 – hydrogen
HAP – hazardous air pollutant
HAZOP – hazards identification process (part of pre-construction and pre-operation safety reviews)
HCl – hydrogen chloride (or hydrochloric acid)
H_2S – hydrogen sulfide
Hg – mercury
HHV – high heating value
HMB – heat and material balance
HP-TGA – high-pressure thermogravimetric analyzer

Hr/hrs – hour/hours
HTS – high-temperature water gas shift
I&C – instrumentation and control
ICP – inductively-coupled plasma analysis
IGCC – integrated gasification combined cycle
IRR – internal rate of return
ISBL – inside the battery limits
K – potassium
K_2CO_3 – potassium carbonate
KW_e – kilowatt equivalent
LF – linear foot
LTGC – low-temperature gas cooling
LTS – low-temperature water gas shift
MBtu – million British thermal units
MDEA - methyldiethanolamine
MgO – magnesium oxide
MH – man-hours
MOC – management of change
MM – million
MVA – monitoring, verification, and accounting (related to carbon dioxide storage)
MW_e – megawatt equivalent
MWh – megawatt hour
Na – sodium
Na_2CO_3 – sodium carbonate
$NaNO_3$ – sodium nitrate
Na_2O – sodium oxide
NH_3 – ammonia
NDA – non-disclosure agreement
NEPA – National Environmental Policy Act of 1969
NETL – National Energy Technology Laboratory (of DOE)
NG – natural gas
NPV – net present value
OPEX – operating costs
OSBL – outside the battery limits
OSHA – Occupational Health and Safety Administration
P&ID – piping and instrumentation diagram
PEP – project execution plan
PFD – process flow diagram
Ppb – parts per billion

Ppbv – parts per billion by volume
Ppm – parts per million
Ppmv – parts per million by volume
PPS – Polk Power Station
PSA – pressure swing adsorption
PSD – Prevention of Serious Deterioration
RAM – reliability, availability, and maintainability
RFP – request for proposal
ROG – regenerator off-gas
RPDS – restricted pipe discharge system
RTI – RTI International
RTSA – reverse temperature swing adsorption
S – sulfur
Scfh – standard cubic feet per hour
Se – selenium
SEM – scanning electron microscope
SiO_2 – silicon dioxide
SO_2 – sulfur dioxide
SOPO – Statement of Project Objectives
Stpd – standard tons per day
SRU – sulfur recovery unit
TASC – total as-spent cost
TCRP – trace contaminant removal process
TEA – techno-economic analysis
TEC – Tampa Electric Company
TN – ton
TOC – total overnight cost
TPC – total plant cost
TS&M – transportation, storage, and monitoring
WDP – warm gas desulfurization process
WGCU – warm gas cleanup
WGS – water gas shift
Wt% - weight percent

XIV. Appendices

a. Appendix A – Statement of Project Objectives (SOPO)
b. Appendix B – Air Permit
c. Appendix C – Environmental Assessment
d. Appendix D – Project Execution Plan
e. Appendix E – Risk Register
f. Appendix F – Operations Summary by Week and Quarter
g. Appendix G – Process Sampling and Analysis Systems
h. Appendix H – TCRP Development and Testing
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k. Appendix K – Ammonia Pre-FEED Topical Report
l. Appendix L – Ammonia FEED Study

Appendix A

Statement of Project Objectives (SOPO)

STATEMENT OF PROJECT OBJECTIVES
(June 30, 2015)
(Revised for Amendment 0022)
DE-FE0000489

RECOVERY: Scale-up of High-Temperature Syngas Cleanup Technology

A. Objectives

The overall objective of this project is to mitigate the technical risk associated with scale up of warm syngas cleaning and carbon dioxide (CO_2) capture technologies, enabling subsequent commercial deployment.

To scale-up the warm syngas cleaning technologies, a syngas slipstream from a commercial coal gasification-based power utility will be used to demonstrate pre-commercial operation. To scale-up carbon capture, up to 300,000 tons per year of CO_2 will be captured from the cleaned syngas utilizing an advanced activated amine (aMDEA) system. The syngas cleaning system that produces the captured CO_2 product also produces a syngas product that is anticipated to be of suitable quality for chemical applications. The proposed site for this project is Tampa Electric Company's (TEC's) gasification facility at Polk Power Station located near Tampa, Florida, which operates based on a feedstock mixture of petroleum coke and coal. This site also has suitable deep saline aquifers for potential future CO_2 sequestration. Valuable geologic characterization data will be developed as part of injection well drilling at the site.

Design, construction, and operation of the proposed syngas cleaning system at pre-commercial scale will accelerate commercial deployment of novel syngas cleaning technologies for coal gasification. One of these advancements is the proposed warm syngas cleaning system which will be sized to mitigate technical risk associated with subsequent full commercial scale up.

Integration of an aMDEA process with warm syngas cleanup offers both economic and performance benefits. Although the aMDEA process is commercially used for ammonia and natural gas, the non-selective removal of H_2S with the CO_2 has prohibited application of this technology for producing a suitable CO_2 product for sequestration for gasification of fuels with high sulfur concentrations, like coal and petroleum coke. The high level of sulfur removal achieved with RTI's warm syngas cleaning system provides a product syngas from which aMDEA can produce a suitable CO_2 sequestration-ready product from gasification of fuels with high sulfur. The syngas produced by integration of warm syngas cleaning and aMDEA system also has very low contaminant concentrations. With this syngas cleaning system effectively capturing up to 90% of the CO_2 in the syngas, the syngas contaminant concentrations are anticipated to be commensurate with the Department of Energy's (DOE's) contaminant removal performance goals for chemical production from syngas shown in Table 1.

Table 1. DOE Performance Goals for Syngas Cleaning and CO_2 Removal

DOE Performance Goals	
Contaminant	Maximum After Cleanup
S (total)	50 ppb*
NH_3	10 ppm*
HCl	10 ppb*
Hg	5 ppbw*
Se	0.2 ppm*
As	5 ppb*
P	20 ppb*
CO_2	> 90%

*At pressure ≥600 psi; Temperatures ≥400ºF

The syngas cleaning units will be designed to process a syngas slipstream which would produce up to about 30 to 50 MW of power in an integrated gasification combined cycle plant. At this scale, the technical risk associated with this technology will be reduced to a commercially acceptable level for subsequent commercial deployment.

During this scale-up project, the specific objectives are to:

1. Design, engineer, procure, construct and commission the syngas cleaning pre-commercial demonstration unit and to continue operation for 5,000 to 8,000 hours to achieve the target of capturing up to 300,000 tons of CO_2/year. The syngas cleaning system will contain the following capabilities:

    - A high temperature desulfurization process (HTDP) system to process a syngas flow equivalent to about 30 to 50 MW of power and producing a desulfurized syngas with a total sulfur concentration (H_2S + COS) < 10 ppmv,
    - A water gas shift (WGS) unit to optimize the ratio of carbon monoxide, carbon dioxide, and hydrogen needed for commercial chemical production in a carbon capture and sequestration (CCS) setting,
    - A low temperature cooling unit for the cleaned syngas to enable CO_2 capture with aMDEA
    - An aMDEA unit for CO_2 capture, and
    - A drying and compression unit for the captured CO_2 product to enable its potential recycle to the syngas turbine, if required (if the captured CO_2 product can be vented directly or indirectly at lower pressure, this compression capability would likely not be needed and could be replaced with a blower).

2. Establish reliability, availability and maintenance (RAM) targets for a full-scale commercial system, based on observed performance during operation of pre-commercial scale units scaled up during this project.

3. Establish operating experience enabling start-up/shut-down, system turndown, and operator training for a commercial system.

4. Mitigate design risk for commercial plant with adequate design data obtained from pre-commercial plant operation.

5. Evaluate performance of a warm syngas Trace Contaminant Removal Process (TCRP) (including but not limited to mercury, arsenic and selenium) with a coal-derived syngas.

   - Since the IGCC system at TEC's Polk Power Station is unsuitable to fully evaluate TCRP performance, TCRP related tasks will be carried out at the commercial coal gasification facility at Eastman Chemical Company located in Kingsport, Tennessee. An existing reactor system will be used to test fixed bed sorbents for Hg, As, and Se capture. Testing with a real 100% coal-derived syngas slipstream provides performance data that should be representative of typical operation of these sorbents in commercial deployment.
   - The performance goals for TCRP are updated to be responsive to the Environmental Protection Agency's proposed Mercury (Hg) and other Air Toxics (e.g., As, Se, Cd, HCl) Standards. The key success criteria to be used during this experimental testing for Hg, As, and Se in this project are shown below. At this time, the scope of this task is limited to Hg, As, and Se. In the future, this scope could be increased to include other air toxics emissions to meet EPA's proposed limits by mutual consent of DOE and RTI.

Coal Syngas Contaminants	EPA Limits (New IGCC)	Syngas Contaminant limits for project
Hg	0.003 lb/GWh	3 ppbw
As	0.020 lb/GWh	20 ppbw
Se	0.30 lb/GWh	300 ppbw
Cd	0.002 lb/GWh	TBD
HCl	2.0 lb/GWh	TBD

*Assumes a heat rate of 7000 Btu/kWh and a syngas heating value of 7,000 Btu/lb
TBD: To be established as the scope of this task is expanded to include other air toxics beyond Hg, Se, and As

6. To augment information learned from aMDEA integration with warm syngas cleanup at TEC's Polk Power Station, and to offer a comparison of potential benefits of emerging CO_2 sorbent technology against the more mature aMDEA technology, a specific objective of this project is to complete the development of the RTI novel CO_2 sorbent.
   - RTI has developed a novel CO_2 sorbent for pre-combustion carbon capture in conjunction with RTI's warm gas cleanup (WGCU) process. The goal of this sorbent-based technology is to capture >90% CO_2 present in syngas at lower cost than conventional technologies (e.g., the aMDEA technology being integrated with scaled up warm gas cleanup at TEC's Polk Power Station).
   - This effort is responsive to the more general DOE program goal to develop carbon capture technology having <10% increase in cost of electricity (COE) for an IGCC plant.

B. Scope of Project

This project will accomplish cleaning of syngas at a pre-commercial scale and integrate CO_2 capture from the entire cleaned syngas stream from the HTDP, up to 300,000 tons/year of CO_2. The syngas stream will be generated from a commercial gasification system (i.e. TEC's Polk Power Station) being operated with a feedstock mixture of petroleum coke and coal. The proposed syngas cleaning system integrates RTI's warm syngas cleaning system and an aMDEA system with the intention of accelerating commercial deployment of these technologies for gasification of coal and petroleum coke. This syngas cleaning system targets removal of the most significant coal contaminants from syngas up to DOE programmatic specifications for chemical production applications.

Scale-up activities to be accomplished in this project are based on field testing of these technologies with real syngas from Eastman Chemical Company's gasifier under DOE Contract DE-AC26-99FT40675 and work under the DOE Cooperative Agreement DE-FC26-05NT42459.

In support of the evaluation of TCRP performance, testing to validate developments for higher capture performance of Hg, As and Se capture will be accomplished using syngas from the Eastman Chemical (Kingsport, TN) facility. This effort will include testing with real coal-derived syngas that is generated from bituminous coals, which is more representative of expected commercial conditions than is petroleum coke derived syngas, with respect to trace contaminant control requirements. This project will include the development of technologies to remove Hg, As, and Se from syngas to meet the new EPA limits for IGCC. Development of additional technologies for removal of other significant coal contaminants (e.g., Cd and HCl) can be added by mutual consent of DOE and RTI. The information collected from the experimental work will evaluate the potential for reducing capital cost and process complexity, while increasing performance and reliability for commercial application of this technology.

In support of analyzing the potential benefits of emerging CO_2 capture technology over more mature capture technologies, RTI will utilize its existing laboratory facilities, and potentially on-stream syngas testing capability at Eastman Chemical Company or the TEC project site, to develop and test a novel CO_2 capture sorbent. The tests shall provide information necessary for a DOE techno-economic assessment, to conclude whether significant process efficiency improvements and/or DOE programmatic goals on economics of carbon capture can be attained with subsequent commercialization.

C. Tasks to be Performed

The project has been divided into seven tasks. These tasks are organized to:

- Complete a preliminary design study
- Prepare the Front End Engineering and Design (FEED) package and environmental and NEPA permitting
- Complete detailed engineering design, procurement, and construction of the syngas cleaning and carbon capture systems
- Commission and startup the syngas cleaning and carbon capture systems

- Continue development and demonstration of TCRP, direct sulfur recovery process (DSRP), and warm CO_2 removal technologies
- Operate the syngas cleaning and carbon capture systems to obtain performance and reliability data
- Decommission the syngas cleaning and carbon capture systems or leave them in place for potential continued operation

Each task consists of a number of subtasks which support a specialized work assignment supporting the overall task and project goals. The preliminary design study will be used to fully define the project by developing contractual agreements with subcontractors outlining their roles and responsibilities. The syngas cleaning and CO_2 capture system will be composed of RTI's warm syngas cleaning technologies, a water gas shift system, an aMDEA system, and a CO_2 drying and compression system (if needed for recycle of the CO_2 to the syngas turbine instead of venting). Engineering, procurement, and construction (EPC) of this system will proceed through the conventional FEED and engineering, procurement and construction activities. Key design information developed during the preliminary design will be used to support obtaining all necessary environmental and NEPA permitting. The goal will be to operate the syngas cleaning and CO_2 capture system for 5,000 to 8,000 hours and effectively capture up to 300,000 tons/year of CO_2 while demonstrating up to 90% CO_2 capture and producing a syngas suitable for chemical production. At the conclusion of the operations period a decision will be made whether to decommission the syngas cleaning and carbon capture systems or leave them in place for potential continued operation. In parallel to the construction, commissioning, and operation of the syngas cleaning and carbon capture systems, continued development and demonstration of warm syngas TCRP technologies, DSRP technology, and warm CO_2 removal technology will be pursued.

Budget Period 1 – Project Management and Planning

The work in this Budget Period is divided into two categories: (1) Tasks to be performed with Advanced Integrated Gasification Combined Cycle (AIGCC) Program Funds, designated with an "A" suffix after task number, and (2) Tasks to be performed with American Recovery and Reinvestment Act (ARRA) Industrial Carbon Capture and Sequestration (ICCS) funds, designated with a "B" suffix after task number.

THE FOLLOWING TASKS, DESIGNATED WITH THE "A" SUFFIX FOLLOWING THE TASK NUMBER, ARE NOT FUNDED BY ARRA FUNDS:

Task 1-A: Preliminary Design Study Supporting Scale-up of HTDP, DSRP, and TCRP Units

The objective of this task will be to develop a firm design basis for the syngas cleaning system being developed for this project. One of the primary challenges with preparing this design basis is that the different technologies being incorporated are at different development stages. To facilitate scale up of the HTDP, DSRP and TCRP, a PreFEED package will be prepared for these units. This package will provide a process design that can be used to effectively incorporate the warm syngas cleaning technologies into the full syngas cleaning system and integrated with the existing equipment, systems, and space available at TEC's Polk Power Station. This will enable preparation of a preliminary design basis for the full syngas cleaning system for starting the FEED package in Task 2-B. Preparation of a Pre-FEED package for the warm syngas cleaning technologies also enables identification of any additional experimental work that will be necessary to reduce any remaining technical risks associated with the pre-commercial syngas cleaning system. This task has been divided into four subtasks described below.

Subtask 1.1-A: Selection of Engineering Partner

A number of target engineering companies will be approached to provide bids for preparation of the FEED package and definitive cost estimate for the warm syngas cleanup systems, which include the HTDP, DSRP, TCRP units. These bids will be evaluated and scored. The scoring of these bids will be accomplished with weighted response factors for technical value of proposed design, previous technical experience with similar technologies, previous project-related experience with TEC, Eastman or RTI, technical/engineering reputation, and cost. Results of this bid evaluation will be shared with DOE/NETL and in consultation with DOE/NETL, a decision on selection of the engineering partner will be made.

Subtask 1.2-A: Preparation of the Pre-Feed Package for the HTDP, DSRP, and TCRP Units

RTI, Eastman, and TEC will be intimately involved in the development of this Pre-FEED package by providing and reviewing the design for consistency with known design issues from the pilot plant testing at Eastman and integration with TEC's equipment and facilities. The engineering partner selected in Task 1.1-A will prepare a Pre-FEED package consisting of the following items:

- Design basis
- Equipment sizing with backup calculation and data.
- Design parameters and scale-up strategies
- Validated process simulation model
- Identified material of construction for critical equipment
- Preliminary plot plan
- Process Flow Diagram(s) (PFD)
- Preliminary Piping and Instrumentation Diagrams (P&IDs)
- Heat and Material Balance tables (HMBs) for multiple design cases
- Start-up and shut down procedures
- Control philosophy
- ± 30% budget estimate

This Pre-FEED package for warm syngas cleaning will serve to help develop the design basis for the full syngas cleaning system, which includes the CO_2 capture and conditioning for potential long-term storage in a deep saline reservoir. Any information gaps requiring further testing, process simulation or CFD work will be identified at this stage.

Subtask 1.3-A: Experimental Support to Fill Technical Information Gaps for the FEED Package

One of the elements included in the Pre-FEED package will be a description of critical information gaps that still exist and increase the technical risk associated with scale up of the warm syngas cleaning technologies. This subtask will be used to support closing these information gaps to enable successful operation of the pre-commercial syngas cleaning system. For any experimental work necessary to address these information gaps, a test plan will be developed. The test plan will include: overall PFD highlighting integration of test components/processes, feed type(s), tests durations, input conditions (each unit), measurements to be taken (what will be measured, measurement device type and sensitivity limits, location of measurement, frequency, etc.), and test goals and success criteria. Test goals and success criteria will focus on attaining critical information necessary for establishing a design basis and preparing the FEED package.

Subtask 1.4-A: Preparation of Design Basis for the FEED Package

The FEED package for the full syngas cleaning system integrates the activated MDEA CO_2 capture and conditioning of the CO_2 product for potential long term sequestration. In addition to the technical challenges involved, the FEED package must effectively integrate with the existing gasification system at TEC with minimal disruption. Finally, the FEED package needs to provide critical information supporting the necessary permitting applications as soon as possible to ensure approved permits are available on schedule to allow EPC work to start.

This will require investigating different process configurations to achieve performance targets for the syngas cleaning system, simplifying the permitting process as much as possible, and optimize integration into TEC's existing gasification plant with minimal impact. The key information generated by this subtask will be a preliminary process flow sheet and preliminary mass and energy balances for the full syngas cleaning system that will be used as the design basis for the FEED package.

Subtask 1.5-A: TCRP Sorbent Development and Testing

Subtask 1.5.1-A – Test Plan: RTI will provide a complete and comprehensive field test plan at Eastman (including operational parameters levels) to DOE Project Manager. DOE Project Manager concurrence is required prior to initiation of applicable tests. The test plan must include experiments at anticipated operating conditions and: overall PFD highlighting integration of test components/processes, feed type(s), tests durations, input conditions (each unit), measurements to be taken (what will be measured, measurement device type and sensitivity limits, location of measurement, frequency, etc.), and test goals and success criteria. Test goals and success criteria must correspond to the project goals. The test plan must also include data collection to establish procedures for steady state operation, and system start-up, shut-down and turndown and to enable risk minimization for a commercial plant. The DOE Project Manager must be provided the test plan prior to beginning of the tests.

Subtask 1.5.2-A – Tests: Perform tests according to the approved test plan. Notify DOE Project Manager of any changes needed to the test plan before implementing them.

<u>Decision Point on continued activity under Subtask 1.5-A</u>:
Upon conclusion of Subtask 1.5.2-A, RTI will provide sufficient information to DOE so that an informed conclusion on whether to continue support of this technology is warranted. RTI will at least provide: (1) details of the tests performed, including operating pressure, inlet and exit gas component concentrations, and process temperature profile through the bed; and (2) results, analysis, and conclusions from the Subtask 1.5-A activities with regard to the success criteria.

When determining the proper course of action with respect to the decision point, continued development of the TCRP will be considered only if DOE techno-economic analysis indicates that removal of Hg and other air toxics from representative IGCC shifted syngas, using the RTI technology, has the potential to meet new EPA limits and support DOE performance and economic goals. If DOE decides to pursue continued development of this technology, this work will be conducted under Subtask 5.1 of Budget Period 2.

Subtask 1.6-A: RTI Novel CO_2 Sorbent Development, Testing, and Analysis

Tests using a high pressure reactor system will be performed to demonstrate both CO_2 removal capacity and suitable regeneration properties on candidate sorbent material, under anticipated operating conditions. This performance data will be used to validate engineering issues relating to reaction rates, heat transfer rates, integration of water gas shift to reduce steam use, and CO_2 effluent profiles for both CO_2 capture and regeneration.

Subtask 1.6.1-A – Test Plan: RTI will provide a complete and comprehensive test plan (including operational parameters levels) to DOE Project Manager. DOE Project Manager concurrence is required prior to initiation of applicable tests. The test plan must at least include experiments at anticipated operating conditions, with data collection sufficient to be able to:

1. Determine the reaction rates for: (1) CO_2 absorption onto fully CO_2 loaded sorbent (when the absorber bed will be switched to regeneration mode), (2) CO_2 absorption onto newly regenerated sorbent, (3) desorption from fully loaded sorbent, (4) desorption from just regenerated sorbent, and (5) intermediary points as needed to show that rates will be sufficiently fast so that the capital costs of the reactor are not excessive.
2. Estimate the limits of CO_2 loading on the sorbent in a commercial system.
3. Estimate parasitic power losses in a commercial system.
4. Understand the advantages and disadvantages of water-gas-shift integration.
5. Estimate sorbent attrition rates in a commercial system.
6. Indicate sufficient temperature control will be feasible in a commercial system.

Success criteria for each of the above items must be provided with the plan.

Subtask 1.6.2-A – Tests: Perform tests according to the approved test plan. Notify DOE Project Manager of any changes needed to the test plan before implementing them.

<u>Decision Point on continued activity under Subtask 1.6-A</u>:
Upon conclusion of Subtask 1.6.2-A, RTI will provide sufficient information to DOE so that an informed conclusion on whether to continue support of RTI novel CO_2 sorbent is warranted. RTI will at least provide: (1) details of the tests performed, including operating pressure, feed and exit gas compositions and changes, and temperature and temperature changes through the bed, (2) data to support each of the items in subtask 2.1, and (3) conclusions from the experiments with regard to the success criteria.

Field Testing of regenerable CO_2 sorbent will be considered if DOE techno-economic analysis indicates that removal of CO_2 from representative IGCC shifted syngas, using the RTI technology, has the potential to support DOE performance and economic goals. If DOE decides to pursue field testing of this technology, this work will be conducted under Subtask 5.3 of Budget Period 2.

Subtask 1.7-A: Ammonia/Urea Integration Study

The integration of RTI's warm syngas cleanup technology for sulfur removal (HTDP) with RTI's warm syngas TCRP technologies offers options to achieve syngas cleanup to very low contaminant levels at costs substantially below that of conventional processes, thus expanding the application of RTI's warm gas cleanup technologies beyond clean power generation to applications such as chemicals, fertilizers, fuels, and hydrogen. Successful use of RTI's warm gas cleanup technologies in these industrial applications will demonstrate the technologies' reliability and economic advantage when needed to support lower cost, ultra-clean coal power generation projects with carbon capture.

To help understand the potential value of these integrated syngas cleanup technologies for poly-generation and/or stand-alone chemicals/fertilizers/ hydrogen production, a study (approximately pre-FEED level) will be conducted to develop a techno-economic assessment of these options using ammonia and urea production as the study basis. Two scales of these processes will be considered, as described in Subtask 1.7.1-A below.

The overall study and techno-economic analyses would be conducted utilizing information provided by an established technology supplier for ammonia and urea plants with process integration assistance from AMEC Kamtech Inc., the EPC contractor for the warm syngas demonstration project at TEC. The results of these studies would be provided to DOE/NETL as valuable information to assist in their own techno-economic modeling studies.

Subtask 1.7.1-A: Feasibility Study for Ammonia/Urea Facilities

An established technology supplier will be contracted to provide a feasibility study for the following ammonia and urea plants for potential integration with the TEC Polk IGCC site:

- A 300 short-tons per day ammonia process and its associated equivalent-scale urea process (sized at 520 short-tons per day to use all 300 short-tons per day of ammonia production and approximately a third of all captured CO_2). This scale is sized to utilize all of the hydrogen produced from the warm syngas proof-of-concept project at TEC and thus evaluate a case involving polygeneration.

- A 1500 short-tons per day ammonia process and its associated equivalent-scale urea process (sized at 2600 short-tons per day to use all 1500 short-tons per day of ammonia production and approximately a third of all captured CO_2). This scale is sized to utilize all of the hydrogen produced from scale-up of the warm syngas cleanup technologies to treat all of the raw syngas produced from the gasifier at TEC and thus evaluate a case involving a standalone fertilizer production process as retrofit for the Polk IGCC facility.

The contracted feasibility study should include a design basis, process and technology descriptions, process flow diagram, heat and material balance (major streams only), feed material requirements and specifications, utilities specifications and consumption, overall space requirement, and budgetary capital cost estimate for each of the above study options.

Subtask 1.7.2-A: Feasibility Study for Integration of Ammonia/Urea Plants into TEC Polk Site

AMEC Kamtech Inc. will be contracted to provide a feasibility study for integration of each of the ammonia and urea plant options from Subtask 1.7.1-A into the existing TEC Polk IGCC site. This feasibility study would address the needs to meet feed specifications and consumption, utility specifications and consumption, and any integration requirements for installation of the proposed ammonia/urea plant options at the TEC Polk site. For the 300 short-tons per day ammonia case (and corresponding urea plant case) this would include any required modifications to the existing TEC plant equipment and to the warm syngas cleanup technologies equipment installed as part of this overall project. For the 1500 short-tons per day ammonia case (and corresponding urea plant case) this would include addition of a new or expanded full-scale warm syngas cleanup technology system, conversion of the existing TEC syngas turbine to natural gas firing, and any process equipment modifications required to integrate the ammonia and/or urea plants with the existing TEC Polk site. As part of this feasibility study, AMEC Kamtech Inc. will also review the feasibility study deliverables from the ammonia/urea technology provider in Subtask 1.7.1-A and suggest modifications to any assumptions made therein with regard to construction labor costs and productivity and commodity piping, steel, electrical costs, etc. in order to reflect AMEC's more accurate knowledge of local site costs/values for such items.

Subtask 1.7.3-A: Techno-economic Analyses for Integration of Ammonia/Urea Plants

Data from the feasibility studies described in Subtasks 1.7.1-A and 1.7.2-A above will be used by RTI, with input and review from TEC, to conduct techno-economic analyses for the various proposed ammonia and urea integration cases. The techno-economic analyses will be focused at determining the viability of such options for retrofit of an IGCC site such as the TEC Polk plant for cases involving polygeneration and/or complete retrofit.

At the conclusion of the techno-economic analyses, the results will be shared in a detailed briefing to the DOE Project Manager at NETL and in a topical report to DOE. Deliverables to DOE from Subtask 1.7-A will include the following for each of the above study options:

- design basis and assumptions,
- process and technology descriptions,
- process flow diagrams,
- heat and material balances (major streams only),
- feed material requirements and specifications,
- utilities specifications and consumption,
- budgetary capital cost estimates, and
- techno-economic analysis results and conclusions.

THE FOLLOWING TASKS, DESIGNATED WITH THE "B" SUFFIX FOLLOWING THE TASK NUMBER, ARE TO BE FUNDED BY ARRA FUNDS:

Task 1-B: Project Management and Planning

As the Recipient, RTI will have the overall responsibility of ensuring all project tasks in each Budget Period of the project are performed and delivered with the highest scientific quality and integrity, on schedule, and within budget to DOE. RTI will also be responsible for project management, coordinating the interactions with the DOE/NETL, and coordinating the activities of the project partners. To effectively manage the risk associated with this project, RTI has assembled a strong team that includes (i) the Tampa Electric Company (TEC) – responsible for providing the site, the syngas slipstream, process utilities, and the process operators for the project, (ii) Shaw Group Incorporated (Shaw) – responsible for completing the FEED, (iii) AMEC Kamtech, Inc. (AMEC) – responsible for EPC of the overall syngas cleaning system and providing assistance in commissioning and operating of the syngas cleaning system, (iv) BASF Corporation – responsible for providing the solvent and the technology package for their aMDEA-based CO_2 capture technology, and (v) Sud-Chemie Incorporated (SCI) – responsible for providing the sorbents and catalysts for the HTDP, DSRP and WGS units. Each of these organizations is a recognized industry leader in their respective fields and their capabilities encompass complimentary experience and expertise critical to successful execution of this project. To further enhance its project management capability for a project of this scale and scope, RTI is also considering engaging an experienced engineering firm which will act as the "owner's engineer" to oversee the overall project management on RTI's behalf. If selected, the owner's engineer will provide a team of 5-6 experienced personnel including an overall project manager, engineering manager, quality and safety manager, constructability manager, and cost and schedule control manager. The owner's engineer would act as RTI's eyes and ears on the ground ensuring the project is executed according to the plan in an efficient manner and in full alignment with DOE's goals and objectives in the field of high temperature syngas cleanup and carbon management.

The following two subtasks must be completed before moving onto any other aspect of the project:

Subtask 1.1-B: Project Manager Identification

The Recipient must identify a project manager (PM) for the project. This individual must have significant project management experience directly applicable to the management needs of this project, especially with respect to its size and complexity. This individual must also have corporate support including: access to the necessary project management tools, personnel assistance as needed, and PM replacement capability. The DOE Project Manager approval is required to staff this position, and replacements.

Subtask 1.2-B: Project Management Plan (PMP):

The Recipient shall manage and direct the project in accordance with a Project Management Plan (sample format provided below) to meet all technical, schedule and budget objectives and requirements. The Recipient will manage, coordinate and report on the technical scope, budget and schedule basis consistent with a task-oriented work breakdown structure in order to effectively accomplish the work. The Recipient shall ensure that project plans, results, and decisions are appropriately documented and project reporting and briefing requirements are satisfied.

The Recipient will update the Project Management Plan as necessary to accurately reflect current status of the project. Examples of when it may be appropriate to update the Project Management Plan include: (a) project management policy and procedural changes; (b) changes to the technical, cost, and/or schedule baseline for the project; (c) significant changes in scope, methods, or approaches; or, (d) as otherwise required to ensure that the plan is the appropriate governing document for the work required to accomplish the project objectives.

Management of project risks shall occur in accordance with the risk management methodology delineated in the Project Management Plan in order to identify, assess, monitor and mitigate technical uncertainties as well as schedule, budgetary and environmental risks associated with all aspects of the project. The results and status of the risk management process shall be presented during project reviews and in Progress Reports with emphasis placed on the medium- and high-risk items.

The Project Management Plan Sample Format follows. **Please note for these ARRA projects, Risk Management, Milestone Log, Funding and Costing Profile, and Resource Loaded Schedule are required sections of the Project Management Plan.**

Project Management Plan Sample Format:
1. Executive Summary: Succinctly describe of the project, background, rationale, goals, and objectives.
2. Risk Management: Identify significant technical, resource, and management issues that have the potential to impede project progress and strategies to minimize impacts from those issues.
3. Milestone Log: Provide a table of significant technical and management project milestones, including milestone title, planned completion date and a description of the method/process/measure used to verify completion. Milestones should be quantitative and show progression towards project goals.
4. Funding and Costing Profile: Provide a table that shows, by fiscal quarter and budget period, the amount of government funding going to each team member/subcontractor along with the associated cost share. This is the project Funding Profile. Provide a second table that projects, by fiscal quarter and budget period, the expenditure of government funding going to each team member/subcontractor along with associated cost share. This is the project Baseline Cost Plan.
5. Resource Loaded Schedule: Provide a schedule timeline of the project (similar to a Gantt Chart) broken down by SOPO task and subtask that incorporates (is consistent with) the work breakdown structure, and funding and cost profiles. The timeline should also show any interdependencies and note project milestones.
6. Organization Structure and Management: Provide a chart showing the entities (Recipient, subcontractors, consultants, etc.), relationships, roles (referenced to SOPO tasks and subtasks) and lead personnel for the project team. Specifically identify key personnel, defined as those personnel deemed critical to project success.
7. Success Criteria at Decision Points: Provide success criteria for each decision point in the project, including go/no-go decision points and the conclusions of budget periods and the entire project. The success criteria should be objective and stated in terms of specific, measurable,

and repeatable data. Usually, the success criteria pertain to desirable outcomes, results, and observations from the project.

<u>Decision Point</u>: **Do not proceed to Task 2-B without written approval from the DOE Contracting Officer for the selection of a qualified Recipient Project Manager. Do not proceed to Task 2-B without Federal Project Manager approval of an acceptable PMP produced in Subtask and 1.2-B.**

Subtask 1.3-B: Management of the Project

To enable execution of this project, the project management task will be further divided into the following subtasks, to mirror the ARRA-funded project tasks preceding Task 1-B:

Subtask 1.3.1-B: Teaming Agreements with Project Partners

In parallel to submission of PMP described in Subtask 1.2-B, RTI will initiate formal subcontract negotiations with the individual partners and develop statement of work documents for each project partner. RTI will also discuss with its project partners particularly with Shaw and make a decision on the need for hiring the owner's engineer. If mutually acceptable, RTI will select an engineering firm as owner's engineer. Selection of the owner's engineer is one method of satisfying requirements set forth in Subtasks 1.1 and 1.2. During this subtask, RTI will also assist TEC to file the local, state and federal permitting and environmental assessment applications. By the end of this Budget Period, the following will be completed: (i) approved PMP (ii) subcontract negotiations with its partners, (iii) an agreement on clearly defined roles and responsibilities of each project partner, (iv) Identification of Project Manager and associated support team (includes a decision on hiring and selection of an owner's engineer), (v) establishment of a preliminary process flowsheet, and (vi) initial filing of the local, state and federal permitting and environmental assessment applications.

Subtask 1.3.2-B: Management of the FEED Effort

RTI, through its Project Manager and associated team, will oversee the development of FEED package as described in Task 2-B. By the end of FEED task a ± 20% cost estimate will be developed for the EPC task so that the Project Manager and DOE will have the tools to complete the project within budget.

Subtask 1.3.3-B: Management of the EPC Effort

During this subtask, AMEC, RTI's Engineering Partner for the project, will perform the detailed engineering as described in Task

3-B and based on information specified in the FEED package. During this subtask, RTI, through its Project Manager and associated team, will interact with its project partners and will ensure that the deliverables assigned to individual partners are delivered on schedule and within budget. This subtask will be continued in Budget Period 2.

Subtask 1.3.4-B: Management of Commissioning, Operation, and Decommissioning Efforts

RTI, through its Project Manager and associated team, will ensure that the project's scaled-up plant is commissioned and operated with minimal impact to TECO's ongoing operations. Under this management subtask, the Project Manager will assure that Task 4 activities occur according to the roles and responsibilities agreed in the teaming agreements (Subtask 1.3.1-B). This subtask will be continued in Budget Periods 2 and 3.

Task 2-B: Front End Engineering and Design (FEED)

The objective of this task will be to prepare a FEED package and a definitive cost estimate for the project. The specific units to be included in the syngas cleaning system include (1) a water gas shift unit, (2) a high temperature desulfurization process (HTDP) unit, (3) a Direct Sulfur Recovery Process (DSRP) unit, (4) a Trace Contaminant Removal Process (TCRP) unit (including but not limited to mercury, arsenic and selenium), (4) a low temperature cooling unit for the syngas, (5) an aMDEA unit for CO_2 capture, and (6) a drying and compression unit for the potential CO_2 sequestration product. This FEED package will build upon the design basis defined in Task 1.4-A and Pre-FEED package developed in Subtask 1.2-A.

Beyond the technical aspects of this integration, preparation of this FEED package will be used to provide technical design and operating information necessary to complete the environmental permitting applications and a design hazard review for the syngas cleaning and CO_2 capture systems.

Subtask 2.1-B: Preparation of FEED Package

RTI, Shaw, BASF, and TEC will be intimately involved in the development of the FEED package by providing and reviewing the design for consistency with known design issues from the pilot plant testing at Eastman and integration with TEC's equipment and facilities. The design review will include potential iterations of unit sizes to optimize support of up to 90% CO_2 capture and potential sequestering of up to 300,000 ton/year of CO_2 in a deep saline reservoir.

The FEED package will consist of the following items:

- Project description
- Soil investigation
- Plot plan – Issued for Design (IFD)
- Process flow diagrams (PFDs) – IFD
- Piping and instrumentation diagrams (P&IDs) –IFD
- Detailed equipment list with final sizes and specifications
- General arrangement diagrams –IFD
- Equipment quotations – firm quotes ready for requisition
- Final specification for power and lighting requirements
- Hazardous area classification
- Preliminary design hazard review
- Hazardous energy control review
- Material take-off for structural steel, piping, valves, fitting, etc
- Definitive estimate for home office and field labor, including construction indirects
- Master schedule with milestones

Using the information in the FEED package, the engineering partner will prepare a ± 20% budget estimate for engineering, procurement, and construction. In addition to this estimate, the project team will develop a budget estimate for commissioning/start up activities and for 5,000 to 8,000 hours of operation.

Subtask 2.2-B: Environmental Permitting

For the proposed project, environmental assessments for both the Department of Energy's National Energy Technology Laboratory (NETL) and local and state environmental permitting agencies are required. The following two subtasks include the preparation of the specific environmental permitting applications. No field work will be initiated until a written approval from DOE/NETL is received that the proposed project meets the National Environmental Policy Act (NEPA) requirements, unless authorization is provided for specific activities from the Contracting Officer. No construction work will be commenced at TEC's site until relevant permitting has been approved.

Subtask 2.2.1-B: Support for Preparation of Environmental Assessment (EA) Document by DOE

Support DOE's effort to prepare an EA document and the review and approval process to meet the NEPA requirements.

Subtask 2.2.2-B: Local and State Permitting

Documentation and applications necessary for local and state environmental permits will be prepared. In addition to preparation of the permit applications, several face-to-face meetings with the Florida Department of Environmental Protection (FDEP) Siting Coordination Office and Air Regulation staff will be arranged.

Based on the preliminary evaluation of the planned design, construction, and operation in this project, no change in existing and/or allowable emission rates compared to current rates at the Polk Power Station are anticipated. As a result, the permitting effort is expected to require only a minor air construction permit and an amendment to the existing Polk site certification. Furthermore, no other permits or permit modifications are currently considered necessary for water use, wastewater discharge or storm water management. This task assumes that the agency review process and permit modification and post-certification amendment are non-controversial and no parties file objections.

Subtask 2.3-B: Site Characterization Work for Deep Saline Reservoir Injection Well

TEC has drilled an on-site well for injection of plant wastewater (IW-1) and is in the process of drilling a second on-site injection well (IW-2) for injection of plant wastewater and for the potential future sequestration of CO_2. Along with IW-2, TEC will also be drilling a dual-zone monitoring well and a potential injection zone monitoring well as part of this effort. Modeling, permitting, and drilling/construction efforts related to all of these wells have together enabled the collection of a wealth of valuable geologic characterization data and information for this site. These data are valuable to the DOE and will be provided by TEC to the DOE as part of this project. Key anticipated elements of this data will include:

- Modeling work done by the University of South Florida (USF) to develop a preliminary model of the site using reservoir data available in the literature. This model was used to simulate the radial extent and pressure buildup from potential CO_2 injection at the Polk Power Station. These model predictions were used to select potential well sites on TEC's site that would ensure that the CO_2 plume generated in this project would stay within Polk Power Station property boundary if it were injected as part of the project. Prior to construction of the IW-2 well, additional information gathered (e.g., on permeability of CO_2 through the rock) during the construction of the wastewater injection well (IW-1) was used to update the model and reassess the proposed site for the IW-2 injection well.

- Part of the installation of the IW-2 injection well will include hydrologic injectivity testing. This testing will be used to infer field-scale permeability, flow geometry, and boundaries of storage formation. These new data will be used to improve the geologic static model and provide more accurate reservoir simulations predicting the size and shape of the CO_2 plume over time.

- Site characterization data were obtained as part of drilling IW-1 and additional site characterization data will be obtained as part of drilling IW-2 and/or specifically for providing such data to DOE. These data are planned to include:

  - Core data collected from various depths as part of drilling each of these wells.

  - Log data such as self-potential logs, gamma ray, density, caliper porosity, induction (resistivity), nuclear magnetic resonance, and acoustic (sonic) logs.

  - Borehole geophysical logs covering geology, lithology, and hydrogeology.

  - Well construction, cementing, and integrity casing logs.

  - Geochemical/fluid sampling data from water samples, including chemical composition, pH, total dissolved solids and other analyses as required by the TEC drilling and packer testing sampling programs.

  - 2-D Seismic survey data to help characterize the geology and correlate with log data.

Due to the time required to drill this well, construction will start as soon as the appropriate UIC well permits are in place. Since IW-2 well construction will extend beyond Budget Period 1 into Budget Period 2, this work will be continued under Subtask 3.4.

Subtask 2.4-B: Initiate Detailed Engineering

The FEED package will be the basis for a detailed engineering design. RTI will work with the EPC contractor to start detailed engineering as part of this subtask. These activities will include development of P&IDs, datasheets, issuance of requests for proposal for major equipment items, bid tab analysis, development of purchase orders for major equipment items, and finalization of site civil plans. Additionally, materials for tie-in equipment will be designed, purchased, and installed at TEC's facility as part of a scheduled shutdown of the TEC IGCC facility. The tie-in materials shall include valves and electrical switchgear equipment. This work will be continued in Budget Period 2 under Subtask 3.1.

Decision Point: Do not proceed into Budget Period 2 without written approval from the DOE Contracting Officer. NEPA documents, such as EA, must be in place to enter into Budget Period 2.

Budget Period 2 – Engineering, Procurement, and Construction Phase

NOTE: Unlike the work in Budget Period 1, which has tasks funded by both program funds and ARRA funds, the tasks in Budget Period 2 were funded from ARRA Funds. Therefore the use of suffixes is not used in Budget Period 2. Because expenditure of funds under Budget Period 2 may extend into the Operational Phase of the project due to delivery and installation of some long lead-time equipment and potential for warranty repairs discovered during normal operations, Budget Period 2 will run concurrently with Budget Period 3.

Task 3: Engineering, Procurement, and Construction (EPC)

The FEED package will be used to complete detailed design of the syngas cleaning system. This is a continuation of Subtask 2.4-B from Budget Period 1. This detailed design package will contain all the necessary information to procure all the equipment materials and supplies and construct the specific units included in the syngas cleaning system. This task also includes the actual work to provide geologic characterization data at TEC's site for the potential long term geological storage of captured CO_2 product.

Subtask 3.1: Detailed Design

The detailed design will be used to finalize the following

- Project description
- Soil investigation
- Plot plan – Issued for Construction (IFC)
- Process flow diagrams (PFDs) – IFC
- Piping and instrumentation diagrams (P&IDs) –IFC
- Detailed equipment list with final sizes and specifications
- General arrangement diagrams –IFC
- Equipment quotations – firm quotes ready for requisition
- Final specification for power and lighting requirements
- Hazardous area classification
- Final design hazard review

- Hazardous energy control review
- Material take-off for structural steel, piping, valves, fitting, etc
- Definitive estimate for home office and field labor, including construction indirects
- Master schedule with milestones
- Decision (as part of Budget Period 2 detailed engineering) on whether to recycle captured CO_2 back to the syngas turbine or to vent it through either the heat recovery steam generator (HRSG) or another stand-alone or existing vent. This decision will be used to establish the final design basis for handling captured CO_2 from the activated MDEA unit.

These items will also be used to complete a detailed cost estimate for the syngas cleanup system. Another action that will be completed during the detailed design is conducting a final design hazard review for the syngas cleaning system, shift reaction system, and CO_2 capture system. Any issues identified during this review will be addressed and implemented prior to construction of the system.

Subtask 3.2: Procurement

Procurement will start as soon as engineering from Subtask 3.1 starts developing the technical specifications for each piece of equipment. Therefore, Subtask 3.1 and Subtask 3.2 will run concurrently. The concurrent activities are necessary to support engineering design, lock in equipment pricing, and lock in delivery schedule.

Additionally, RTI will work with Süd Chemie to procure the required quantities of the RTI-3 sorbent and various catalysts for this project.

Subtask 3.3: Construction

Construction will start as soon as all permits are in place and IFC drawings for early construction activities (such as underground, civil foundations, pipe rack, and piping tie-ins) are issued. During this phase, all mechanical equipment will be set, structural steel erected, civil foundations poured, pipe installed and hydro-tested, electrical and instrumentation wiring completed, instrumentation installed, motor control center (MCCs) installed, and insulation and painting completed. Additionally, TEC will install a natural gas fuel line to the syngas turbine to reduce operational costs for electric power and steam associated with the warm syngas cleanup demonstration facility operation.

Subtask 3.4: Continue IW-2 Well Construction for Geologic Characterization Data

IW-2 well construction will continue during this budget period. Work under this task will be an extension of the work previously described under Subtask 2.3-B.

Task 4: Commissioning and Startup

After final construction activities of the syngas cleaning systems are completed, commissioning and startup of the systems will begin. The main commissioning activities will be used to demonstrate that the system has been constructed according to plans and that it is operationally functional. Specific activities to be performed as part of commissioning and shakedown are pressure testing, leak checks, proper functioning of all the instrumentation and controls, and functioning of units in the syngas cleaning system.

In addition to these activities, a pre-commissioning design hazard review (Process HAZOP) will be conducted and operators trained. Pre-commissioning activities will also include the preparation of all operations procedures and manuals, including procedures for normal and transient operations such as start-ups, normal shutdowns, and emergency shutdowns.

Task 5: Continued Development and Demonstration of TCRP, DSRP and Warm CO_2 Removal Technologies

DECISION POINT: Recipient shall not initiate Task 5.1 without the DOE Contracting Officer's written approval, as described in Task 1.5-A of this SOPO and the Decision Point article of this Cooperative Agreement.

Task 5.1 TCRP Sorbent Development and Testing

If the DOE/NETL techno-economic analysis based on the work completed in Task 1.5-A indicates that removal of Hg and other air toxics from representative IGCC shifted syngas, using the RTI technology, has the potential to meet new EPA limits and support DOE performance and economic goals and sufficient funds are available in this budget period, RTI will prepare a subtask plan and a budget for this task and submit it for DOE review and approval.

The objective of this task will be to get the RTI technology ready for commercial exploitation addressing Hg, As, Se, (based on results from Task 1.5-A) HCl, and NH_3 (listed in Table 1). Optimum integration of these trace contaminant removal technologies with warm sulfur removal and possibly warm CO_2 removal processes will be critical to reduce the overall capital and operating costs and increase the thermal efficiency. Removal of these contaminants is very critical to use the syngas for production of chemicals and fuels. All the field test work for this task will be done at the Coal-to-Chemicals facility at Eastman Chemical in Kingsport, TN.

Task 5.2 DSRP Reactor Optimization and Process Integration

Direct Sulfur Recovery Process (DSRP) is a complimentary technology to treat a high-pressure SO_2 containing off-gas from sorbent regeneration. This technology was developed with DOE/NETL support, which has included testing at bench-scale at RTI and limited pilot-scale testing at Eastman. There were plans to integrate DSRP at TEC at a scale of 5 ton/day of sulfur. However, TEC is not interested in DSRP as they produce sulfuric acid as a saleable product.

Previous development efforts for DSRP have been focused on streams with relatively low concentrations of SO_2 (typically <5 vol%). At these concentrations, the exothermic nature of the SO_2 reduction reactions can be easily handled by small adjustments in the reactor design. However, the typical SO_2 concentration present in the regenerator tail gas stream from RTI's transport desulfurization system is typically >10 vol%. At this concentration, reactor design becomes significantly more challenging due to the highly exothermic nature of the SO_2 reduction reaction. One of the commercial reactor designs, which is extensively used commercially for similar applications, is a shell-and-tube reactor where catalyst is filled in tubes and circulating water on the shell side is used to extract the heat as steam. Based on recent laboratory data, it appears feasible that this type of reactor system may work for DSRP. Therefore, the objective of this task will be to demonstrate this reactor design on a scale where sufficient engineering data can be obtained for a full commercial design. It is anticipated that this testing will be done at TEC using a slipstream of the regeneration off-gas from the transport reactor desulfurization system.

Depending upon the availability of funds within this budget period, RTI will prepare a subtask plan detailing the activities and a budget for DOE review and approval.

DECISION POINT: Recipient shall not initiate Task 5.3 without the DOE Contracting Officer's written approval, as described in Task 1.6-A of this SOPO and the Decision Point article of this Cooperative Agreement.

Task 5.3 Field testing the novel sorbent-based process for CO_2 removal from warm syngas

From the work done in Task 1.6-A, if DOE techno-economic analysis indicates that removal of CO_2 from representative IGCC shifted syngas, using the RTI technology, has the potential to support DOE performance and economic goals and availability of sufficient funds in this budget period, field testing of regenerable CO_2 sorbent will be considered. RTI will prepare a subtask plan and a budget for this task and submit it for DOE review and approval.

It is anticipated that technology development effort in this task will shift from sorbent development to process development and demonstration in the field. The goal for this development phase will be to evaluate the sorbent-based CO_2 capture process in a high-fidelity process unit using real, coal-derived syngas and to demonstrate the feasibility of removing >90% of the carbon from syngas under warm clean-up conditions in a continuous manner. The main focus of the field testing effort will be the evaluation of the most-promising process arrangements, identified in Task 1.6-A, that address the major technical hurdles facing the development of a CO_2 capture process for warm syngas CO_2 removal, including

- effective heat transfer/integration between the CO_2 capture and sorbent regeneration stages,
- efficient integration of the high-temperature water-gas shift and CO_2 removal processes into one process unit,
- pressure swing between absorption and regeneration conditions, and
- continuous operation.

The field testing campaign will consist of:

- demonstrating that the process is capable of addressing the above technical hurdles,
- performing detailed parametric studies to identify optimal operating conditions to minimize total parasitic energy demand, and
- long-term, continuous operation using real, coal-derived syngas.

DECISION POINT: Recipient shall not initiate Task 5.4 without the DOE Contracting Officer's written approval, as described in Task 1.7-A of this SOPO and the Decision Point article of this Cooperative Agreement.

Task 5.4 Ammonia/Urea Integration Design

If the techno-economic analyses from the work completed in Subtask 1.7-A indicate that one or more of the ammonia/urea integration options at TEC is a valid candidate for commercial consideration, and if sufficient project funds are available, RTI will prepare a subtask plan and a budget for this Task 5.4 and submit it for DOE review and consideration for partial or complete inclusion in this project.

The objective of this Task 5.4 would be to conduct a more detailed study (approximately FEED-level) of the selected ammonia and/or urea integration option(s) from Subtask 1.7-A to determine its commercial viability. If determined to be commercially viable, this could help lead to the commercial deployment of advanced ultra-clean gasification projects in the U.S. (starting at the TEC Polk site) and around the globe for polygeneration and industrial applications that include CO_2 re-use.

Budget Period 3 – Operational Phase

The work in this Budget Period is divided into two categories: (1) Tasks to be performed with Advanced Integrated Gasification Combined Cycle (AIGCC) Program Funds, designated with an "A" suffix after task number, and (2) Tasks to be performed with American Recovery and Reinvestment Act (ARRA) Industrial Carbon Capture and Sequestration (ICCS) funds, designated with a "B" suffix after task number.

THE FOLLOWING TASKS, DESIGNATED WITH THE "B" SUFFIX FOLLOWING THE TASK NUMBER, ARE TO BE FUNDED BY ARRA FUNDS:

Budget Period 3B – Operational Phase

Task 6B: Normal Operations

Completion of the commissioning activities will lead into the actual operation of the syngas cleaning system. Individual units will be brought online following a sequence that will establish satisfactory operation of each unit. When all the units are operational, the objective will be to continue operation for 5,000 to 8,000 hours of operation and achieve the target of capturing up to 300,000 tons of CO_2/year. To extract the maximum benefit from this operation, a test plan will be developed to demonstrate the performance of the system to effectively capture up to 90% of the CO_2 and produce a syngas product that is suitable for chemical production applications. A key component of this plan will include collection of key data about the performance of the different process units.

Subtask 6.1B: Test Plan

A test plan for the syngas cleaning system and for CO_2 capture will be developed to meet the overall project goals of warm syngas cleanup pre-commercial demonstration and up to 90% CO_2 capture of up to 300,000 tons of CO_2/year. In addition, this test plan will include parametric testing of the distinct units within the syngas cleaning system. The test plan will include: overall PFD highlighting integration of test components/processes, feed type(s), tests durations, input conditions (each unit), measurements to be taken (what will be measured, measurement device type and sensitivity limits, location of measurement, frequency, etc.), and test goals and success criteria. Test goals and success criteria will focus on attaining DOE programmatic goals for syngas cleaning for power and chemical production applications to enable commercial deployment of this technology for coal gasification.

Subtask 6.2B: Operation

The primary focus during operation will be achieving the target objectives and implementing the test plan. However, the most valuable feature of this operation will be the data collected and its analysis.

The data collected from the different units will include temperatures, pressures, and feed and product and potentially intermediate compositions. These data will be used to determine the efficiency of each unit, effective operation ranges for key operating parameters, and critical data to design and operate commercial-scale units. Beyond the actual data, attempts will be made to capture the lessons learned by the operators during startup, shutdown and operation of the syngas cleaning system and carbon capture system.

Task 7B: Decommissioning or Continued Operation

At the end of the Period of Performance, decommissioning of the unit will be determined by RTI only after consultation and agreement with TEC and DOE/NETL. In the event RTI determines that the unit should be decommissioned, it is authorized to sell the unit, including all components thereof, and to deduct the reasonable and actual costs incurred in decommissioning (including the costs of dismantling, packaging, selling, and disposing of the unit as well as restoring the site) from the proceeds of the sale prior to paying the DOE its share of the equipment's fair market value. RTI agrees to be solely responsible for all decommissioning costs, and agrees to hold DOE/NETL harmless against such costs.

In the event RTI determines, after consultation with TEC and DOE/NETL, that the unit should remain available for additional operations and testing and thus, not decommissioned, it shall be permitted to leave the equipment in place at the TEC site. Performance and operating data obtained from such continued operation shall be provided periodically to DOE/NETL.
. These data will include:

- Performance data from the WGCS unit, including sulfur removal efficiency and sulfur level in the cleaned syngas product, sorbent regeneration efficiency, sorbent attrition rate, and sorbent lifetime and cost data,
- Performance data from the carbon capture system, including carbon dioxide capture efficiency, sulfur level in hydrogen-rich syngas product, and activated amine replacement rate and cost, and
- Reliability, availability, maintainability (RAM) data on the WGCS and carbon capture systems.

<u>THE FOLLOWING TASK(S), DESIGNATED WITH THE "A" SUFFIX FOLLOWING THE TASK NUMBER, ARE TO BE FUNDED BY NON-ARRA FUNDS:</u>

Budget Period 3A – Operational Phase

Task 8A: Continued Operation

This task will be a continuation of Task 6.2 under which operation of the warm syngas cleanup pre-commercial demonstration plant will continue to meet the SOPO objectives of achieving 5,000 to 8,000 hours of operation to get the technology ready for commercial deployment.

D. Deliverables

In addition to the reports required according to the "Reporting Requirement Checklist" the contractor shall submit topical reports for these Tasks within 30 days of task completion: 1.2-A, 1.5-A, 1.7-A, 2.1-B, 2.2-B, 3.1, 3.4, 5, and 6.2.

The Recipient will provide electronic updates to the Resource Loaded Schedule on a quarterly basis to the DOE Project Manager. A format compatible with Microsoft Office Project 2007 is recommended but not required.

The Recipient shall report Earned Value data used for tracking schedule and cost performance of the project. Earned Value is a project management tool which allows for the review of both the schedule and financial progress, as compared to the initial project plan.

The Recipient shall gather, record, and report Earned Value data at a Task level and a quarterly basis. The Earned Value Analysis Report shall include Earned Value data as follows:

- Actual Cost (AC) for the period and to date
- The Cost Performance Index (CPI) for the period and cumulative
- The Schedule Performance Index (SPI) for the period and cumulative
- Cumulative Percent Complete
- Estimated Cost to Complete
- Variance Analysis

The Final Report will be subject to review by DOE prior to final submission. The final report will summarize the entire project, and will discuss project results in relation to unresolved technical issues, any remaining work that must be done prior to commercial deployment, and the industry-wide value of each component of the WGCU system, the carbon capture process, and all system working together in an integrated system. Describe how these new technologies could be expected to impact a gasification power plant's capital and operating costs. The detailed information required in all of the Topical Reports shall also be included in the Final Report, but can either be included through reference to, or attachment of, the Topical Reports.

F. Briefings and Presentations

The Recipient shall prepare and deliver the following briefings and presentations to DOE/NETL:

- A detailed “Kick-off” briefing to the DOE Project Manager at NETL at the beginning of the project.
- A detailed briefing on the status of the project to the DOE Project Manager at NETL once per year.
- A detailed briefing to the DOE Project Manager at NETL at the end of each Budget Period and at any Decision Point.

These meetings may be combined, if practical. The meetings may be changed to another location with DOE Project Manager approval.

Appendix B

Air Permit

TECHNICAL EVALUATION
&
PRELIMINARY DETERMINATION

APPLICANT

Tampa Electric Company
Post Office Box 111
Tampa, Florida 33601-0111

Polk Power Station Unit 1
Solid Fuel-based Integrated Gasification and Combined Cycle (IGCC)
Facility ID No. 1050233

PROJECT

Project No. 1050233-027-AC
Application for Minor Source Air Construction Permit
Temporary High Temperature Syngas Cleanup and
Carbon Capture and Sequestration Demonstration Project

COUNTY

Polk County, Florida

PERMITTING AUTHORITY

Florida Department of Environmental Protection
Division of Air Resource Management
Office of Permitting and Compliance
Chemicals and Combustion Key Industry Group
2600 Blair Stone Road, MS#5505
Tallahassee, Florida 32399-2400

October 5, 2011

1. GENERAL PROJECT INFORMATION

Air Pollution Regulations

Projects at stationary sources with the potential to emit air pollution are subject to the applicable environmental laws specified in Section 403 of the Florida Statutes (F.S.). The statutes authorize the Department of Environmental Protection (Department) to establish regulations regarding air quality as part of the Florida Administrative Code (F.A.C.), which includes the following applicable chapters: 62-4 (Permits); 62-204 (Air Pollution Control – General Provisions); 62-210 (Stationary Sources – General Requirements); 62-212 (Stationary Sources – Preconstruction Review); 62-213 (Operation Permits for Major Sources of Air Pollution); 62-296 (Stationary Sources - Emission Standards); and 62-297 (Stationary Sources – Emissions Monitoring). Specifically, air construction permits are required pursuant to Rules 62-4, 62-210 and 62-212, F.A.C.

In addition, the U. S. Environmental Protection Agency (EPA) establishes air quality regulations in Title 40 of the Code of Federal Regulations (CFR). Part 60 specifies New Source Performance Standards (NSPS) for numerous industrial categories. Part 61 specifies National Emission Standards for Hazardous Air Pollutants (NESHAP) based on specific pollutants. Part 63 specifies NESHAP based on the Maximum Achievable Control Technology (MACT) for numerous industrial categories. The Department adopts these federal regulations on a quarterly basis in Rule 62-204.800, F.A.C.

Facility Description and Location

The Tampa Electric Company (TECO) Polk Power Station (PPS) is an electric power facility consisting of five key electrical generating units (Units 1 – 5). The facility is categorized under Standard Industrial Classification Code No. 4911. The existing Polk Power Station is located in Polk County at 9995 State Road 37 South in Mulberry, Florida. The UTM coordinates are Zone 17, 402.45 kilometers (km) East, and 3067.35 km North. This site is in an area that is in attainment (or designated as unclassifiable) for all air pollutants subject to state and federal Ambient Air Quality Standards (AAQS).

Figure 1 - TECO PPS Unit 1 IGCC

Unit 1 consists of a nominal 260 megawatt (MW – net, electrical) solid fuel-based integrated gasification and combined cycle (IGCC) including: a nominal 192 MW (gross) syngas/No. 2 fuel oil-fired General Electric (GE) 7FA combustion turbine-electrical generator (CTG) designated as Emission Unit (EU) 001; a heat recovery steam generator (HRSG); a nominal 123 MW (gross) steam turbine-electrical generator (STG); a solid fuel handling system designated as EU-005; an entrained flow solid fuel gasification system designated as EU-006; an oxygen plant; a synthetic gas (syngas) cleanup and sulfur recovery system; a sulfuric acid plant designated as EU-004. There is also a 120 million Btu per Hour (mmBtu/hr) auxiliary boiler designated as EU-003. Approximately 65 MW are consumed by the oxygen plant and process auxiliary equipment which is the difference between net and gross power production.

Units 2, 3, 4 and 5 (EU 009 through 012) consist of natural gas or natural gas/fuel oil-fired GE 7FA simple cycle CTG.

Facility Regulatory Categories

- The facility is a major source of hazardous air pollutants (HAP).

- The facility operates units subject to the acid rain provisions of the Clean Air Act.
- The facility is a Title V major source of air pollution in accordance with Chapter 213, F.A.C.
- The facility is a major stationary source in accordance with Rule 62-212.400, F.A.C. for the Prevention of Significant Deterioration (PSD) of Air Quality.
- The facility operates units subject to the New Source Performance Standards in Part 60, Title 40 of the Code of Federal Regulations (CFR).

Project Description

On August 12, 2011, the Department received an application from Tampa Electric Company (TECO) to install and operate a pre-commercial scale demonstration high-temperature syngas cleanup system (HTSC) and an integrated carbon dioxide (CO_2) capture and sequestration (CCS) system at Polk Power Station Unit 1. The project will receive United States Department of Energy funding. The demonstration project will include a high-temperature desulfurization process, trace contaminant removal process and direct sulfur recovery process. These cleanup systems will support Unit 1 and will treat approximately 20 percent (%) of the syngas prior to its combustion. Emission sources associated with this demonstration project includes two small heaters, one sorbent storage hopper, one regenerator fines storage bin and one amine surge drum.

A slipstream of syngas from the IGCC plant will be treated in the cleanup systems to simulate commercial operations. The high-temperature desulfurization process will remove 99.9 % of the sulfur in the syngas. The trace contaminant removal process will reduce arsenic, selenium and mercury concentrations in the syngas. The direct sulfur recovery process will convert sulfur dioxide (SO_2) to commercial grade elemental sulfur. The high level of sulfur removal in the high-temperature desulfurization process will provide a syngas stream which will undergo the water gas shift reaction to convert water (H_2O) and carbon monoxide (CO) to hydrogen (H_2) and CO_2. Thereafter, activated methyldiethanolamine (aMDEA) will be used to capture up to 90% of the CO_2 in the cleaned syngas. A pressurized pipeline will transfer the compressed CO_2 to an onsite injection well for injection and sequestration in a saline aquifer within a deep and naturally capped geologic formation.

The demonstration project is planned to commence construction in March 2012 and be completed by April 2013. The goal for the operation phase is to achieve at least 8,000 hours of operation, an approximate 18 month demonstration period, which is expected to be completed in the third quarter of 2015.

Processing Schedule

08/12/11 Received the application for a minor source air pollution construction permit, application complete.

2. PSD APPLICABILITY

General PSD Applicability

The Department regulates major stationary sources in accordance with Florida's PSD program pursuant to Rule 62-212.400, F.A.C. PSD preconstruction review is required in areas that are currently in attainment with the state and federal Ambient Air Quality Standards (AAQS) or areas designated as "unclassifiable" for these regulated pollutants.

PSD pollutants include: CO; nitrogen oxides (NO_X); sulfur dioxide (SO_2); particulate matter (PM); PM smaller than 10 micrometers (PM_{10}); volatile organic compounds (VOC); lead (Pb); Fluorides (F); sulfuric acid mist (SAM); total reduced sulfur (TRS), including H_2S; municipal waste combustor (MWC) organics measured as total tetra- through octa-chlorinated dibenzo-p-dioxins and dibenzofurans (D/F); MWC metals measured as PM; MWC acid gases measured as SO_2 and hydrogen chloride (HCl); and mercury (Hg).

As defined in Rule 62-210.200(179)(a)1, F.A.C., a “major stationary source” is any of 28 listed stationary sources of air pollutants which emits, or has the potential to emit, 100 tons per year (TPY) or more of any PSD pollutant. Link to Rule 62-210, F.A.C.

The list given in the citation includes the category of “fossil fuel-fired steam electric plants of more than 250 million British thermal units per hour heat input”. The Polk Power Station is a major stationary source based on its actual emissions and its potential to emit PSD pollutants. The major stationary source threshold for source categories not on the cited list is 250 TPY or more of any PSD pollutant.

For major stationary sources, PSD applicability is based on emissions thresholds known as the significant emission rates (SER) as defined in Rule 62-210.200, (Definitions) F.A.C. Emissions of PSD pollutants from the project that equal or exceed these SER are considered “significant”. BACT must be employed to minimize emissions of each PSD pollutant and an air quality impact analysis must be conducted for the PSD pollutants for which AAQS are defined. SER also means any emissions rate or any net emissions increase of a PSD pollutant associated with a major stationary source or major modification which would construct within 10 kilometers of a Class I area and have an impact on such area equal to or greater than 1 gram per cubic meter, 24-hour average.

Although a facility may be “major” for only one PSD pollutant, a project must include BACT controls for any PSD pollutant that exceeds the corresponding SER given in Table 1.

Table 1 – List of SER by PSD-Pollutant [1, 4]

Pollutant	SER (TPY)	Pollutant	SER (TPY)
CO	100	NO_X	40
PM/PM_{10} [2]	25/15	Ozone (VOC) [3]	40
Ozone (NO_X) [3]	40	SAM	7
SO_2	40	F	3
Pb	0.6	TRS	10
H_2S	10	Hg	0.1

1. Excluding those defined exclusively for MWC and MSW landfills.
2. PM with a diameter less than 2.5 micrometers ($PM_{2.5}$) is also a PSD pollutant, but an SER has not yet been defined in the Department’s rules. It is regulated by its precursors and surrogates (e.g. PM/PM_{10} ammonia, SO_2 and NO_X).
3. Ozone (O_3) is regulated by its precursors (VOC and NO_X).
4. There is a federal SER of 75,000 TPY for Greenhouse Gases (GHG) as CO_2 equivalent ($CO_{2}e$) that has not been incorporated into Department rules. .

$PM_{2.5}$ is also a Federal PSD pollutant and the Department is in the process of adopting a SER of 10 TPY. Refer to Link to $PM_{2.5}$ Rule . Until the rule is finalized, projects in Florida are not subject to a SER for $PM_{2.5}$.

PSD Applicability for Project

The demonstration project will be located in Polk County, which is in an area that is currently in attainment with (or designated as unclassifiable for) the state and federal Ambient Air Quality Standards (AAQS). The applicant provided the following PSD applicability analysis summarizing the proposed project emissions. The projected actual emissions are based on worst-case emissions produced by two process heaters. Emissions associated with the storage hopper and bin are also included in the emissions of PM/PM_{10}. No emissions increases are projected from the existing IGCC Unit 1 (i.e. the CTG and associated equipment). As shown in the following table, total project emissions will not exceed the PSD significant emissions rates; therefore, the project is not subject to PSD preconstruction review.

Table 2 - Applicant's Annual Emission Summary and PSD Applicability Analysis

Pollutant	Annual Emissions (TPY)		Subject to PSD?
	Projected Actual	SER	
CO	3.5	100	No
NO_X	6.5	40	No
PM/PM_{10}	1.12	25/15	No
SO_2	0.7	40	No
VOC	0.4	40	No

3. PROJECT REVIEW

Existing Process with Low-Temperature Syngas Cleanup System (LTCS)

The following figure shows the present Unit 1 configuration.

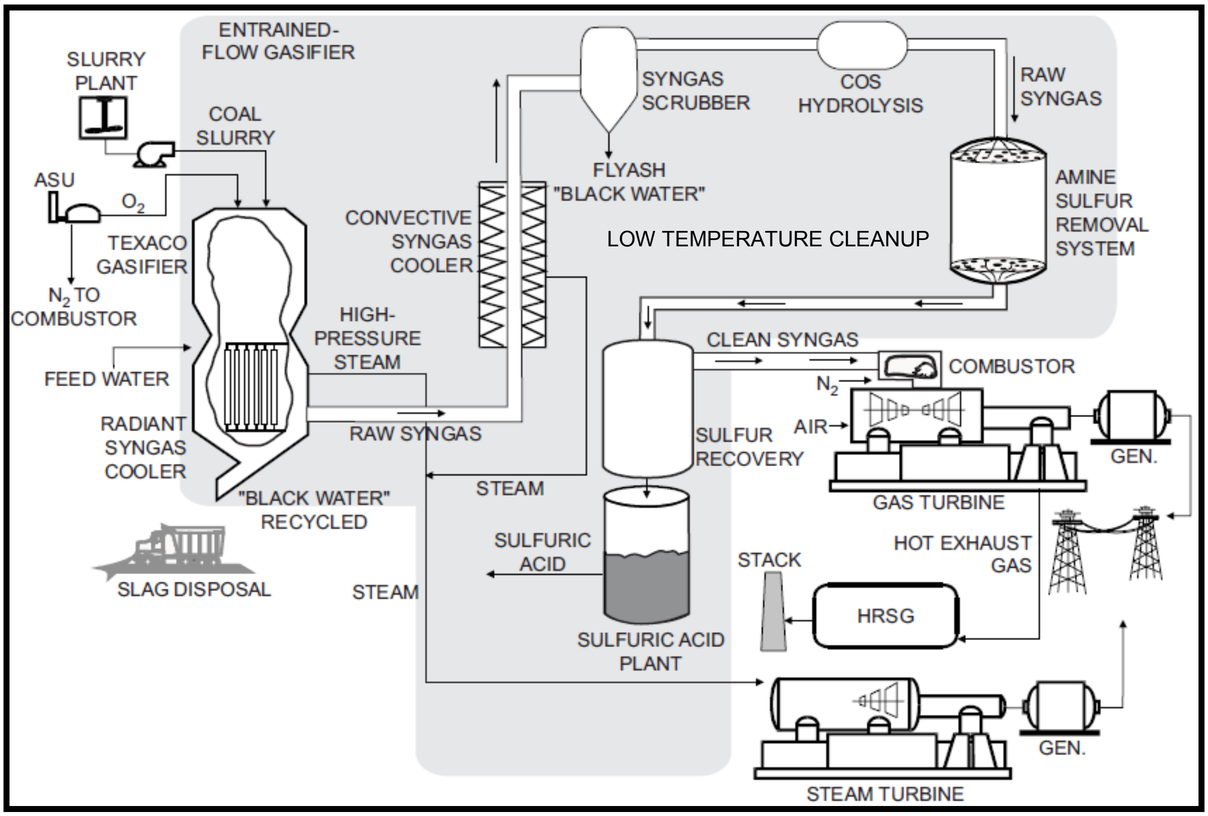

Figure 2 – Process Flow Diagram for the Existing TECO PPS Unit 1 IGCC with LTCS

Following is an explanation of the process:

An air separation unit (ASU) cryogenically separates ambient air into its major constituents, oxygen (O_2) and nitrogen (N_2). The O_2 stream is used in the gasifier and a small amount is consumed in the sulfuric acid plant (SAP). Most of the N_2 produced goes to the CTG to dilute the syngas for NO_X abatement and to increase power production as the N_2 expands through the CTG.

Solid fuels - primarily coal and petroleum coke (petcoke) and water are processed in a rod mill to produce a solids/water slurry. The slurry is injected along with O_2 into the gasifier, which operates at roughly 25 times atmospheric pressure. Partial oxidation of the feedstock generates temperatures in the range of 2,400 - 2,700 Fahrenheit (°F) and transforms the slurry water into steam.

The heat, pressure, and steam break the bonds between feedstock constituents and initiate chemical reactions that produce syngas consisting primarily of hydrogen (H_2) and carbon monoxide (CO). Sulfur contained in the fuel is converted to hydrogen sulfide (H_2S) and carbonyl sulfide (COS). Ash is removed from the bottom of the gasifier as an inert, glassy slag (frit). The remaining portion of the ash (flyash) is either entrained in the raw gas stream or separates with the frit.

{Note that with all carbon present as compressed gases and without N_2, it is easier to consider ways to remove the carbon during cleanup rather than after combustion/expansion when massive amounts of N_2 and excess air are present.}

The raw gas stream produced in the gasifier passes first through a radiant syngas cooler (RSC) just below the gasifier and then through two parallel fire-tube convective syngas coolers (CSC). The RSC together with the CSC produce much of the IGCC system high-pressure steam and drop the raw gas temperature to a range of 700–800°F. Flyash and hydrogen chloride (HCl) are removed from the raw gas in an intensive water scrubbing step in syngas scrubbers.

COS in the raw gas stream is converted through hydrolysis to H_2S. Nearly all the remaining heat in the raw gas stream is recovered by pre-heating clean syngas and boiler feedwater. A reactor containing a circulating methyldiethanolamine (MDEA) solution strips H_2S from the raw gas stream. The H_2S is sent to a sulfur recovery system that oxidizes the H_2S to produce roughly 200 tons per day (TPD) of 98% pure sulfuric acid.

{Note that the sulfur removal occurs after significant cooling of the syngas, which is then reheated by a complex system of heat exchangers. If the sulfur removal could be accomplished with less cooling and reheat, this would eliminate some expensive systems and improve overall system efficiency.}

The flyash removed from the raw gas stream contains significant amounts of carbon and is recycled to the slurry preparation system. The "grey" process water resulting from the flyash separation is used in the syngas scrubbers.

The main products of combustion in the CTG are water (H_2O) and carbon dioxide (CO_2). The N_2 from the ASU (and which is reintroduced into the CTG) and excess air processed through the CTG compressor and expanded in the rotor section are the other main components in the exhaust gas along with small amounts of air pollutants and noble gases like argon (Ar).

High-Temperature Cleanup System (HTCS) and Carbon Capture and Sequestration

During the original operation of TECO PPS Unit 1 (mid-1990's) it was recognized that a hot cleanup system could could improve the thermodynamic efficiency of the process. A demonstration project was included during the early IGCC operation using a 10% gaseous slipstream as shown in Figure 2.

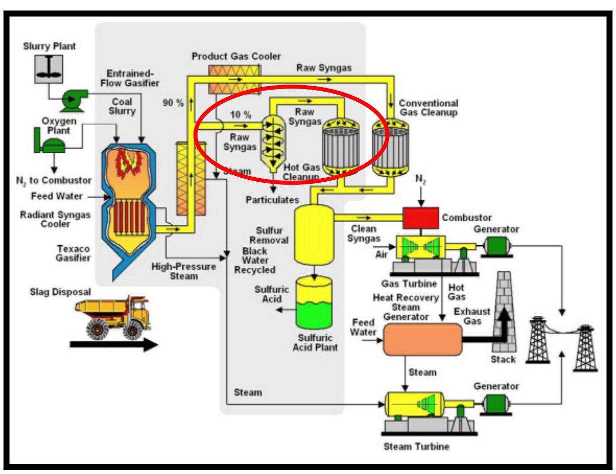

Figure 3 - Previous Hot Cleanup Demonstration

The stream was drawn prior to the product gas cooler (equivalent of convective syngas cooler in Figure 2). The system suffered from pluggage and stress corrosion. TECO dedicated most of its efforts to more critical parts of the process that required attention such as development of a COS hydrolysis step and improving gasifier refractory liners.

Since then, a number of new methods have been developed to accomplish higher temperature cleanup and there is renewed interest in commercializing such processes.

The purposes of the project presently proposed by TECO are: to demonstrate a higher temperature cleanup of the syngas than presently practiced with a benefit to the overall efficiency of Unit 1; and to demonstrate a carbon capture and sequestration (CCS) process to reduce CO_2 greenhouse gas (GHG) emissions.

The proposed project syngas cleanup and CO_2 capture and sequestration systems will include the following steps:

- High-temperature desulfurization;
- Trace contaminant removal;
- Direct sulfur recovery;
- Water gas shift reaction of the primary syngas constituents ($CO + H_2O = CO_2 + H_2$);
- Low temperature gas cooling.
- Activated amine CO_2 capture; and
- CO_2 compression and drying system.

The project will use a process developed by Research Triangle Institute (RTI) International, which will be integrated with the existing TECO PPS Unit 1 IGCC as shown in Figure 3.

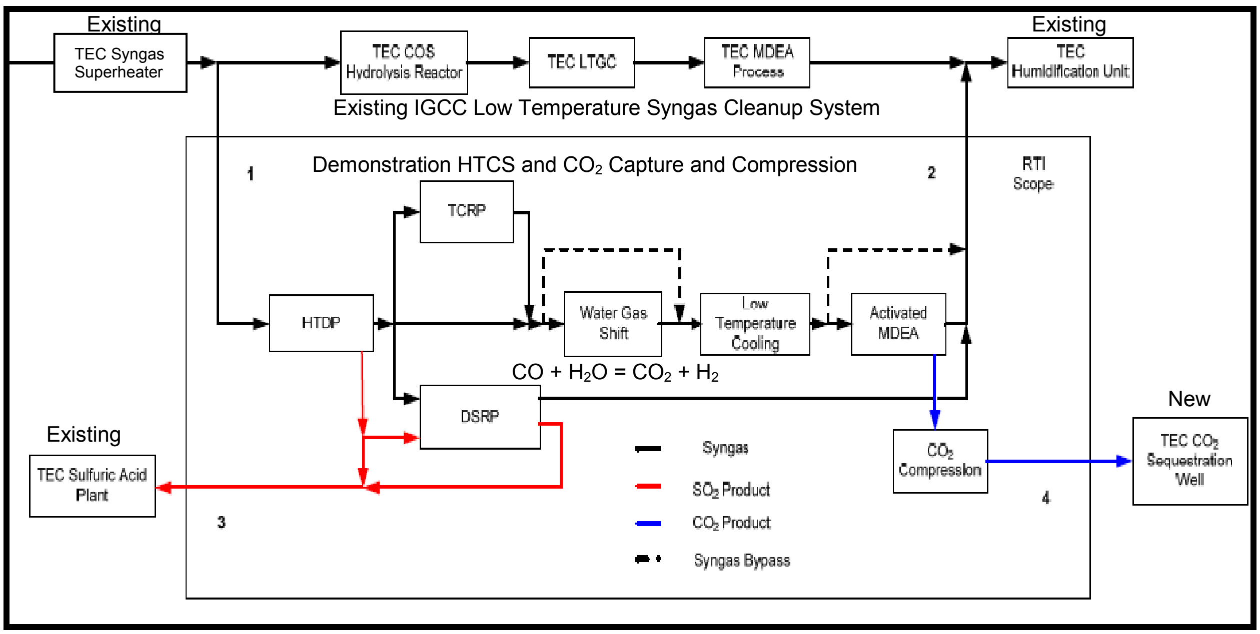

Figure 3 – Process Flow Diagram of HTCS, CCS and Integration with TECO PPS Unit 1 IGCC

Although RTI calls its process "Warm Syngas Cleanup Technology" it actually incorporates high temperature desulfurization and the high temperature terminology will be used in this review. The inner box includes the new components for the HTCS. For further information about the RTI process refer to the following link: Link to RTI

The flows of raw and treated syngas taken from and returned to the Unit 1 IGCC are indicated as Flows 1 and 2, respectively. The flows of sulfur/SO_2 and compressed CO_2 to TECO are shown as Flows 3 and 4. The HTCS includes the following components:

High-Temperature Desulfurization Process

The proposed technology will begin with a 50 MW slip stream consisting of untreated syngas (Flow 1) coming from the IGCC plant at a flow rate of 2 million standard cubic feet/hour (mscf/hour). A process heater is used to start up the high-temperature desulfurization process by heating the absorber and regenerator systems. The process heater fires propane, natural gas and ultra-low sulfur diesel (ULSD) fuel oil. During startups, the regenerator is further preheated by direct injection of ULSD fuel oil into the regenerator above its auto-ignition temperature to preheat the regenerator. The untreated syngas initially introduced into the absorber and regenerator gases is sent to the existing flare until the absorber is online.

The untreated syngas contains a H_2S concentration of approximately 7,200 parts per million by volume (ppmv). The high temperature desulfurization process system consists of two coupled transport reactors, the first serving as the sulfur absorber and the second as the sorbent regenerator. The sulfur absorber utilizes chemical reactions with the RTI International proprietary sorbent to remove H_2S and COS from the syngas to produce a syngas with a total sulfur concentration of less than 10 ppmv.

In the sorbent regenerator reactor, the sorbent is regenerated by oxidizing the sulfur compounds to produce a flue gas stream containing SO_2. Most of this stream is directed to the existing PPS SAP. As part of the proposed project, a small portion of this SO_2 stream is routed to the direct sulfur recovery system. This process removes more than 99.9% of the sulfur in the syngas.

<u>Trace Contaminant Removal Process</u>

A slip stream of the desulfurized syngas from the high-temperature desulfurization process is further treated by the trace contaminant removal process. This process consists of three fixed-bed reactors for removing arsenic, selenium and mercury contaminant from the syngas. The mercury reactor is protected by a sulfur guard bed. The treated syngas (Flow 2) is then recombined with the main desulfurized syngas stream.

<u>Direct Sulfur Recovery Process</u>

The SO_2 rich slipstream from the high-temperature desulfurization process generator is converted into approximately 5 TPD of commercial grade elemental sulfur. The SO_2 in the slipstream is converted by reducing it with H_2 and CO with the sulfur product then condensed out of the slipstream. After analyzing the quality of the elemental sulfur, the sulfur product is oxidized using air to create an SO_2 stream (Flow 3), which is sent to the existing PPS SAP. A propane fired heater, vented to the atmosphere, is operated continuously to provide the required heat for this process.

Carbon Capture and Sequestration (CCS) System

The carbon capture step will produce up to 300,000 TPY of high-quality CO_2, which is suitable for geologic sequestration at the Polk Power Station site. The high temperature/high pressure IGCC process with an ASU employed by TECO lends itself to removal of carbon from the fuel prior to combustion. Essentially the energy contained in the CO is made available as additional energy from H_2 by means of the water gas shift reaction described below. The CCS system includes the following components:

<u>Water Gas Shift Reactor System</u>

The water gas shift reactor system (Fuel Gas CO_2 Cleanup in Figure 4) converts CO in the desulfurized syngas from the high-temperature desulfurization process to CO_2.

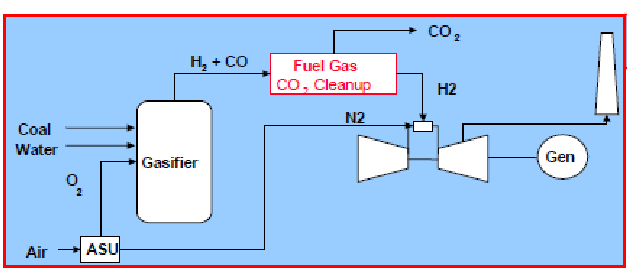

Figure 4 – Pre-combustion CO_2 Removal

The hydrogen bound in water is converted to H_2. The system consists of three fixed-bed reactors operating in parallel and uses conventional commercial catalyst technologies.

The syngas is mixed and preheated with steam provided from the IGCC facility to the reactor inlet temperature of 650 ºF with water injected to control the temperature. In the reactors, CO and H_2O are shifted to CO_2 and H_2.

The syngas provided to the CTG (after further cleaning) will, therefore, contain more H_2 and less CO compared with the syngas presently combusted.

Low-Temperature Gas Cooling System

The low-temperature gas cooling system cools the shifted gas stream from the water gas shift reactor system from approximately 650 to 100 ºF in the boiler steam drums and a heat exchanger with cooling feedwater provided by the existing IGCC cooling system. The cooling process generates steam that is routed to the IGCC system. Condensate is also separated from the gas stream and routed to the IGCC system.

Activated Amine CO_2 Capture System

The activated amine CO_2 capture system separates CO_2 from H_2 in the cooled shifted syngas for subsequent absorption by aMDEA in the amine absorber. The aMDEA process technology is commercially available. The absorbed CO_2 is separated from the amine in a regenerator/separation drum and the high-quality CO_2 stream is sent to the CO_2 compression station. The separated H_2-rich stream is sent to the IGCC syngas stream for firing in the combustion turbine.

CO_2 Compression and Drying System

The captured CO_2 stream from the amine system is compressed in a five-stage compression station to 1,500 pounds per square inch gauge (psig). The CO_2 exits the compression station as a supercritical fluid, which is then cooled to approximately 100 ºF in coolers. The CO_2 stream is then dried, and the condensate treated and sent to the IGCC system. The compressed CO_2 (Flow 4) is sent to the new TECO deep well injection sequestration system.

CO_2 Deep Well Injection Sequestration System

The compressed CO_2 at a temperature of 120 ºF would be transferred through an approximately 2,100-ft, 6-inch stainless steel, pressurized (1,500 psig) pipeline to the injection well for injection and sequestration in a deep saline aquifer geologic formation under the Polk Power Station site. Up to 300,000 TPY of CO_2 would be sequestered during the demonstration period for the proposed project. A vent stack will be installed to vent the captured CO_2 during startups, shutdowns and malfunction of the CO_2 deep well sequestration system. Table 3 summarizes the estimated composition of the CO_2 stream to be sequestered.

Table 3 - Sequestered CO_2 Stream

Composition	CO_2 Stream (molar %)
CO_2	99.44
H_2	0.50
CO	0.05
N_2	0.01
H_2S	<100 ppmv
COS	<10 ppmv
H_2O	<15 ppmv
O_2	---

The target CO_2 injection zone is a deep saline carbonate (dolomite/limestone) reservoir system extending between 4,200 and 8,000 feet below the land surface. Based on site-specific testing and geological information available the following relevant observations were made regarding the injection zone:

- A laterally continuous, thick (more than 1,000 feet) low permeability confining unit (cap rock) is present.
- Fractures, faults, or folds potentially serving as traps or migration pathway are not present.
- Major horizontal variation in depositional environment (and hence the carbonate strata) are not expected.
- The nearest penetration of the confining unit is located approximately 10 miles away.
- Suitable zones for CO_2 storage with horizontal porosity and permeability are present.
- Vertical variations of porosity and permeability are expected to enhance CO_2 storage capacity.
- West-central Florida is seismically stable and experiences little seismic activity.

- The hydrodynamic (physical) and geochemical properties are favorable for long-term CO_2 storage.

Therefore, the injection zone is both viable and well suited for the purpose of the proposed CO_2 sequestration demonstration project.

TECO is planning a dual-use for the injection well. After the CO_2 sequestration project has been completed, the IW-2 well will be used for the disposal of wastewater from the power plant operations.

Emissions

During the approximate 18-month operation phase, the following emissions sources associated with temporary operation of the proposed demonstration project will include two small process heaters, one sorbent storage hopper, one regenerator fines storage bin and one amine surge drum. Table C summarizes the estimated potential emissions based on the applicants estimated hours of operation of some of this equipment versus the worst case scenario with both of the process heaters operating continuously (8,760 hours/year).

Table 4 - Estimated Potential Emissions

Pollutant	Potential Emissions (TPY)	
	During Limited Hours of Operation	Assuming Continuous Hours of Operation
CO	3.5	9.3
NO_X	6.5	17.3
PM/PM_{10}	1.1	2.9
SO_2	0.7	1.9
VOC	0.4	1.0

Based even on the worst case scenario, the impacts on ambient air quality of these temporary, intermittent and minor level of emissions associated with this project will be minimal.

A description of these emissions sources associated with this temporary demonstration project includes:

Process Heaters

High-Temperature Desulfurization Process Startup Heater

The startup heater will have the following specifications:

- The maximum heat input rate is 23.75 mmBtu/hr.
- The heater will fire propane, natural gas and ULSD fuel oil.
- The ULSD fuel oil will have a maximum sulfur content of 0.0015%.
- The requested maximum hours of operation will be 2,820 hours/year; approximately 32% of the time.

This process heater will be used to start the high-temperature desulfurization process by heating the absorber and regenerator systems. Emissions produced by the combustion of the dual fuels in the heater will be exhausted to ambient air at 400 ºF through a 60-feet tall exhaust stack at a volumetric flow rate of 10,340 actual cubic feet per minute (acfm).

Direct Sulfur Recovery Process Tailgas Recycle Heater

The tailgas recycle heater will have the following specifications:

- The maximum heat input rate is 2.1 million British thermal unit (mmBtu)/hour.
- The heater will fire only propane.
- The maximum hours of operation will be 8,760 hours/year; continuously.

Emissions produced by the combustion of the propane heater will be exhausted to ambient air at 400 ºF through a 0.5 feet diameter by 60-feet tall exhaust stack at a volumetric flow rate of 750 acfm.

New Source Performance Standards (NSPS) Provisions

The process heaters are not subject to applicable NSPS provisions in 40 Code of Federal Regulations (CFR) 60 for Subpart Dc (Standards of Performance for Small Industrial-Commercial –Institutional Steam Generating Units) as defined in §60.41c "*Steam Generating Unit*," which excludes process heaters in the definition. "*Process Heaters*" are defined as, "a device that is primarily used to heat a material to initiate or promote a chemical reaction in which the material participates as a reactant or catalyst."

National Emission Standards for Hazardous Air Pollutants (NESHAP) Provisions

The demonstration project process heaters do not meet the definition of an "*industrial boiler*" as defined in §63.11237 of the NESHAP provisions in 40 CFR 63 for Subpart JJJJJJ (National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers Area Sources). An *"industrial boiler"* is defined as a boiler used in manufacturing, processing, mining, and refining or any other industry to provide steam, hot water, and/or electricity. The heaters do not provide steam, hot water, and/or electricity; therefore are not subject to the applicable NESHAP provisions as defined in Subpart JJJJJJ.

Flare

The existing flare is a standard open flare that is currently used as an emergency safety device and is the only control device associated with the gasification system. The open flare is currently used to burn gas from the process during startup, shutdown and emergencies. The flare stack is 150 feet and the exit temperature of the exhaust gas is 1,830 ºF. Emissions from the flare's pilot flame are currently negligible. The open flare is subject to an opacity standard of 20%.

The flare will operate during initial startup of this high-temperature desulfurization process. The untreated syngas initially introduced into the absorber and regenerator gases will be sent to the existing flare until the absorber is online. The flare will be used to oxidize intermittent emissions associated with startups, shutdowns and malfunctions of the demonstration project equipment. The flare will operate under the current regulated performance restrictions and emission standards, pursuant to air construction Permit No.PSD-FL-194.

Miscellaneous Equipment

- High-temperature desulfurization process unit sorbent hopper will operate for approximately 104 hours per year. Intermittent emissions of particulate matter are estimated to be 0.10 TPY. The sorbent hopper will be equipped with a cartridge-type filter to control PM emissions.
- Amine (aMDEA) surge drum will operate for approximately 12 hours per year. Due to the low vapor pressure of aMDEA (less than 0.0002 pound per square inch absolute at 68 ºF) and the limited duration of venting, VOC emissions from the amine surge drum will be negligible.
- The high-temperature desulfurization process unit regenerator system regenerator fines bin will operate approximately 104 hours per year. Intermittent emissions of particulate matter are estimated to be 0.10 TPY. The regenerator fines bin will also be equipped with a cartridge-type filter to control PM emissions.

State Regulations

According to Section 403.061(18), F.S., the department has the power and the duty to encourage and conduct studies, investigations, and research relating to pollution and its causes, effects, prevention, abatement, and control. The project is the largest demonstration of a HTSC system and an integrated CCS system on an IGCC installation.

The applicant could have requested exemption from permitting based on one or more provisions under Department rules 62-4.040 and 62-210.300, Florida Administrative Code (F.A.C.). However, the applicant decided to pursue a permit for the project.

The facility will continue to operate under its existing air construction and facility Title V operation permits. The most recent applicable permit is Title V Permit No. 1050233-026-AV available at:

Link to Title V Permit

Construction-Related Activities Resulting in Secondary Emissions

Emissions from the temporary construction of the high-temperature syngas cleanup system and an integrated CO_2 capture and sequestration system and related activities are considered *secondary emissions*, which are defined in Rule 62-210.200, F.A.C. as, "The emissions which occur as a result of the construction or operation of a facility or a modification to a facility, but which are not discharged into the atmosphere from the facility itself. Secondary emissions may include but are not limited to emissions from ships or trains coming to or leaving a new or modified facility and emissions from any off-site support facility which would not otherwise be constructed or increase its emissions except as a result of the construction or operation of the new or modified facility. Secondary emissions must be specific, well-defined, quantifiable, and impact the same general area as the facility or modification which causes the secondary emissions." As provided in the definition of *potential to emit*, "Secondary emissions are not included when determining the potential to emit of an emission unit or facility." BACT determinations are not required for activities related to construction since emissions will be temporary and occur before the permanent emissions units are fully operational.

4. PRELIMINARY DETERMINATION

The Department makes a preliminary determination that the proposed project will comply with all applicable state and federal air pollution regulations as conditioned by the draft permit. This determination is based on a technical review of the complete application, reasonable assurances provided by the applicant, and the conditions specified in the draft permit. No air quality modeling analysis is required because the project does not result in a significant increase in emissions. Tammy McWade is the project engineer responsible for reviewing the application and drafting the permit. Additional details of this analysis may be obtained by contacting the project engineer at the Department's Office of Permitting and Compliance at Mail Station #5505, 2600 Blair Stone Road, Tallahassee, Florida 32399-2400.

Florida Department of Environmental Protection

Bob Martinez Center
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

PERMITTEE

Tampa Electric Company
P.O. Box 111
Tampa, FL 33601-0111

Authorized Representative:
Karen Sheffield, Director Polk Power Station

Air Permit No. 1050233-027-AC
Permit Expires: December 31, 2015
Minor Air Construction Permit

Polk Power Station
HTSC/CCS Demonstration Project

PROJECT

This is the final air construction permit, which authorizes the installation and operation of a high-temperature syngas cleanup system (HTSC) and an integrated carbon capture and sequestration (CCS) system. The proposed work will be conducted at the existing Polk Power Station, which is a electrical generating plant categorized under Standard Industrial Classification No. 4911. The existing facility is located in Polk County at 9995 State Route 37 South in Mulberry, Florida. The UTM coordinates are Zone 17, 402.45 km East, and 3067.35 km North.

This final permit is organized into the following sections: Section 1 (General Information); Section 2 (Administrative Requirements); Section 3 (Emissions Unit Specific Conditions). As noted in the Final Determination provided with this final permit, no changes were made to the draft permit.

STATEMENT OF BASIS

This air pollution construction permit is issued under the provisions of: Chapter 403 of the Florida Statutes (F.S.) and Chapters 62-4, 62-204, 62-210, 62-212, 62-296 and 62-297 of the Florida Administrative Code (F.A.C.). The permittee is authorized to conduct the proposed work in accordance with the conditions of this permit. This project is subject to the general preconstruction review requirements in Rule 62-212.300, F.A.C. and is not subject to the preconstruction review requirements for major stationary sources in Rule 62-212.400, F.A.C. for the Prevention of Significant Deterioration (PSD) of Air Quality.

Upon issuance of this final permit, any party to this order has the right to seek judicial review of it under Section 120.68 of the Florida Statutes by filing a notice of appeal under Rule 9.110 of the Florida Rules of Appellate Procedure with the clerk of the Department of Environmental Protection in the Office of General Counsel (Mail Station #35, 3900 Commonwealth Boulevard, Tallahassee, Florida, 32399-3000) and by filing a copy of the notice of appeal accompanied by the applicable filing fees with the appropriate District Court of Appeal. The notice must be filed within 30 days after this order is filed with the clerk of the Department.

Executed in Tallahassee, Florida

(Electronic Signature and Date)
Jeffery F. Koerner, Program Administrator
Office of Permitting and Compliance
Division of Air Resource Management

CERTIFICATE OF SERVICE

The undersigned duly designated deputy agency clerk hereby certifies that this Final Air Permit package (including the Final Determination and Final Permit) was sent by electronic mail, or a link to these documents made available electronically on a publicly accessible server, with received receipt requested before the close of business on the date indicated below to the following persons.

Ms. Karen Sheffield, TECO: kasheffield@tecoenergy.com
Mr. Paul L. Carpinone, TECO: plcarpinone@tecoenergy.com
Mr. Byron Burrows, TECO: btburrows@tecoenergy.com
Mr. Thomas W. Davis, P.E., ECT: tdavis@ectinc.com
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Ms. Cindy Mulkey, DEP Siting Office: cindy.mulkey@dep.state.fl.us
Ms. Heather Ceron, EPA Region 4: ceron.heather@epa.gov
Ms. Anne Harvey: aharvey@earthjustice.org
Ms. Lynn Scearce, DEP PC Reading File: lynn.scearce@dep.state.fl.us
Ms. Barbara Friday, DEP PP Reading File: barbara.friday@dep.state.fl.us

Clerk Stamp

FILING AND ACKNOWLEDGMENT FILED, on this date, pursuant to Section 120.52(7), Florida Statutes, with the designated agency clerk, receipt of which is hereby acknowledged.

____
(Electronic Signature of Clerk and Date)

FACILITY DESCRIPTION

Polk Power Station is an electric power plant, which is categorized under Standard Industrial Classification Code No. 4911. The existing Polk Power Station is located in Polk County at 9995 State Road 37 South in Mulberry, Florida. The UTM coordinates are Zone 17, 402.45 km East, and 3067.35 km North. This site is in an area that is in attainment (or designated as unclassifiable) for all air pollutants subject to state and federal Ambient Air Quality Standards (AAQS).

The facility is an integrated gasification combined-cycle (IGCC) plant consisting of Unit 1 (EU 001) a 260 megawatt (MW) (electric) combined cycle combustion turbine, which fires synthesis gas (syngas) produced from gasification of solid fuels including coal and petroleum coke (petcoke) or No. 2 fuel oil; an auxiliary boiler (EU 003), which fires No. 2 fuel oil; a sulfuric acid plant (EU 004); a solid fuel handling system (EU 005); a solid fuel gasification system (EU 006); Units 2 and 3 (EU 009 and 010) are two nominal 165 MW simple cycle gas turbines firing either natural gas or No. 2 fuel oil; and, Units 4 and 5 (EU 011 and 012) are two nominal 165 MW simple cycle gas turbines that fire only natural gas.

PROPOSED PROJECT

The project consists of installation and operation a pre-commercial scale demonstration high-temperature syngas cleanup system (HTSC) and an integrated carbon dioxide (CO_2) capture and sequestration (CCS) system at the Polk Power Station. The demonstration project will include a high-temperature desulfurization process, trace contaminant removal process and direct sulfur recovery process. These cleanup systems will be integrated with the existing IGCC Unit 1. Emission sources associated with this demonstration project includes two small heaters, one sorbent storage hopper, on regenerator fines storage bin and one amine surge drum.

A slipstream of syngas from the IGCC plant will be treated in the cleanup systems to simulate commercial operations. The high-temperature desulfurization process will remove 99.9 percent (%) of the sulfur in the syngas. The trace contaminant removal process will reduce arsenic, selenium and mercury concentrations in the syngas. The direct sulfur recovery process will convert sulfur dioxide (SO_2) to commercial-grade elemental sulfur. The high level of sulfur removal in the high-temperature desulfurization process will provide a syngas stream from which activated methyldiethanolamine (aMDEA) will be used to capture up to 90% of the CO_2 in the cleaned syngas. A pressurized pipeline will transfer the compressed CO_2 to an onsite injection well for injection and sequestration in a deep saline aquifer geologic formation.

The demonstration project is planned to commence construction in March 2012 and be completed by April 2013. The goal for the operation phase is to achieve at least 8,000 hours of operation during the approximate 18 month demonstration period, which is expected to be completed in the third quarter of 2015.

This project will add the following emissions units.

EU No.	Emission Unit Description
015	High-Temperature Syngas Cleanup System (HTSC) and Carbon Capture and Sequestration System (CCS)

FACILITY REGULATORY CLASSIFICATION

- The facility is not a major source of hazardous air pollutants (HAP).
- The facility operates units subject to the acid rain provisions of the Clean Air Act.
- The facility is a Title V major source of air pollution in accordance with Chapter 213, F.A.C.
- The facility is a major stationary source in accordance with Rule 62-212.400, F.A.C. for the Prevention of Significant Deterioration (PSD) of Air Quality.
- The facility operates units subject to the New Source Performance Standards in Part 60, Title 40 of the Code of Federal Regulations (CFR).

SECTION 2. ADMINISTRATIVE REQUIREMENTS

1. Permitting Authority: The permitting authority for this project is the Office of Permitting and Compliance, Division of Air Resource Management, Florida Department of Environmental Protection (Department). The Office of Permitting and Compliance mailing address is 2600 Blair Stone Road (MS #5505), Tallahassee, Florida 32399-2400.

2. Compliance Authority: All documents related to compliance activities such as reports, tests, and notifications shall be submitted to the Southwest District Office at: 13051 N. Telecom Parkway, Temple Terrace, Florida 33637-0926.

3. Applicable Regulations, Forms and Application Procedures: Unless otherwise specified in this permit, the construction and operation of the subject emissions units shall be in accordance with the capacities and specifications stated in the application. The facility is subject to all applicable provisions of: Chapter 403, F.S.; and Chapters 62-4, 62-204, 62-210, 62-212, 62-213, 62-296 and 62-297, F.A.C. Issuance of this permit does not relieve the permittee from compliance with any applicable federal, state, or local permitting or regulations.

4. New or Additional Conditions: For good cause shown and after notice and an administrative hearing, if requested, the Department may require the permittee to conform to new or additional conditions. The Department shall allow the permittee a reasonable time to conform to the new or additional conditions, and on application of the permittee, the Department may grant additional time. [Rule 62-4.080, F.A.C.]

5. Modifications: The permittee shall notify the Compliance Authority upon commencement of construction. No new emissions unit shall be constructed and no existing emissions unit shall be modified without obtaining an air construction permit from the Department. Such permit shall be obtained prior to beginning construction or modification. [Rules 62-210.300(1) and 62-212.300(1)(a), F.A.C.]

6. Source Obligation:

   (a) At such time that a particular source or modification becomes a major stationary source or major modification (as these terms were defined at the time the source obtained the enforceable limitation) solely by exceeding its projected actual emissions, then the requirements of subsections 62-212.400(4) through (12), F.A.C., shall apply to the source or modification as though construction had not yet commenced on the source or modification. [Rule 62-212.400(12), F.A.C.]

7. Application for Title V Permit: This permit authorizes construction of the permitted emissions units and initial operation to determine compliance with Department rules. A Title V air operation permit is required for regular operation of the permitted emissions unit. The permittee shall apply for a Title V air operation permit at least 90 days prior to expiration of this permit, but no later than 180 days after commencing operation. To apply for a Title V operation permit, the applicant shall submit the appropriate application form, compliance test results, and such additional information as the Department may by law require. The application shall be submitted to the appropriate Permitting Authority with copies to the Compliance Authority. [Rules 62-4.030, 62-4.050, 62-4.220 and Chapter 62-213, F.A.C.]

B. HTSC and CCS System Demonstration Project (EU 015)

This section of the permit addresses the following emissions units.

EU No.	Emission Unit Description
015	High-Temperature Syngas Cleanup System (HTSC) and Carbon Capture and Sequestration System (CCS)

{Permitting Note: The temporary cleanup systems will be integrated with the existing integrated coal gasification combined-cycle (IGCC) Unit 1 to remove more than 99.9% of sulfur in the synthetic gas (syngas) slipstream and capture 90% of the carbon dioxide (CO_2) in the clean syngas slipstream for subsequent geological sequestration. The demonstration project is planned to commence construction in March 2012 and be completed by April 2013. The goal for the operation phase is to achieve at least 8,000 hours of operation during the approximate 18 month demonstration period, which is expected to be completed in the third quarter of 2015.

COMPLIANCE WITH EXISTING PERMIT CONDITIONS

1. Existing Permits: This permit supplements all existing valid permits. The permittee shall continue to comply with all applicable conditions from valid air construction and facility Title V operation permits. [Permit No. 1050233-026-AV]

EQUIPMENT

2. High-Temperature Syngas Cleanup System: The permittee is authorized to install and operate the following processes:
   a. High-temperature desulfurization process;
   b. Trace contaminant removal process; and
   c. Direct sulfur recovery process.

   [Application No. 1050233-027-AC]

3. Carbon Capture and Sequestration System: The permittee is authorized to install and operate the following processes:
   a. Water gas shift reactor system;
   b. Low-temperature gas cooling system.
   c. Activated amine CO_2 capture system.
   d. CO_2 compression and drying system.
   e. CO_2 deep well injection sequestration system.

   [Application No. 1050233-027-AC]

4. High-Temperature Desulfurization Process Startup Heater: The permittee is authorized to install and operate the startup process heater that will fire propane, natural gas and ultra-low sulfur diesel (ULSD) fuel oil with a design heat input rate of approximately 24 million British thermal units (MMBtu)/hour. [Application No. 1050233-027-AC]

5. Direct Sulfur Recovery Process Tailgas Recycle Heater: The permittee is authorized to install and operate the tailgas recycle heater that will fire only propane with a design heat input rate of approximately 2 MMBtu/hour. [Application No. 1050233-027-AC]

6. Miscellaneous Ancillary Equipment: The permittee is authorized to install and operate the adsorber sorbent hopper, aMDEA surge drum and regenerator fines bin. [Application No. 1050233-027-AC]

PERFORMANCE RESTRICTIONS

7. Hours of Operation: The hours of operation for the temporary high-temperature syngas cleanup system and integrated CO_2 capture and sequestration system are not limited (8,760 hours per year).

Appendix C

Environmental Assessment

DOE/EA-1867

FINAL
ENVIRONMENTAL ASSESSMENT

for

RTI INTERNATIONAL SCALE-UP OF HIGH-TEMPERATURE SYNGAS CLEANUP AND CARBON CAPTURE AND SEQUESTRATION TECHNOLOGIES, POLK COUNTY, FLORIDA

U.S. DEPARTMENT OF ENERGY
National Energy Technology Laboratory

U.S. DEPARTMENT OF ENERGY

NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

October 2011

COVER SHEET

Responsible Agency: U.S. Department of Energy (DOE)

Title: Final Environmental Assessment for RTI International Scale-Up of High-Temperature Syngas Cleanup and Carbon Capture and Sequestration Technologies, Polk County, Florida (DOE/EA-1867)

Contact: For additional copies or for more information concerning this environmental assessment (EA), please contact:

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Abstract: DOE prepared this EA to evaluate the potential environmental consequences of its Proposed Action to provide cost-shared funding to RTI International (RTI) for its proposed project to demonstrate the precommercial scale-up of RTI's high-temperature syngas cleanup and carbon capture and sequestration technologies. Approximately $168.8 million of DOE's total $171.8 million funding for the proposed project would be provided from funds authorized in the American Recovery and Reinvestment Act of 2009 (Public Law 111-5, 123 Stat. 115). RTI's proposed project would advance the commercial deployment of cost-effective, environmentally sound technology options that reduce the constraints associated with using domestic coal energy resources and may ultimately assist in reducing greenhouse gas intensity.

RTI's proposed project would be located at Tampa Electric Company's existing Polk Power Station in Polk County, Florida. The proposed project would treat a slipstream, equivalent to up to 66 megawatts of electricity generation, of coal-derived syngas from the existing Polk Unit 1 integrated gasification combined-cycle power plant to remove 99.9 percent of the sulfur, reduce trace contaminant (arsenic, selenium, and mercury) concentrations, and convert the removed sulfur compounds to commercial-grade elemental sulfur. Also, up to 300,000 tons per year, or 90 percent, of the carbon dioxide (CO_2) in the cleaned syngas would be captured and sequestered in a deep geologic formation and not released to the atmosphere.

This EA evaluates the potential impacts of the proposed project in 13 environmental resource areas. Based on initial impact screening evaluations, DOE determined that no or negligible impacts would occur in six of these resource areas. Additional impact evaluations for air quality, geology and soils, water resources, socioeconomics, transportation, waste management, and human health and safety identify negligible or minimal impacts due to the proposed project's construction and operation. In this EA, potential cumulative impacts of the proposed project with other past, present, or future actions are also evaluated, and no adverse cumulative impacts are identified.

Availability: The Final EA is available on DOE's National Energy Technology Laboratory (NETL) website at <http://www.netl.doe.gov/publications/others/nepa/ea.html>.

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degree Celsius
°F	degree Fahrenheit
$\mu g/m^3$	microgram per cubic meter
aMDEA	activated methyldiethanolamine
ASRus	ASRus, LLC
BEBR	Bureau of Economic and Business Research
CCSP	U.S. Climate Change Science Program
CDC	Centers for Disease Control and Prevention
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cm/sec	centimeter per second
CO	carbon monoxide
CO_2	carbon dioxide
COS	carbonyl sulfide
CR	County Road
DOE	U.S. Department of Energy
DSRP	direct sulfur recovery process
EA	environmental assessment
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
F.A.C.	Florida Administrative Code
F.S.	Florida Statutes
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FGT	Florida Gas Transmission
FONSI	Finding of No Significant Impact
FRP	fiber reinforced piping
ft	foot (feet)
ft bls	foot (feet) below land surface
ft/day	foot (feet) per day
GHG	greenhouse gas
H_2S	hydrogen sulfide
hr/yr	hour per year
HTDP	high-temperature desulfurization process
IAS	intermediate aquifer system
ICCS	industrial carbon capture and sequestration
ICP	integrated contingency plan
IDLH	immediately dangerous to life or health
IGCC	integrated gasification combined-cycle
InSAR	interferometric synthetic aperture radar
IPCC	International Panel on Climate Change
kV	kilovolt
LFAS	Lower Floridan aquifer system
LOS	level of service
MGD	million gallons per day
MMBtu/hr	million British thermal units per hour
MMSCFH	million standard cubic feet per hour
mph	mile(s) per hour

LIST OF ACRONYMS AND ABBREVIATIONS

(Continued, Page 2 of 3)

MVA	monitoring, verification, and accounting
MW	megawatt
NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NEPA	National Environmental Policy Act of 1969
NETL	DOE's National Energy Technology Laboratory
NIOSH	National Institute for Occupational Safety and Health
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NSR	new source review
NWS	National Weather Service
OSHA	Occupational Safety and Health Administration
PBR	polished borehole receptacle
PFT	perfluorocarbon tracer
PM	particulate matter
PM_{10}	particulate matter less than 10 microns in aerodynamic diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in aerodynamic diameter
ppb	part per billion
ppm	part per million
ppmv	part per million by volume
PPSA	Florida Electrical Power Plant Siting Act
psig	pound-force per square inch gauge
RCRA	Resource Conservation and Recovery Act
Recovery Act	American Recovery and Reinvestment Act of 2009
RTI	RTI International
SAS	surficial aquifer system
SCA	site certification application
SCS	Soil Conservation Service
SHPO	State Historic Preservation Office
SIP	State Implementation Plan
SO_2	sulfur dioxide
SR	State Road
SWFWMD	Southwest Florida Water Management District
syngas	synthesis gas
Tampa Electric	Tampa Electric Company
TCLP	toxicity characteristic leaching procedure
TCRP	trace contaminant removal process
THPO	Tribal Historic Preservation Office
tpd	ton(s) per day
tpy	ton(s) per year
U.S.C.	United States Code
UFAS	Upper Floridan aquifer system
UIC	underground injection control
USACE	U.S. Army Corps of Engineers
USC	United States Code
USDA	U.S. Department of Agriculture

LIST OF ACRONYMS AND ABBREVIATIONS

(Continued, Page 3 of 3)

USDW	underground source of drinking water
VMT	vehicle-mile traveled
VOC	volatile organic compound

SUMMARY

The U.S. Department of Energy (DOE) proposes to provide $171.8 million in cost-shared funding to RTI International (RTI) for its proposed project to demonstrate the precommercial scale-up of RTI's high-temperature synthesis (syngas) cleanup and carbon dioxide (CO_2) capture and sequestration technologies. Approximately $168.8 million of DOE's funding would be provided from Industrial Carbon Capture and Sequestration Program funds authorized in the American Recovery and Reinvestment Act of 2009. RTI's proposed project would be located at Tampa Electric Company's (Tampa Electric's) existing Polk Power Station electric generating facilities in southwestern Polk County, Florida. The project facilities would occupy approximately 2.4 acres adjacent to the existing power plant facilities. RTI's proposed project would treat a slipstream, equivalent to up to 66 megawatts of electricity generation, of the coal-derived syngas from the Polk Unit 1 integrated gasification combined-cycle (IGCC) power plant to remove 99.9 percent of the sulfur, reduce trace contaminant (arsenic, selenium, and mercury) concentrations, and convert removed sulfur compounds to elemental sulfur. Also, the proposed project would capture up to 300,000 tons per year, or 90 percent, of the CO_2 in the cleaned syngas and sequester the CO_2 by deep well injection in a deep geologic formation at the site. The proposed project would have a target to operate for approximately 8,000 hours over the 18-month demonstration period.

In compliance with the National Environmental Policy Act of 1969 (NEPA) (Title 42, Section 4321 *et seq.*, United States Code) and DOE's NEPA implementing procedures (Chapter 10, Part 1021, Code of Federal Regulations), this environmental assessment (EA) evaluates the potential environmental impacts of DOE's Proposed Action to provide funding to RTI, RTI's proposed project, and the no-action alternative, under which it is assumed the proposed project would not be constructed. This EA is intended to provide DOE with information on the potential environmental consequences of the proposed project for consideration in its decision-making on proceeding with its Proposed Action.

In this EA, the potential impact evaluations considered all the environmental resource areas that DOE typically considers in NEPA documents. Based on initial impact screening evaluations, some of the resource areas were not carried forward for additional analyses because DOE determined the proposed project would not impact these resources or the potential impacts would be negligible. DOE focused the more detailed impact evaluations on the following resource areas:

- Air quality.
- Geology and soils.
- Water resources.
- Socioeconomics.
- Transportation.
- Waste management.
- Human health and safety.

AIR QUALITY

The proposed project site area is designated as attainment for all National Ambient Air Quality Standards (NAAQS) criteria air pollutants. Construction of the proposed project would result in fugitive dust air emissions during site preparation activities and the release of nitrogen oxides, carbon monoxide, and other fuel combustion emissions from equipment and vehicles. The potential air quality impacts of the construction-related emissions would be minor due to the temporary and localized nature of the emissions. During operations, the proposed project would have three sources of intermittent emissions and one continuous emissions source, a propane-fired heater. Due to the intermittent and minor level of emissions from these sources, potential air quality impacts would be minor and would not contribute to exceedances of NAAQS or changes in attainment status.

During the demonstration period, the proposed project would reduce greenhouse gas emissions by capturing and sequestering 300,000 tons per year of CO_2, which would otherwise have been released to the atmosphere.

GEOLOGY AND SOILS

Soils on the proposed project site have been previously disturbed by phosphate mining activities and construction activities for the existing power plant facilities. The general geologic framework at the Polk Power Station site consists of surficial layers of unconsolidated sands, clays, and consolidated carbonate strata underlain by a series of thick, stratigraphic units consisting of sedimentary carbonate (limestone and dolomite) rocks.

The targeted CO_2 injection zone would be a deep saline carbonate (limestone and dolomite) system located between 4,200 and 8,000 feet below land surface (ft bls). The injection zone is overlain by a laterally continuous, more than 1,300-feet-thick, low-permeability confining unit. A release of CO_2 vertically through the geologic materials up to the surface or nearer surface geologic units would be considered unlikely because of the proposed injection well design plus the proposed operational monitoring program and the presence of the thick confining unit. Therefore, the proposed project would be expected to have minimal impacts on geologic or soil resources.

The operation of the injection well for injection of CO_2 in its supercritical fluid state for the proposed project is not expected to contribute to or increase the probability for the formation of sinkholes based on several reasons. First, the Polk Power Station site is located in an area of Florida that has experienced only minor, shallow depression sinkhole activity to date, and cover-collapse sinkhole occurrence is unlikely. Second, the depth of the targeted injection zone (i.e., 4,200 to 8,000 ft bls) and the thickness of the overlying units would limit the likelihood of sinkhole development. Further, based on geochemical modeling, the CO_2 plume would dissolve into the saline carbonate system and would no longer be acidic in nature after a short 2- to 3-year period of time, which would limit the dissolution of formation materials and the development of cavities.

WATER RESOURCES

The proposed project site is located within the headwaters of Little Payne Creek that flows from the site to Payne Creek, which is a tributary of the Peace River. Key surface water features on the Polk Power Station site include the 755-acre cooling reservoir, a 26-acre stormwater detention pond, old water-filled mine cuts, and a reclaimed lake. During construction of the proposed project, soil erosion and stormwater runoff from the project facility area and construction laydown/parking areas would be the primary potential surface water resource concern. During construction, appropriate stormwater management and erosion control measures would be used to avoid or minimize potential impacts, and any potential impacts would be minor and temporary. During operation, the proposed project would use minor amounts of additional water resources and discharge minimal amounts of wastewater. Water would be provided from the existing Polk Power Station water supply system, and wastewater would be discharged to the existing wastewater treatment system, which ultimately discharges to the cooling reservoir. Therefore, potential impacts to surface water resources would be minimal.

The groundwater aquifer systems below the proposed project site area include, in descending order, the surficial, intermediate, and the Upper and Lower Floridan aquifers. The Upper Floridan aquifer, which extends between 300 and 1,000 ft bls in the site area, is the major source of drinking water supply in the project area, as well as in most of the northern and central portions of the Florida Peninsula. The targeted CO_2 injection zone for the proposed project would be a deep saline carbonate system between 4,200 and 8,000 ft bls. This zone is primarily separated from the Upper Floridan drinking water aquifer system by a thick, low-permeability confining unit that extends between 2,900 and 4,000 ft bls, as well as an intermediate low-permeability confining unit directly below the aquifer. The unplanned release of CO_2 vertically up to the drinking water aquifer would be considered unlikely due to the presence of these confining units, as well as the proposed design of the injection well, which would include multiple steel casings and cement packings through and below the aquifer. Further, should a release of CO_2 occur, preliminary geochemical modeling indicates the CO_2 solution would react with carbonate materials and be dissolved prior to reaching drinking water aquifers. Therefore, potential impacts to groundwater resources are expected to be minor.

SOCIOECONOMICS

The proposed project would be located in a rural, unincorporated area of Polk County. The proposed project facilities would be situated adjacent to, and integrated with, the existing IGCC power plant within the Polk Power Station. Because of its nature, size, and location, the proposed project would have negligible impacts on local socioeconomic resources such as population, housing, schools, and police and fire protection. The proposed project would create a monthly average of 107 jobs on the site during the 13-month construction period and 12 jobs during the 18-month operational period. The creation of jobs would provide minor short-term benefits to the local economy.

TRANSPORTATION

Transportation facilities in the vicinity of the Polk Power Station site include several state and county roadways and a railroad. The roads in the vicinity of the site are functioning at an acceptable level of service (LOS). During construction, the proposed project would have short-term, minor transportation impacts due to the movement of construction workers and equipment and material deliveries to and from the site. These potential impacts would involve minor traffic congestion and delays in the vicinity of access road entrances to the Polk Power Station. These potential impacts would be temporary and would not be expected to cause the roads to function at an unacceptable LOS. During operations, the potential impacts of the proposed project on transportation would be minimal due to the small number of operational employees.

WASTE MANAGEMENT

The existing Polk Power Station Unit 1 IGCC operations generate various wastes and byproducts, including some materials with potentially hazardous properties. Under applicable Resource Conservation and Recovery Act (RCRA) regulations (Chapter 40, Parts 260 through 279, Code of Federal Regulations [CFR]), the Polk Power Station is classified as a large-quantity hazardous waste generator. Currently, all wastes, byproducts, and potential hazardous materials are managed by Tampa Electric in accordance with applicable RCRA and state requirements.

The proposed project would store and use various chemicals and materials and generate moderate quantities of waste products, some of which may be potentially hazardous. During the proposed project operations, the wastes would be managed, controlled, characterized by testing, and transported offsite for appropriate disposal. Further, workers responsible for the proposed project operations would be properly trained on waste handling procedures, as well as emergency response procedures in case of an accidental release. Based on these measures, the proposed project is expected to have minimal impacts due to the generation, handling, and disposal of wastes.

HUMAN HEALTH AND SAFETY

Potential human health and safety impacts associated with the proposed project may result from air pollution releases, accidental spills or releases of hazardous materials or toxic gases, and worker injuries due to accidents. These potential concerns are similar to those associated with the existing Polk Power Station operations. The proposed project would have minor, intermittent air emissions that would not create any major air pollution nor contribute to exceedances of NAAQS, which were established to protect human health and welfare. Potentially hazardous wastes and materials generated by the proposed project would be managed, controlled, and disposed in accordance with applicable federal and state regulations to minimize potential human health risks due to accidental releases. Applicable Occupational Safety and Health Administration procedures, similar to the existing plant programs, would be followed during construction and operation of the proposed project to minimize the potential for worker injury due to accidents.

The proposed project would involve the handling of two gas streams, which have human health exposure concerns. These streams would include gas removed from the untreated syngas in the high-temperature desulfurization process, which would have high concentrations of hydrogen sulfide (H_2S) and the CO_2 gas captured in the activated amine system. The equipment, vessels, and piping for the H_2S and CO_2 gas streams would be designed and constructed to minimize the potential for leaks. These systems would also be regularly inspected and equipped with monitoring detectors and alarms to minimize human health and safety risks.

During preparation of this EA, DOE consulted with the Florida State Historic Preservation Office (SHPO), Seminole Tribe of Florida, and Seminole Nation of Oklahoma regarding the potential impacts of the proposed project on historic and tribal resources property. Based on initial evaluations, DOE determined that no resources or properties would be affected by the proposed project. The Florida SHPO and Seminole Tribal Historic Preservation Office concurred with DOE's determinations.

Cumulative impact considerations included air emissions from the existing power plant units and potential future generating units at the Polk Power Station and Tampa Electric's future use of the same injection well, which would be used for CO_2 injection for the proposed project, for disposal of wastewater from the existing operations. Due to the intermittent, minor level of emissions from the proposed project, the cumulative impacts on air quality would be negligible. Based on preliminary geochemical modeling, the combined CO_2 and wastewater plumes would not migrate a considerable distance from the injection site, and the CO_2 plume would react with and dissolve in the brine wastewater within the injection zone in a relatively short period of time. Therefore, the cumulative impacts of the future use of the injection well are expected to be minimal.

Under the no-action alternative, DOE would not provide funding to RTI, and the proposed project would not be constructed or operated. Therefore, no impacts to environmental resources would occur, and no short-term benefits to the local economy would occur. Also, under the no-action alternative, Tampa Electric would proceed with its plans to construct and use two injection wells for the disposal of wastewater from the power plant operations.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) proposes to provide cost-shared funding to RTI International (RTI) for a project that would demonstrate the scale-up of high-temperature synthesis gas (syngas) cleanup and carbon dioxide (CO_2) capture and sequestration technologies. RTI's proposed project would be located at Tampa Electric Company's (Tampa Electric's) existing integrated gasification combined-cycle (IGCC) electric generating facility at its Polk Power Station in Polk County, Florida. The overall objective of RTI's proposed project is to mitigate the technical risks associated with scale-up of syngas cleanup and CO_2 capture and sequestration technologies to enable subsequent commercial deployment.

DOE proposes to provide approximately $171.8 million in funding to RTI for the proposed project. DOE intends to provide approximately $168.8 million of its funding from Industrial Carbon Capture and Sequestration Program funds authorized in the American Recovery and Reinvestment Act of 2009 (Recovery Act) (Public Law 111-5, 123 Stat. 115). Congress appropriated the Recovery Act funds to stimulate the economy and reduce unemployment in addition to furthering DOE's Industrial Carbon Capture and Sequestration (ICCS) Program. The RTI project was selected by DOE to receive noncompetitive financial assistance from funds authorized in the Recovery Act as an expansion of a smaller project previously funded by DOE.

DOE's decision (i.e., DOE's Proposed Action) to provide funding for the RTI project requires compliance with the National Environmental Policy Act of 1969 (NEPA) (Title 42, Section 4321, *et seq.*, United States Code [USC]), Council on Environmental Quality (CEQ) regulations for implementing NEPA (Chapter 40, Parts 1500 to 1508, Code of Federal Regulations [CFR]), and DOE's NEPA Implementing Procedures (10 CFR 1021). To comply with NEPA, DOE's National Energy Technology Laboratory (NETL) prepared this Final Environmental Assessment for the RTI International Scale-Up of High-Temperature Syngas Cleanup and Carbon Capture and Sequestration Technologies, Polk County, Florida. This environmental assessment (EA) evaluates the potential environmental effects of DOE's Proposed Action to provide cost-shared funding to RTI for the construction and operation of its proposed project. The EA also evaluates the potential environmental effects of the no-action alternative, under which DOE would not provide funding to RTI, and RTI would not proceed with the proposed project.

The remainder of this chapter describes NEPA and other related environmental procedures for the proposed project (Section 1.1), DOE's purpose and need for the Proposed Action (Section 1.2), previous environmental studies for the Polk Power Station (Section 1.3), a related project (Section 1.4), the environmental resources DOE did not carry forward for detailed analysis in the EA (Section 1.5), and the consultations and public comment and response process (Section 1.6). Chapter 2.0 describes DOE's Proposed Action, RTI's proposed project, and the no-action alternative. Chapter 3.0 provides descriptions of the affected environment and the potential environmental effects of the proposed project and the no-action alternative. Chapter 4.0 discusses the cumulative impacts, and Chapter 5.0 provides DOE's conclusions from the analyses in the EA. Chapter 6.0 lists the references for the EA document. Other supporting information is provided in the appendices.

1.1 NEPA AND RELATED PROCEDURES

DOE prepared this EA in accordance with the requirements of NEPA and the CEQ and following DOE's NEPA implementing procedures. NEPA requires federal agencies to consider the potential consequences of a Proposed Action (e.g., funding decision) in their decision-making process. NEPA also encourages federal agencies to protect, restore, or enhance the environment through well-informed federal decisions. DOE must comply with these requirements prior to making a decision to proceed with the Proposed Action to provide funding for RTI's proposed project.

In accordance with DOE's NEPA implementing procedures, DOE determined that preparation of an EA is the appropriate level of analysis for RTI's proposed project. DOE based this determination of its initial review of the scope of the proposed project, its environmental setting, and its potential environmental effects. To meet DOE's regulatory requirements under NEPA, this EA evaluates the potential environmental impacts of RTI's proposed project on the physical, human, and natural environment. For comparison purposes, the EA also evaluates the potential environmental impacts of DOE's no-action alternative. This EA is intended to provide DOE with the information needed to make an informed decision on providing funding for RTI's proposed project. Based on this EA, DOE will either issue a Finding of No Significant Impact (FONSI) or determine that additional detailed analyses are needed through preparation of an environmental impact statement (EIS).

Further, in accordance with the CEQ regulations and DOE NEPA implementing procedures, the EA incorporates appropriate agency and American Indian tribal consultation and public involvement processes. All input received through these processes is considered in the environmental analyses and development of the final EA, which will form the basis for DOE's decision on its Proposed Action.

1.2 PURPOSE AND NEED FOR DOE'S PROPOSED ACTION

One of DOE's primary goals is to catalyze the timely, material, and efficient transformation of the nation's energy system and secure United States leadership in clean energy technologies (DOE, 2011). DOE's NETL contributes to this goal by funding and managing research, development, and demonstration programs to advance cost-effective technologies focused on clean energy production and use of United States domestic fossil energy resources. A key environmental issue and constraint associated with using domestic fossil fuels involves emissions of CO_2, a greenhouse gas (GHG) that contributes to global climate change. NETL's Industrial Carbon Capture and Sequestration Program fulfills a critical need by providing opportunities for the advancement of CO_2 capture and sequestration technologies. One of the principal goals of this program is to gain technical, engineering, and economic information on these technologies through large-scale testing in order to advance the commercial deployment of cost-effective, environmentally sound options that may ultimately lead to a reduction in GHG levels.

The purpose of RTI's proposed project is to design, build, and demonstrate high-temperature syngas cleanup technologies integrated with carbon capture and sequestration at a precommercial scale. The overall objective of the project is to mitigate the technical risks associated with scale-up of the syngas cleanup and CO_2 capture and sequestration technologies to enable subsequent commercial deployment. The project would support the goal of advancing cost-effective technologies to make coal power plants and other industrial facilities cleaner by removing contaminants from the coal-derived syngas and by reducing the cost and improving the efficiency of capturing and sequestering CO_2. Also, DOE believes a number of other industrial applications can potentially benefit from the RTI cleanup technologies, including the production of hydrogen for use in petroleum refineries and petrochemical plants and the production of chemicals and plastics.

In addition to providing needed information on the commercialization of syngas cleanup technologies, RTI's proposed project would also provide large-scale field testing information on the geologic sequestration characteristics, storage capacity, and processes in the deep saline aquifer formations underlying Tampa Electric's Polk Power Station in west-central Florida. The CO_2 injection process would be carefully controlled and monitored to determine potential effects and facilitate the effective design of potential CO_2 sequestration projects at other power plants near similar saline formations.

Further, DOE's Proposed Action to provide funding for RTI's proposed project would support the goals of the Recovery Act to create jobs and restore economic growth through measures that modernize the nation's infrastructure and enhance the nation's energy independence. The construction of the proposed project would create a monthly average of 107 jobs and a peak of 160 jobs on the site over the 13-month construction period and would involve expenditures for equipment, materials, and service of more than $62 million. During the subsequent 18-month operational period, the project would create 12 jobs. Additional economic benefits to the local community may also be realized.

1.3 PREVIOUS ENVIRONMENTAL STUDIES

The proposed project would be located at Tampa Electric's Polk Power Station in Polk County, Florida. The project facilities would be located adjacent to and integrated with the existing facilities and systems for the Polk Unit 1 IGCC plant. The Polk Power Station site and existing power plant facilities have been subject to various environmental studies, impact assessments, and licensing/permitting requirements. These previous environmental studies include:

- Tampa Electric Company Polk Power Station Site Certification Application, Environmental Consulting & Technology, Inc. (ECT), July 1992. This site certification application (SCA) was prepared to fulfill the environmental licensing requirements under the Florida Electrical Power Plant Siting Act (PPSA), Section 403.501 through .518, Florida Statutes (F.S.), for construction and operation of 1,150 megawatts (MW) of new electric generating facilities at the Polk Power Station site, including the Polk Unit 1 IGCC facilities. The SCA is a comprehensive environmental document, similar to an EA or EIS, which includes detailed descriptions of the existing physical, biological, and socioeconomic environment and the effects of the plant construction and operation.
- Final Environmental Impact Statement, Tampa Electric Company, Polk Power Station, U.S. Environmental Protection Agency (EPA), June 1994. This EIS was prepared by EPA, as lead agency, to meet NEPA requirements under the National Pollutant Discharge Elimination System (NPDES) permitting program. DOE was a cooperating agency for the EIS preparation to meet its NEPA requirements based on its proposed cost-shared funding for the Polk Unit 1 IGCC plant under DOE's Clean Coal Technology Demonstration Program. The U.S. Army Corps of Engineers (USACE) was also a cooperating agency.
- Polk Power Station Unit 6, Site Certification Application, ECT, September 2007. This SCA was prepared to meet the environmental licensing requirements under the Florida PPSA for construction and operation of a nominal 630-MW IGCC generating unit at the Polk Power Station site. The SCA included detailed descriptions of the existing environment and effects of the proposed unit. Tampa Electric withdrew the SCA prior to approval due to changes in economic conditions.
- Various Deep Underground Injection Well Permit Applications, ECT and ASRus, LLC (ASRus), August 2007, August 2009, February 2010a, April 2010b, May 2011a, and May 2011b. These permit applications were submitted under the Florida Department of Environmental Protection (FDEP) Underground Injection Control (UIC) Program rules (Chapter 62-528, Florida Administrative Code [F.A.C.]) for the drilling and construction of two deep injection wells (IW-1 and IW-2) and associated monitoring wells at the Polk

Power Station site. These two injection wells will be used to dispose of wastewaters from the existing power plant operations and one well (IW-2) would also be used for injection of CO_2 during RTI's proposed project demonstration period. The permit applications include information on the hydrogeologic characteristics at the site, well inventories, well design, injectate characterization, and testing and monitoring programs.

These previous environmental studies and permitting applications include useful information to support the analyses in this EA, such as detailed information on the existing affected physical, biological, and socioeconomic environmental conditions on and in the vicinity of the Polk Power Station site.

1.4 RELATED PROJECT

Prior to agreeing to provide the host site for RTI's proposed project, Tampa Electric initiated efforts to permit, drill, and construct two deep injection wells at the Polk Power Station site to be used for the disposal of wastewaters from its existing power plant operations. These efforts are part of Tampa Electric's overall plans to reduce groundwater use at the plant by using reclaimed water from the city of Lakeland for cooling reservoir makeup water.

Under its Proposed Action for RTI's proposed project, DOE would provide partial funding for the drilling, construction, and modification of one of the deep wells (IW-2) to be temporarily used to inject and sequester CO_2. After the DOE-funded RTI project demonstration period has been completed, Tampa Electric intends to use the IW-2 well for injection of wastewaters. Also, after completion of the project and if the demonstration results were favorable, Tampa Electric may consider the option of continuing the operation of all or some portion of the syngas cleanup systems. Tampa Electric has no current plans to continue the injection of CO_2 in well IW-2. The cumulative impacts of Tampa Electric's future use of the well for wastewater injection purposes are addressed in Chapter 4.0 of this EA.

1.5 ENVIRONMENTAL RESOURCES NOT CARRIED FORWARD

This EA analyzes the potential environmental impacts that may occur from DOE's Proposed Action, the implementation of RTI's proposed project, and DOE's no-action alternative. Under the no-action alternative, DOE would not provide funding to RTI, and RTI would not proceed with the proposed project. Further, under the no-action alternative, Tampa Electric would proceed with its ongoing plans to drill and construct two deep wells for the injection of wastewaters from its existing Polk Power Station facilities. However, one of the wells would not be used for injection of CO_2 during RTI's proposed demonstration project.

The focus of the detailed analyses in Chapter 3.0 is on those environmental resources with the potential for adverse impacts, controversy, or public interest. Based on its initial screening evaluation of the project's potential impacts, DOE identified the following environmental resource areas for more detailed analyses:

- Air quality.
- Geology and soils.
- Water resources.
- Socioeconomics.
- Transportation.
- Solid and hazardous waste management.
- Human health and safety.
- Energy and utilities.

DOE EAs typically address other environmental resource areas not included in the previous list. However, during its internal scoping and impact screening evaluations for the project, DOE determined that certain resource areas did not warrant detailed analysis because the proposed project would not impact these resources, or the impacts would be negligible, temporary, and/or limited to the immediate project area within the existing Polk Power Station site. Table 1-1 provides a listing of the environmental resource areas that were considered by DOE, but not carried forward for detailed analysis in this EA, and DOE's conclusions for eliminating these areas from further discussion.

1.6 CONSULTATIONS AND PUBLIC COMMENT AND RESPONSE PROCESS

The CEQ NEPA implementing regulations encourage federal agencies to involve Native American tribes; local, state, and other federal agencies; as well as the public, in the preparation of NEPA documents, such as this EA. The purpose of these consultations is to obtain inputs and comments on environmental and cultural issues from the tribes, agencies, and persons who may be interested or affected by a proposed action.

1.6.1 CONSULTATIONS

1.6.1.1 State Historic Preservation Office

On April 11, 2011, DOE sent a formal consultation letter to the Florida State Historic Preservation Office (SHPO) in accordance with the requirements of Section 106 of the National Historic Preservation Act (Title 16, Section 470, United States Code [U.S.C.], *et seq*.). The letter provided information on the proposed project and its location and requested any comments the agency may have on the potential impacts of the proposed project. The Florida SHPO provided a letter response dated April 25, 2011, stating that no historic properties will be affected by the proposed project. Appendix B contains copies of these letters.

Table 1-1. Environmental Resource Areas Not Carried Forward

Environmental Resource Area	Impact Screening Conclusions
Land use	The proposed project facilities would be located within an approximately 2.4-acre area on the existing 4,348-acre Polk Power Station site, which is a certified power generation facility under the Florida PPSA. The zoning and future land use designation for the site is Phosphate Mining, within which a certified power generation facility is allowed with the approval of a conditional use permit. Polk County approved the conditional use permit for the Polk Power Station site on June 2, 1992. The proposed project is consistent with current land uses on the site and would not affect other existing or proposed land uses near the site.
Biological	The previous environmental licensing studies for the initial development and subsequent expansions of the Polk Power Station included detailed surveys and assessments for wetlands, vegetation, and protected wildlife and plant species. The specific area for the proposed project facilities has been previously impacted and disturbed by phosphate mining activities and construction and operation of the existing power plant facilities. This immediate area contains no wetlands or suitable wildlife habitat. The proposed project would have no additional impacts on biological resources.
Noise	During construction of the proposed project, noise levels may be slightly, temporarily higher than existing noise levels of the power plant operations. During operation, noise levels from the proposed project are expected to be similar to existing noise levels. Project workers would be required to follow similar noise protection procedures as used by the existing power plant workforce in accordance with Occupational Safety and Health Administration (OSHA) standards. The project site is located more than 0.7 mile from the Polk Power Station property boundary and more than 1.7 miles from the nearest residential receptor; therefore, no adverse noise impacts are expected to offsite receptors. Noise levels are expected to meet noise level standards established in Section 761 of the Polk County Land Development Code (Polk County, 2005).
Aesthetic, visual, and recreational	The Polk Power Station site and most of the adjacent and nearby areas have been previously disturbed by phosphate mining, and the existing industrial power plant has been in operation since 1996. The proposed project would be similar, on a smaller scale, in appearance to the existing industrial facilities, and would not alter the existing visual landscape. No significant recreational, park, scenic, or natural areas occur in the vicinity of the site; therefore, no impacts are expected.
Cultural	A cultural resources assessment was conducted on the Polk Power Station site in 1991 as part of the original environmental licensing for the power plant (ECT, 1992). No archaeological or historic resources were identified during the assessment, and the State Historic Preservation Office (SHPO) concurred that no significant resources are expected on the Polk Power Station site. The SHPO was also consulted for this EA and determined that no historic properties would be affected by the proposed project (see Appendix B).

Table 1-1. Environmental Resource Areas Not Carried Forward (Continued, Page 2 of 2)

Environmental Resource Area	Impact Screening Conclusions
Environmental justice	Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations, requires federal agencies to identify and address disproportionately high and adverse human health or environmental effects of their programs and policies on minority and low-income communities and Native American tribes. The following provides information regarding the racial and Hispanic/Latino makeup and income and poverty levels in Polk County and the state of Florida.

Population by Race and Hispanic/Latino Origin, 2010

Area	Total Population	Race (%) White	Black	American Indian/ Alaska Native	Other	Hispanic/ Latino Origin (%)
Polk County	602,095	75.2	14.8	0.4	9.6	17.7
State of Florida	18,801,310	75.0	16.0	0.4	8.6	22.5

Income and Poverty Level, 2009

Area	Median Household Income	Per Capita Income	Persons Below Poverty Level (%)
Polk County	$41,913	$22,283	16.8
State of Florida	$44,755	$26,503	15.0

Source: U.S. Census Bureau, 2011.

Based on these data, the racial and Hispanic/Latino origin composition of Polk County's population and levels of income and poverty are relatively similar to the statewide averages. Therefore, no disproportionately high or adverse impacts to minority or low-income communities are expected due to the proposed project.

Source: ECT, 2011.

1.6.1.2 Seminole Tribe

On April 11, 2011, DOE sent a formal consultation letter to tribal leaders and the Tribal Historic Preservation Offices (THPOs) of the Seminole Tribe of Florida and Seminole Nation of Oklahoma in accordance with Section 106 of the National Historic Preservation Act and the Native Americans Graves Protection and Repatriation Act of 1990. The letters stated that DOE had completed an initial evaluation of the potential impacts of the proposed project and determined that no tribal resources or properties would be affected. The letters also requested tribal concurrence with DOE's finding and any comments on the potential impacts of the project on tribal resources. The Seminole Tribe of Florida's THPO provided a letter response dated May 2, 2011, stating that the THPO has no objection to DOE's findings. Appendix B provides copies of these letters.

1.6.2 PUBLIC COMMENT AND RESPONSE PROCESS

A public notice describing the proposed project and providing notice of the availability of the Draft EA was published in the local newspaper, the *Lakeland Ledger*, on July 31 and August 1 and 2, 2011. The notice requested comments on the Draft EA for a period of 15 days following publication of the notice. Copies of the Draft EA were distributed to various agencies with jurisdiction or special expertise, and copies were sent to Polk County libraries in Mulberry and Lakeland (see distribution list in Appendix A). Also, the Draft EA was made available to the public on the DOE NETL website at http://www.netl.doe.gov/publications/others/nepa/ea.html.

DOE received comments on the Draft EA from the Florida SHPO and EPA Region 4. Appendix C provides copies of these letters. No other public comments were received. The comment letter from the Florida SHPO dated August 15, 2011, stated that the office reviewed the project and concluded that, due to the nature of the project, no historic properties will be affected.

In the correspondence, dated August 19, 2011, EPA stated that, "based on the information provided in the EA, we support the project and believe the proposed facility and its operation do not appear to represent a significant impact to human health and the environment." The EPA correspondence also included seven comments on the Draft EA for consideration as the project proceeds. The following lists the topics of EPA's comments and the section of the EA that has been revised or supplemented to address the comment:

EPA Comment Topic	EA Section
Climate change	4.2
Ambient air quality conditions	3.1.1.2
Clean diesel recommendations	3.1.2.1

EPA Comment Topic	EA Section
Community impacts	3.7.2.1
Sinkhole potential	3.2.1.1 and 3.2.2.1
Energy use—CO_2 emissions	3.1.2.1
Miscellaneous—air deposition	3.1.2.1

Appendix C provides an overall summary of DOE's responses to the EPA comments.

2.0 PROPOSED ACTION AND ALTERNATIVES

This chapter describes DOE's Proposed Action, RTI's proposed project, and the no-action alternative.

2.1 DOE'S PROPOSED ACTION

DOE's Proposed Action would provide RTI $171.8 million in cost-shared funding to demonstrate the scale-up of its high-temperature syngas cleanup and CO_2 capture and sequestration technologies at Tampa Electric's Polk Power Station in Polk County, Florida. The proposed project would demonstrate these technologies at a large scale for a period of 18 months. The successful demonstration would potentially mitigate the technical risks associated with subsequent commercial deployment of these technologies that provide high-purity syngas, from which 90 percent of the carbon has been removed and sequestered, at lower costs than current technology alternatives.

2.2 RTI'S PROPOSED PROJECT

RTI's proposed project would involve the design, construction, and demonstration of its high-temperature syngas cleanup technologies integrated with CO_2 capture and sequestration at a precommercial scale. The project would build on the field tests of these cleanup technologies completed at a pilot scale using syngas from the Eastman Chemical Company's gasifier in Kingsport, Tennessee.

2.2.1 PROJECT LOCATION AND EXISTING FACILITIES

The proposed project would be located at Tampa Electric's 4,348-acre Polk Power Station site in southwestern Polk County, Florida. As shown in Figure 2-1, this site is located approximately 11 miles south of the city of Mulberry, 17 miles south of the city of Lakeland, and 28 miles southeast of the city of Tampa. The Polk Power Station site currently contains five electric generating units and associated facilities, including the nominal 260-MW Polk Unit 1 IGCC plant that began commercial operation in 1996. Polk Unit 1 is fired with syngas produced by gasifying coal and petroleum coke and consists of a nominal 190-MW combustion turbine and a nominal 70-MW heat recovery steam generator and steam turbine. The other four existing Polk units (Units 2 through 5) are 165-MW, simple-cycle combustion turbine facilities fired on natural gas with distillate fuel oil as the backup fuel for Units 2 and 3. The existing power plant facilities are located on the 2,837-acre eastern portion of the Polk Power Station property on the east side of State Road (SR) 37 (see Figure 2-2). Tampa Electric is in the process of donating the 1,511-acre western portion of the site to FDEP as a wildlife management/recreation area.

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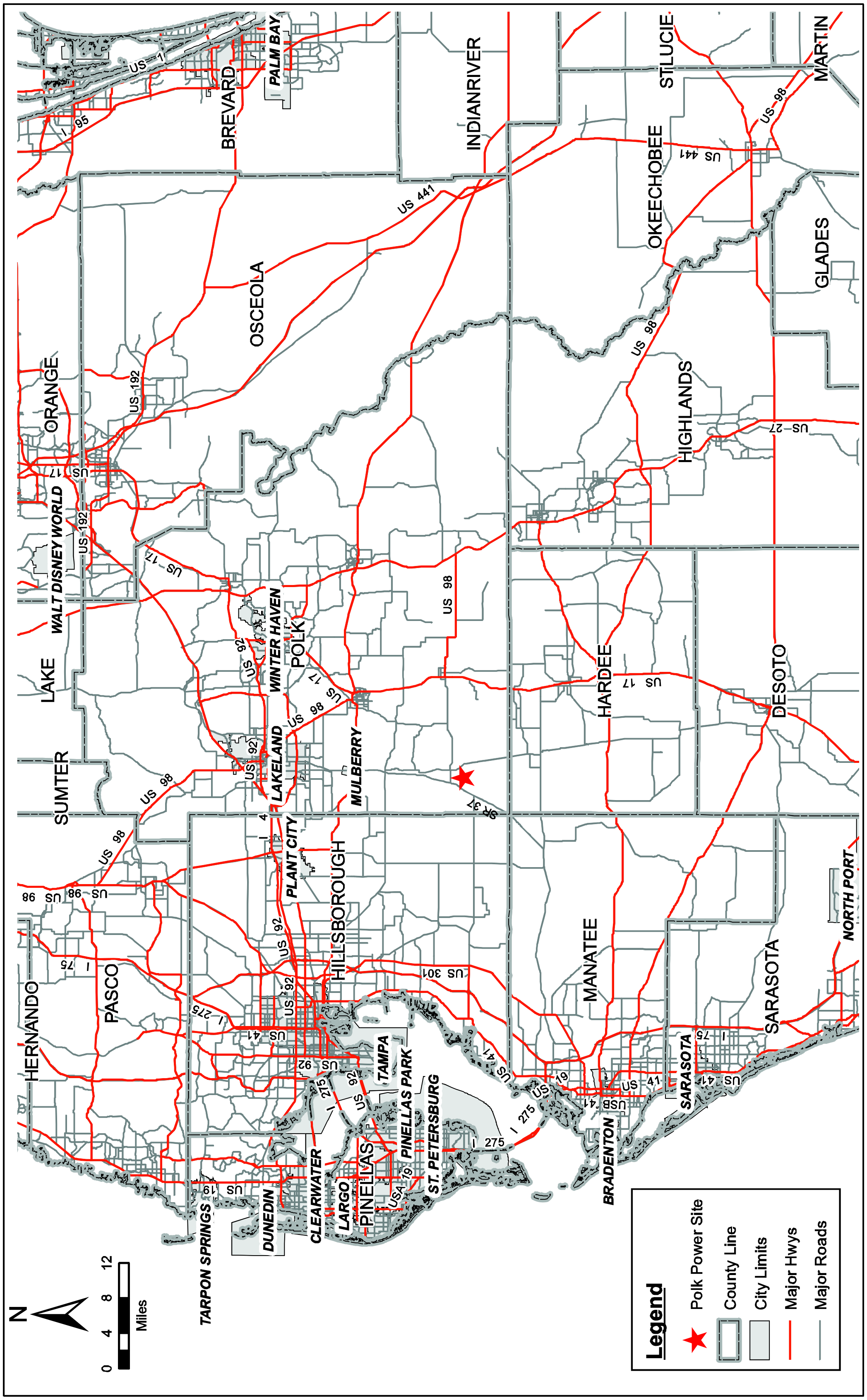

Figure 2-1. Regional Location of the Polk Power Station Site
Sources: FGDL, 2006. ECT, 2011.

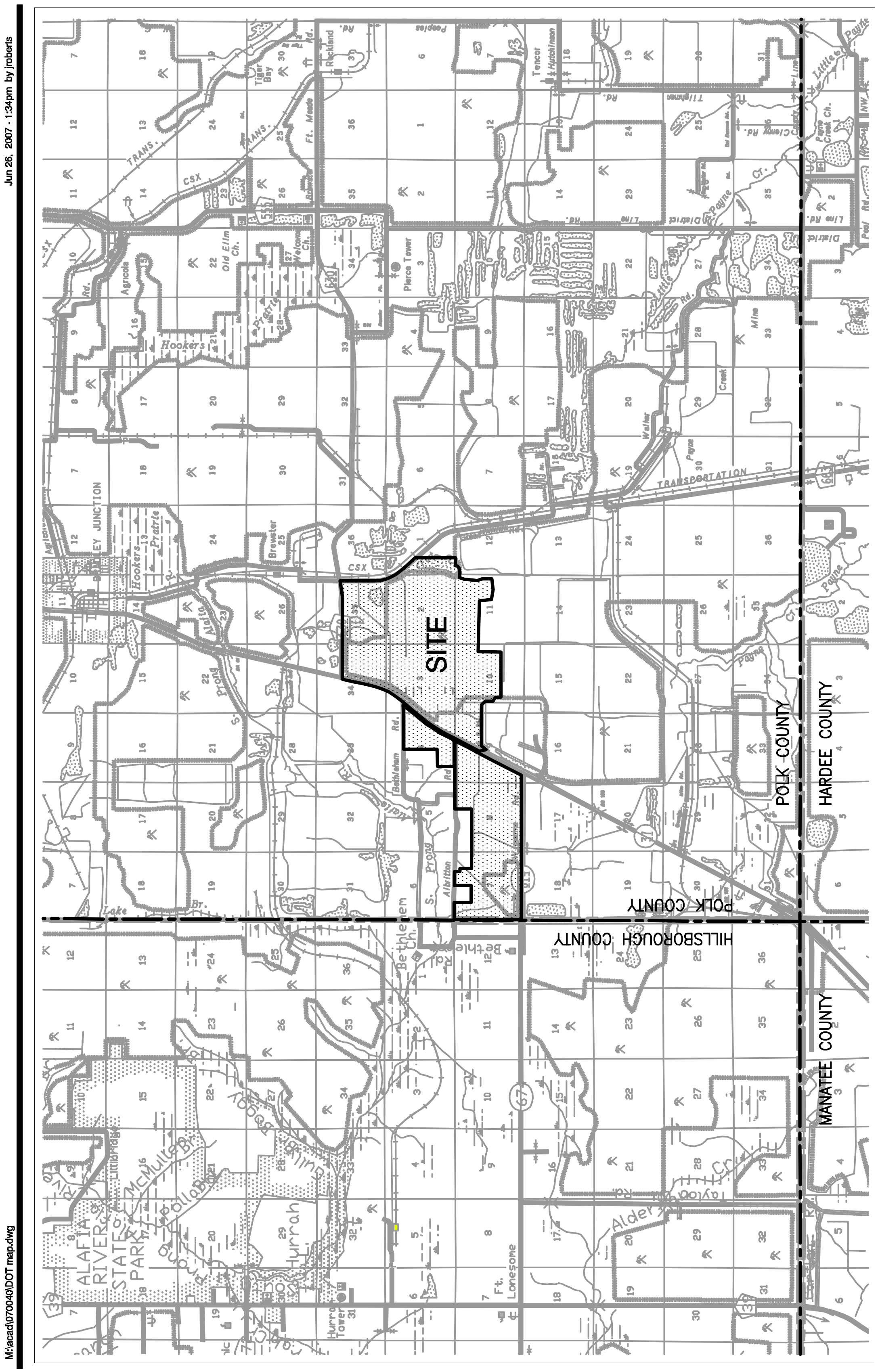

Figure 2-2. General Vicinity Map and Boundaries of the Polk Power Station Site

Sources: FDOT Map, 2000. ECT, 2011.

Figure 2-3 provides a recent aerial photograph of the eastern portion of the Polk Power Station site. Prior to Tampa Electric's construction of the Polk Power Station, which began in November 1994, much of the site was previously impacted by phosphate mining activities and consisted of water-filled mine cuts between spoil piles. The specific portion of the site containing the existing power plant facilities, as well as the area for RTI's proposed project facilities, was not mined but was disturbed by equipment and material storage activities associated with mining. In general, the majority of lands surrounding the site and in the region have also been impacted by phosphate mining operations and currently consist of undeveloped, reclaimed, and unreclaimed lands. Properties to the south and east of the eastern portion of the site contain retired clay settling areas, which contain clay materials produced during phosphate ore processing. Several areas with low-density, scattered residential uses are located more than 1.7 miles west of the project site. These areas are located north of the western portion of the site along Bethlehem and Albritton Roads and west of the site along SR 674 in Hillsborough County. The only other areas of residential development in the site vicinity are located in the unincorporated community of Bradley Junction, approximately 4 miles north of the site.

The Polk Unit 1 IGCC facility represents a technology to cleanly and efficiently generate electricity using coal and other solid fuels. The technology integrates environmental control systems to achieve lower air emissions compared to many other coal-fired generating units. Polk Unit 1 was developed by Tampa Electric with funding support from DOE under its Clean Coal Technology Demonstration Program to demonstrate the commercialization of the IGCC technology. Tampa Electric has successfully operated Polk Unit 1 for more than 15 years.

Key major, existing facilities at the Polk Power Station site include:

- 755-acre cooling reservoir.
- Oxygen-blown gasifier.
- Air separation unit.
- Sulfuric acid plant.
- Slag byproduct storage area.

As shown in Figure 2-3, the existing approximately 755-acre (i.e., water surface) cooling reservoir was constructed by modifying previously mined-out areas. The cooling reservoir is currently primarily used for condenser and other cooling purposes for Polk Unit 1; however, the reservoir was designed during initial development to be capable of providing additional cooling capacity to support the ultimate buildout of the Polk Power Station.

The existing oxygen-blown gasifier facility is used to produce syngas for firing in Polk Unit 1. The existing air separation unit is used to separate air into its primary components: nitrogen and oxygen. The

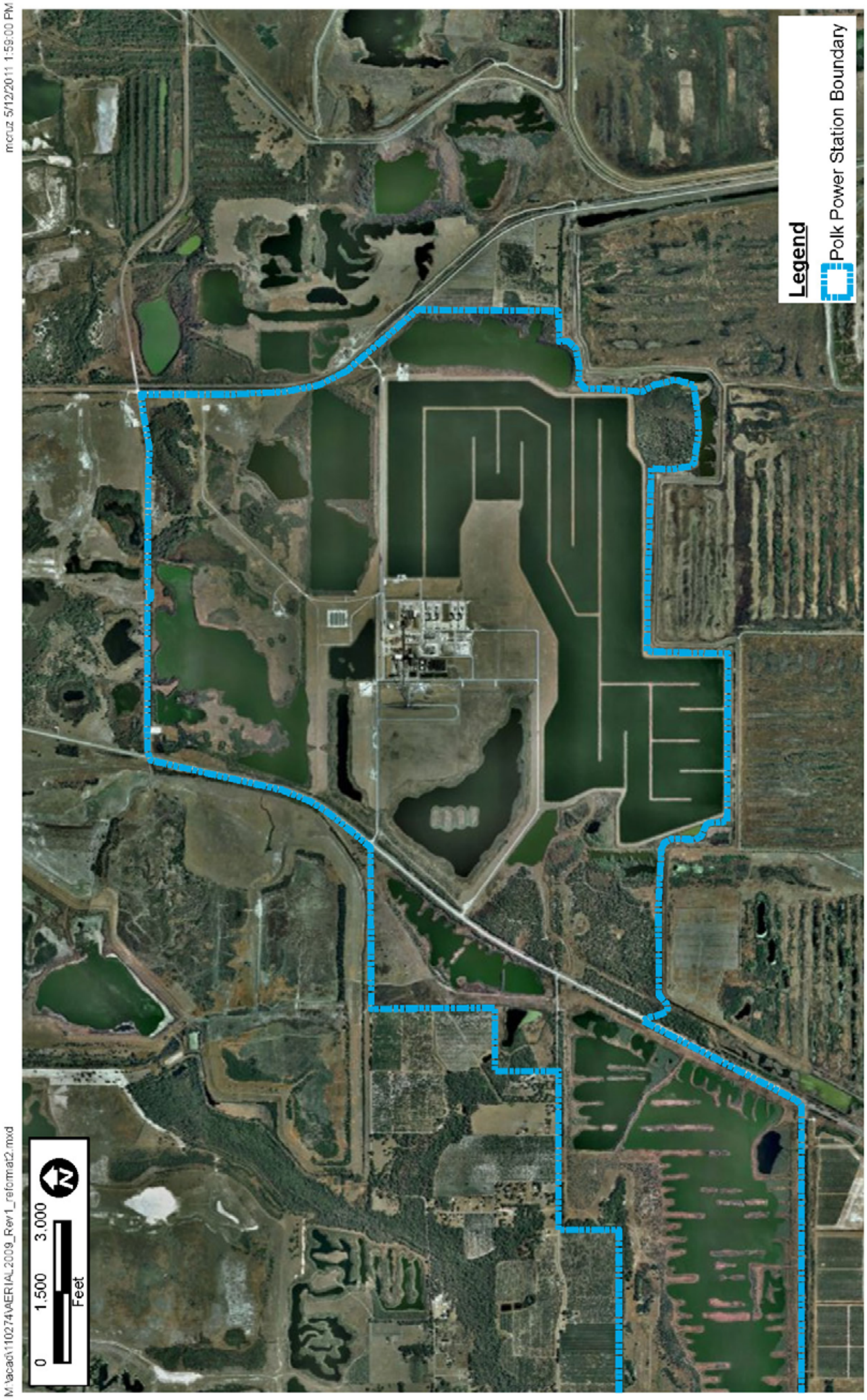

Figure 2-3. Aerial Photograph of Polk Power Station Site
Sources: Aerials Express, 2009. ECT, 2011.

oxygen is used in the fuel gasification process as an oxidant, while the nitrogen is injected into the combustion turbine to control nitrogen oxides (NO_x) emissions, as well as provide power augmentation for Polk Unit 1.

Prior to firing in the Polk Unit 1 combustion turbine, the syngas is treated to remove sulfur compounds. The resultant sulfur-laden gas (i.e., acid gas) removed from the syngas is converted to commercial-grade sulfuric acid in the existing sulfuric acid plant at the Polk Power Station site. This byproduct is sold for offsite commercial uses, and the existing Polk Power Station site includes facilities for the temporary storage and shipment of this byproduct. Slag byproduct from the gasification process for Unit 1 is also currently sold for offsite commercial uses. For the existing Polk Unit 1 operations, noncommercial-grade slag is separated and temporarily stored in the existing lined slag storage area for reuse in the gasification process.

The existing Polk Power Station site is served by four 230-kilovolt (kV) transmission circuits and an onsite substation, a spur from a CSX railroad line, and a Florida Gas Transmission (FGT) natural gas pipeline. Plant process and cooling reservoir makeup water is currently supplied from four onsite ground water wells, and process wastewater is treated and reused within the processes. Potable water is provided from the onsite wells and treatment facility. Sanitary wastewater is disposed through an existing septic system. Other existing onsite facilities include an administration building, control room, warehouse, and construction management building. The main entrance road to the site is from SR 37 on the west side and Fort Green Road on the east side of the site.

As shown in Figure 2-4, RTIs proposed project facilities would be located within an approximately 2.4-acre area adjacent to the existing Polk Unit 1 IGCC facilities to facilitate integration of the proposed project with the IGCC systems. In addition, as shown in Figure 2-4, the proposed project would temporarily utilize two areas totaling approximately 20 acres for construction laydown and parking during the construction period. The project facility area and construction laydown/parking areas currently contain no power plant-related facilities and are primarily covered by mowed native grass.

2.2.2 CONSTRUCTION ACTIVITIES

According to RTI's proposed schedule, construction activities for the project syngas cleanup facilities would start in April 2012, after receipt of applicable environmental permits and approvals, and construction would be completed in March 2013. For the proposed project, Tampa Electric would be responsible for permitting and construction of the deep injection well IW-2 and the required monitoring wells to support the carbon sequestration aspects of the project. Tampa Electric plans to mobilize the drill

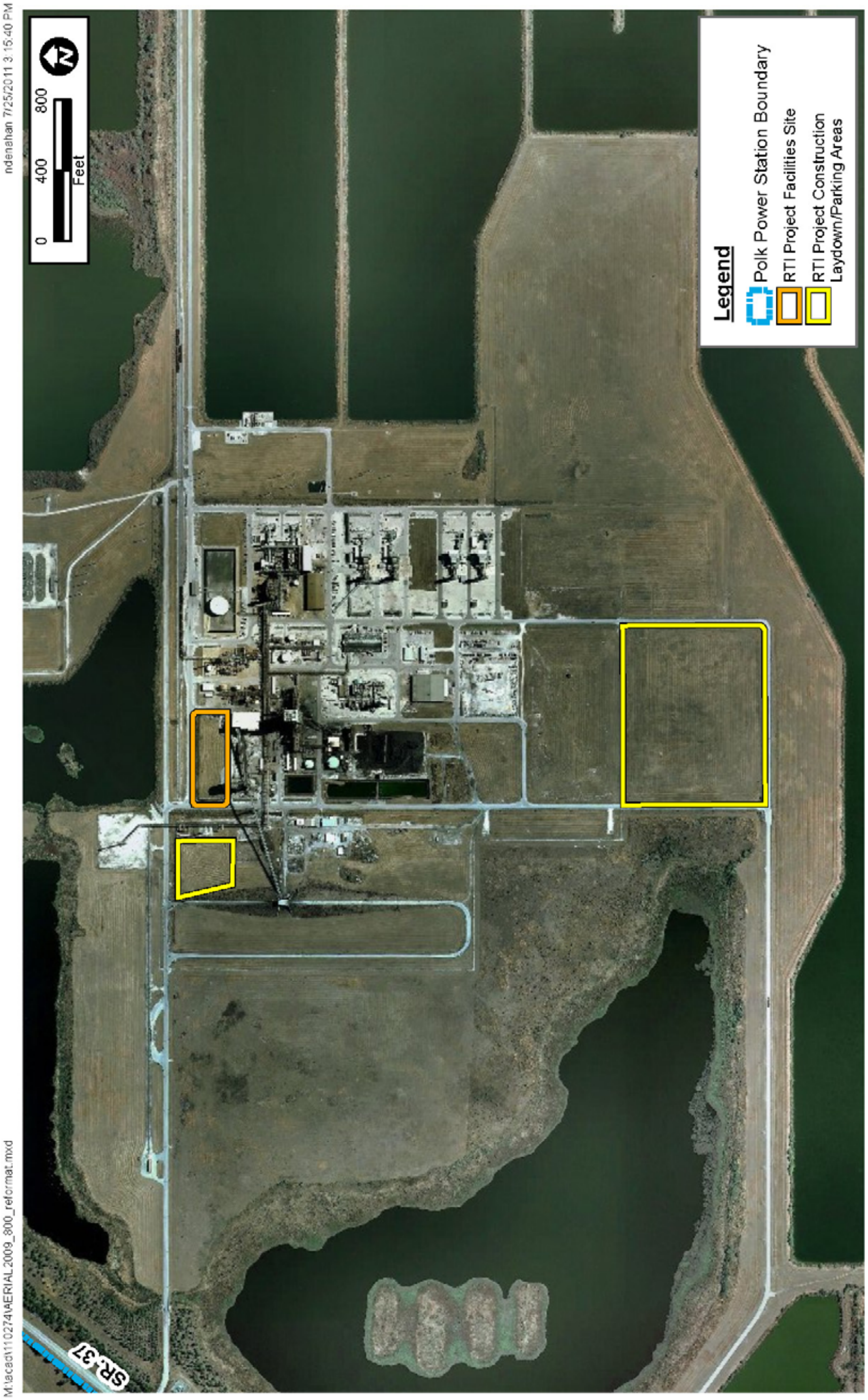

Figure 2-4. Location of RTI Proposed Project Site within the Polk Power Station Site

Sources: Aerials Express, 2009. ECT, 2011.

rig and begin drilling of the injection and monitoring wells in August 2011, with completion of the wells anticipated in June 2013. DOE approved RTI's request for an interim action to proceed with the drilling of the IW-2 injection well prior to completion of the EA and issuance of a FONSI. This decision was based on the onsite location of the well and the anticipation of minimal impacts associated with its development. After a period of system testing and checkout, RTI anticipates that operation of the overall demonstration facilities would begin in the third quarter of 2013 and be completed by the third quarter of 2015. The targeted goal for the project would be to achieve at least 8,000 hours of precommercial scale operations.

Construction of the project facilities would involve the following general activities and phases:

- Construction Mobilization—Construction equipment would be mobilized, and temporary facilities, construction trailers, and prefabrication areas would be established.
- Site Grading—Plot area would be graded to minimize soil erosion and sedimentation. Erosion control measures would be established, and the plot area would be graveled suitable to start work.
- Above/Underground Tie-Ins—Construction would install fire loop and tie into Tampa Electric's existing fire loop system. Storm and oily water drains would be connected to the existing site drain systems. Finally, construction would tie into aboveground tie-in points for utilities as necessary.
- Civil Foundations—Plot would be prepared for foundations. This includes excavation, forming, rebar installation, and concrete pouring.
- Equipment Setting—Equipment would be set on the foundations.
- Structural Steel—Structural steel and pipe-racks would be installed.
- Piping Installation—Piping would be installed followed by hydro-testing.
- Electrical Installation—Appropriate electrical switchgear, cable trays, wiring, and landing would be accomplished.
- Instrument and Controls Installation—Instruments and controls would be installed. Additionally, communications between the field and the distributed control system would be established.

During construction of the proposed project, the majority of the equipment and materials would be delivered to the Polk Power Station site by trucks using the existing roadway system, similar to the construction deliveries for the existing power plant units. The existing main plant access roads from

SR 37 on the west side of the site and the access road from Fort Green Road on the east side would be used to accommodate deliveries, as well as the construction workforce. These access roads and intersections were constructed and used for delivery of equipment and materials for Polk Unit 1 and are anticipated to be adequate to support the proposed project construction activities. Additionally, the CSX railroad network and existing onsite rail spur would be used for oversized equipment.

Once on the site, the equipment and construction materials would be unloaded for immediate erection or placed in designated construction laydown areas using cranes and trucks. The construction laydown and parking areas would be graded, and appropriate drainage provisions would be provided. These areas would include access roads that would typically consist of gravel. A portion of the laydown area would be used for equipment storage and equipment assembly along with space for prefabrication, preassembly, welding, painting, and other activities necessary for the preparation of the equipment. Temporary fencing would be installed around the construction laydown and parking areas. The construction laydown and parking areas would be compacted, and water wagons would be used, as necessary, during the construction activities to control fugitive dust emissions. Also, appropriate stormwater runoff management systems would be provided to control sediment erosion impacts.

2.2.3 SYNGAS CLEANUP SYSTEMS

The proposed project would include scale-up of syngas cleanup technologies developed by RTI and CO_2 capture and sequestration systems. Figure 2-5 provides a simplified block flow diagram of these proposed syngas cleanup and CO_2 capture systems and key tie-ins with existing IGCC facilities.

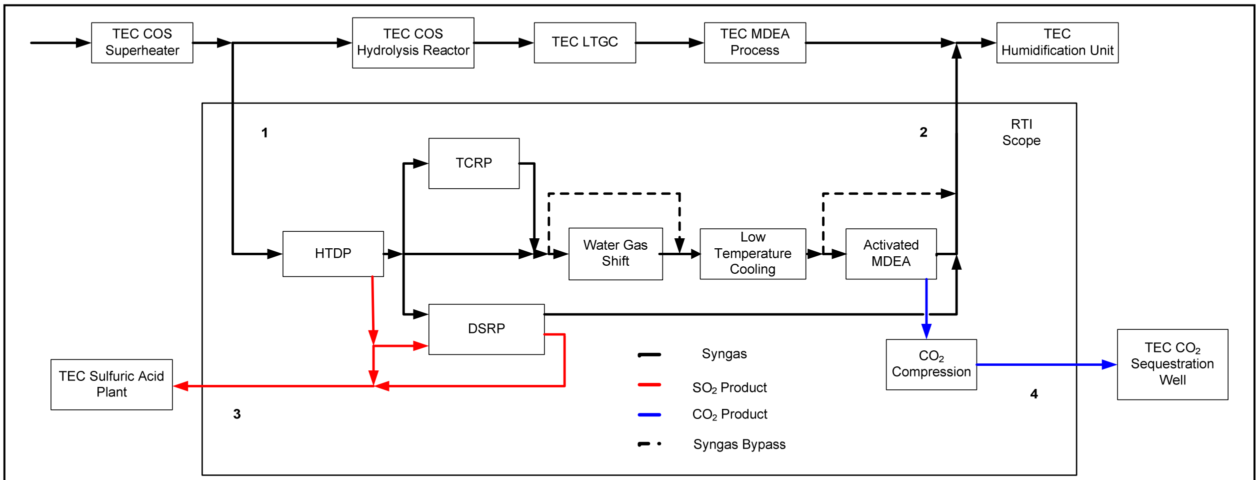

Figure 2-5. Simplified Block Flow Diagram of Syngas Cleanup Systems and Integration with Tampa Electric's IGCC Unit

Source: RTI, 2011.

For the proposed project, an up to 66-MW equivalent slipstream of syngas from the existing IGCC plant would be treated in the cleanup systems to mimic commercial operations. The cleanup systems would remove more than 99.9 percent of the sulfur in the syngas; reduce arsenic, selenium, and mercury concentrations in the syngas; and convert sulfur dioxide (SO_2) to commercial-grade elemental sulfur. The high level of sulfur removal would provide a syngas product from which activated methyldiethanolamine (aMDEA) can be used to capture up to 90 percent of the CO_2 in the cleaned syngas, which would be suitable for geologic sequestration. The CO_2 product generated from the aMDEA system would have a sulfur concentration of less than 100 parts per million by volume (ppmv).

The following descriptions of the proposed project syngas cleanup and CO_2 capture and sequestration technologies are primarily based on information provided by RTI (Gardner, 2011).

The proposed scale-up project would include the demonstration at a precommercial scale of the following syngas cleanup technologies:

- High-temperature desulfurization process (HTDP).
- Trace contaminant removal process (TCRP).
- Direct sulfur recovery process (DSRP).

These cleanup systems would be integrated with Tampa Electric's Polk Unit 1 IGCC facilities.

Figure 2-6 shows the general arrangement of the proposed syngas cleanup systems on the approximately 2.4-acre area within the existing Polk Power Station site layout.

The following subsections provide descriptions of the proposed syngas cleanup processes.

2.2.3.1 High-Temperature Desulfurization Process

A slipstream of syngas from the IGCC plant with a flow rate of up to 2 million standard cubic feet per hour (MMSCFH), which would be equivalent to up to 66 MW of electric power, would be treated in the HTDP system. The untreated syngas would contain a hydrogen sulfide (H_2S) concentration of approximately 7,200 ppmv. The HTDP system consists of two coupled transport reactors, the first serving as the sulfur absorber and the second as the sorbent regenerator. The sulfur absorber utilizes chemical reactions with RTI's proprietary sorbent to remove H_2S and carbonyl sulfide (COS) from the syngas to produce a syngas with a total sulfur concentration of less than 10 ppmv.

In the sorbent regenerator reactor, the sorbent is regenerated by oxidizing the sulfur compounds to produce a flue gas stream containing SO_2. Most of this stream would be directed to Tampa Electric's

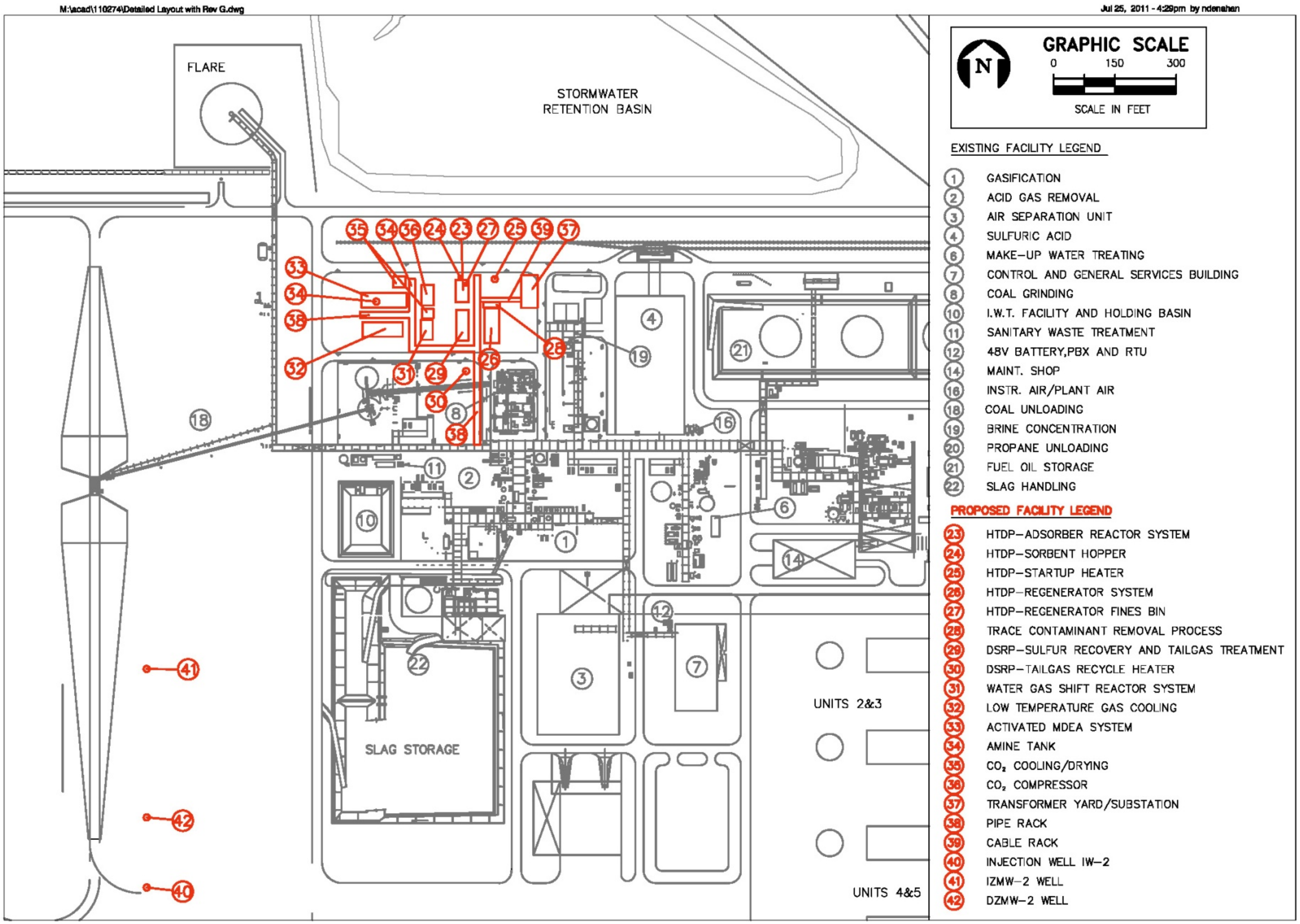

Figure 2-6. General Arrangement of RTI's Proposed Project Facilities within Tampa Electric's Existing Facility Layout

Sources: RTI, 2011. Tampa Electric, 2011. ECT, 2011.

existing sulfuric acid plant, where the SO_2 would be converted to sulfuric acid. As part of the proposed project, a small portion of this SO_2 stream would be routed to the DSRP system.

The HTDP system would involve several intermittent sources of air emissions. During startup of the system, a propane-fired heater, which is vented to the atmosphere, would be used to heat the absorber and regenerator systems. During startups, the regenerator is further preheated using distillate fuel oil. The syngas initially introduced into the absorber and regenerator gases would be sent to Tampa Electric's existing flare to minimize impacts on downstream processes (i.e., combustion turbine and steam turbine), while the gas does not meet specifications during startup. Also, intermittent particulate matter (PM) emissions would occur from the vented sorbent storage hopper and regenerator fines bin.

2.2.3.2 Trace Contaminant Removal Process

A slipstream (equivalent to approximately 5 MW of electric power) of the desulfurized syngas from the HTDP system would be further treated in the TCRP system. The TCRP system would consist of three fixed bed reactors to reduce the concentrations of the arsenic, selenium, and mercury contaminants in the syngas. The mercury reactor would be preceded by a sulfur guard bed to investigate the potential of achieving a higher mercury removal. The treated syngas slipstream would then be recombined with the main desulfurized syngas stream and sent to the water gas shift reactor.

2.2.3.3 Direct Sulfur Recovery Process

In the DSRP system, SO_2 in the small slipstream of SO_2-rich gas from the HTDP regenerator would be converted into approximately 5 tons per day (tpd) of commercial-grade, elemental sulfur. The SO_2 in the slipstream is converted by reducing it with hydrogen and carbon monoxide (CO), and the sulfur product is condensed out of the stream. After analyzing the quality of the elemental sulfur, it would be burned using air to create an SO_2 stream, which is sent to Tampa Electric's sulfuric acid plant.

The DSRP system facilities would include a propane-fired heater, which would be vented to the atmosphere and operated continuously to provide required heat for the DSRP system.

2.2.4 CARBON CAPTURE SYSTEM

For the proposed project, the carbon capture system would produce up to 300,000 tons per year (tpy) of high-quality CO_2, which is suitable for geologic sequestration at the Polk Power Station site. The carbon capture system would be comprised of the following components:

- Water gas shift reactor unit.
- Low-temperature gas cooling unit.

- Activated amine CO_2 capture unit.
- CO_2 compression and drying unit.

The following subsections provide descriptions of these facilities.

2.2.4.1 Water Gas Shift Reactor Unit

In the water gas shift reactor unit, CO in the desulfurized syngas from the HTDP would be converted to CO_2. The system would consist of three fixed-bed reactors operating in parallel and use conventional commercial catalyst technologies. Similar catalysts are used in the processes for producing methanol and ammonia. In the unit, the syngas would be mixed and preheated with steam provided from the IGCC facilities to the reactor inlet temperature of 650 degrees Fahrenheit (°F), with water injected to control the temperature. In the reactions, CO and water would be converted to CO_2 and hydrogen.

2.2.4.2 Low-Temperature Gas Cooling Unit

In the low-temperature gas cooling unit, the product stream from the shift reactor system would be cooled from approximately 650 to 100°F in boiler steam drums using feedwater provided from the Tampa Electric IGCC cooling system and a heat exchanger. The cooling process would generate steam, which would be provided back to the Tampa Electric steam system. Process condensate would also be separated from the gas stream and returned to Tampa Electric's wastewater treatment system.

2.2.4.3 Activated Amine CO_2 Capture Unit

In this unit, the cooled CO_2 in the shifted syngas would be separated from the hydrogen by absorption in the aMDEA absorption column. The proposed aMDEA process technology is commercially available only from BASF. The absorbed CO_2 would be separated from the amine in a regenerator/separation drum and the high-quality CO_2 steam would be piped to the CO_2 compression station. The separated hydrogen-rich stream would be sent back to Tampa Electric's syngas stream to the IGCC plant for firing in the combustion turbine.

2.2.4.4 CO_2 Compression and Drying

The captured CO_2 stream from the aMDEA unit would be compressed in a five-stage compression station from approximately 7 to 1,500 pounds-force per square inch gauge (psig). During the compression process, the water in the CO_2 stream would be removed in a series of interstage knockout drums. The CO_2 would exit the compression station as a supercritical fluid and would be cooled to approximately 120°F in coolers. Condensate collected in the drying process would be treated and sent to Tampa Electric's existing wastewater treatment facilities and/or cooling water system.

2.2.5 CARBON SEQUESTRATION

The compressed CO_2 would be transferred through an approximately 2,100-ft, 6-inch stainless steel, pressurized pipeline to the injection well for injection and sequestration in a deep saline aquifer geologic formation under the Polk Power Station site. As shown in Figure 2-6, the injection well (IW-2) would be located in an open, grassy area adjacent to the southwest corner of the proposed syngas cleanup facilities. Up to 300,000 tpy of CO_2 would be sequestered during the demonstration period for the proposed project. Table 2-1 provides the estimated composition of the high-quality CO_2 stream to be sequestered.

Prior to agreeing to provide the host site for RTI's proposed project, Tampa Electric initiated efforts to permit, drill, and construct two deep injection wells (i.e., IW-1 and IW-2) at the Polk Power Station site to be used for disposal of wastewater from its existing power plant operations. Therefore, as part of the agreement with RTI, Tampa Electric would be responsible for the permitting, drilling, and construction of the injection well (IW-2) that would be used to inject CO_2 for the proposed project. After the CO_2 sequestration aspects of the proposed project have been completed, Tampa Electric would use IW-2 for injection of wastewater. This dual use of IW-2 has been considered in the well design and drilling schedule. This dual-use approach has been discussed with and agreed to by FDEP and EPA Region 4 UIC program staff.

Table 2-1. Estimated Composition of the CO_2 Stream to be Sequestered

Parameter	CO_2 Stream
Temperature (°F)	120
Pressure (psig)	1,500
Composition (molar %)	
Hydrogen gas	0.50
CO	0.05
CO_2	99.44
Nitrogen	0.01
Argon	0.00
Methane	0.00
H_2S	<100 ppmv
COS	<10 ppmv
Water	<15 ppmv
Ammonia	0.00
SO_2	
Oxygen	
Total	100.00

Source: RTI, 2011.

The following subsections describe the proposed injection zone at the site; injection and monitoring permitting efforts; well design and drilling/construction activities; operations and maintenance plans; and proposed monitoring, verification, and accounting program.

2.2.5.1 Target Injection Zone

The targeted CO_2 injection zone for the proposed project would be a deep saline carbonate (dolomite/ limestone) reservoir system extending between 4,200 and 8,000 feet below land surface (ft bls). This zone includes the lower Cedar Keys Formation of Paleocene Age, the Lawson limestone (which may correlate to the upper Pine Key Formation), and the Pine Key Formation of the Upper Cretaceous Age. Much of the data and information initially used to characterize the upper portion of this injection zone were obtained from the KCI Mulberry UIC injection well that began operations in the mid 1970s and is located approximately 10 miles north of the Polk Power Station site. Tampa Electric recently completed the drilling of IW-1 through this depth interval and performed various sampling, logging, and testing activities to improve the site-specific characterization of the injection zone.

Based on review of the site-specific testing completed to date, plus the available regional deep geologic information (Amato *et al.*, 1986; Chen, 1965; FDEP, 2010; USF, 2011; USGS, 2010; and Winston, 1994), several relevant observations can be made regarding the injection zone:

- A laterally continuous, thick (more than 1,000 foot [ft]) low permeability confining unit (cap rock) is present.
- Fractures, faults, or folds potentially serving as traps or migration pathways are not present.
- Major horizontal variation in depositional environment (and hence the carbonate strata) are not expected.
- The nearest penetration of the confining unit is located approximately 10 miles away.
- Suitable zones for CO_2 storage with horizontal porosity and permeability are present.
- Vertical variations of porosity and permeability are expected to enhance CO_2 storage capacity.
- West-central Florida is seismically stable and experiences little seismic activity.
- The hydrodynamic (physical) and geochemical properties are favorable for long-term CO_2 storage.

Therefore, the proposed subsurface injection zone is expected to be both viable and well suited for the purpose of the proposed CO_2 sequestration demonstration project.

2.2.5.2 Injection and Monitoring Well Permitting

Tampa Electric recently completed the drilling of IW-1 and its associated dual zone monitoring well, DZMW-1. This well and its associated monitoring well were permitted individually as UIC Class V, Group 9 exploratory borings. Upon the completion of its installation, Tampa Electric will submit a Class I construction/testing well permit application for IW-1 for industrial wastewater injection (late summer/early fall 2011). Following between 18 to 24 months of preliminary testing, a subsequent Class I operational UIC well permit will be obtained (early to mid-2013). Information gained from the drilling and testing program for IW-1 would be incorporated into the permit application for IW-2.

In April 2010 and prior to agreeing to host the proposed project, Tampa Electric submitted a UIC Class V, Group 9 exploratory boring permit application for IW-2 and DZMW-2, which would be used for wastewater injection and monitoring. FDEP issued this UIC permit in June 2011. Approval of this permit allows Tampa Electric to avoid unnecessary drilling schedule delays or additional costs resulting from mobilizing a new contractor or remobilizing the same drilling contractor, or alternatively resulting from undesirable idle rig time waiting for permit approval to start drilling the IW-2 wells. For the proposed project, DOE also considered the cost and schedule effectiveness of proceeding with the drilling of IW-2, as well as any environmental impacts, and approved RTI's request for an interim action to proceed with the drilling prior to completion of the EA and issuance of a FONSI. This decision was based on the onsite location of the well and the anticipation of no significant environmental impacts associated with its development.

An injection zone monitoring well (IZMW-2) would also be added to this Class V, Group 9 permit through a UIC permit modification (submitted in August 2011). However, unlike the Class I construction/testing permit anticipated for IW-1, for the purpose and duration of the proposed demonstration project, the IW-2 wells would be covered by a UIC Class V experimental technology well permit. This Class V experimental technology well permit application was submitted in August 2011. The permitting of the carbon sequestration demonstration project using the UIC Class V experimental technology well approach is consistent with that taken at numerous other proposed carbon sequestration pilot projects (e.g., Frio, Texas [Kopema, 2007], and Plant Daniel, Mississippi [Papadeas *et al*., 2005]). Additionally, the proposed permitting approach is consistent with UIC Program Guidance No. 83, issued by EPA on March 1, 2007. Upon the completion of the demonstration project, Tampa Electric plans to operate IW-2 and DZMW-2 under a subsequent Class I industrial UIC well permit for wastewater injection. This permitting approach has been discussed with and agreed to by FDEP and EPA Region 4 UIC program staff.

2.2.5.3 Well Design and Drilling/Construction

Figure 2-7 provides an illustration of the proposed UIC well design for IW-2. The basic design for IW-2 would be similar to that approved and implemented for IW-1. A series of telescoping steel casings would be designed to isolate the overlying underground source of drinking water (USDW) from the proposed injection zone located beneath the confining unit. These casings would include:

- 52-inch diameter steel casing in an approximately 60-inch diameter borehole to approximately 300 ft bls.
- 42-inch diameter steel casing in an approximately 50-inch diameter borehole to approximately 1,200 ft bls.
- 28-inch diameter steel casing in an approximately 40-inch diameter borehole to approximately 3,300 ft bls (based on the lowermost USDW at approximately 3,000 ft).

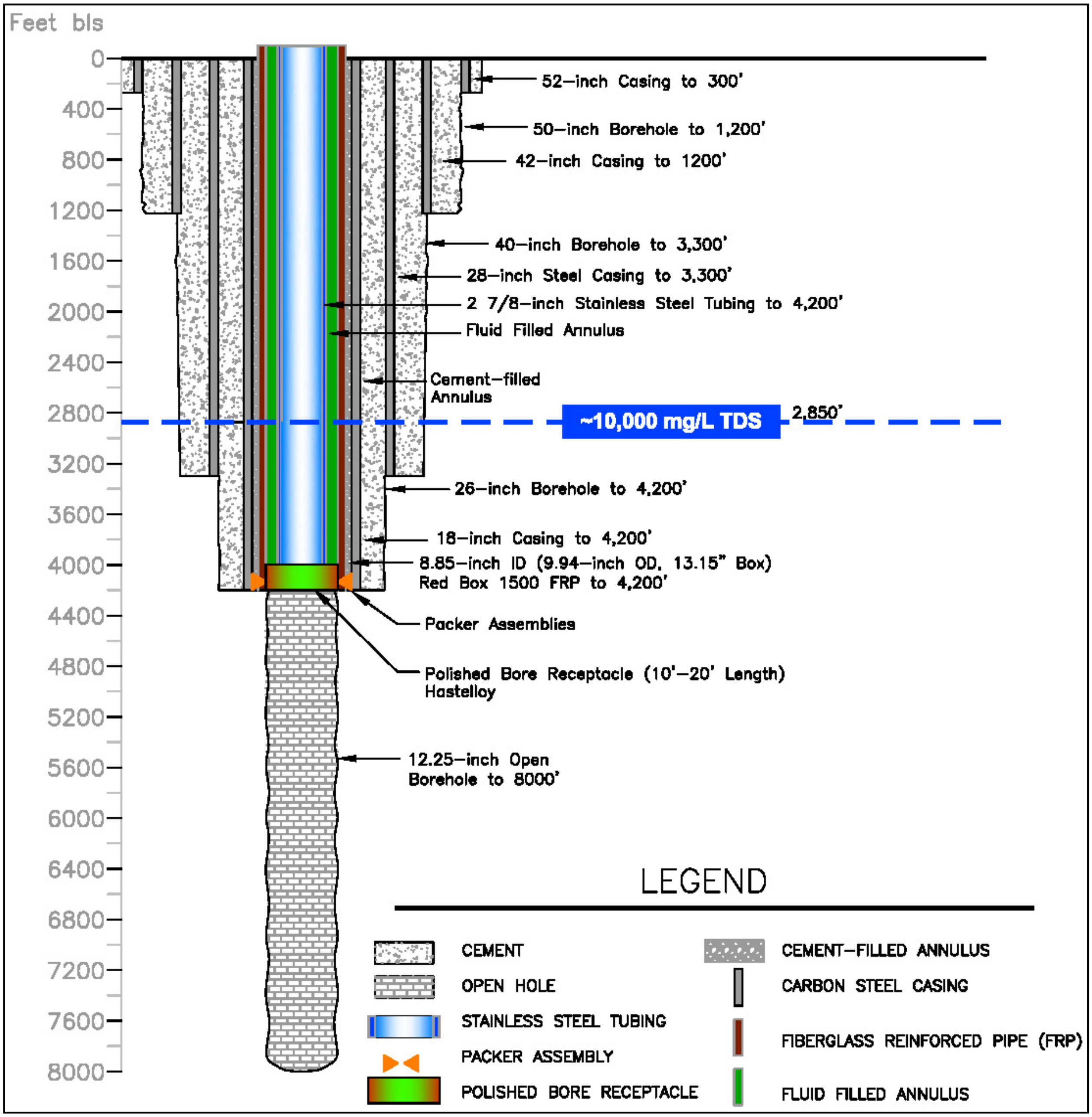

Figure 2-7. Injection Well IW-2 Design, Tubing, and Fluid-Filled Annulus Details for Carbon Sequestration

Source: ECT, 2011.

- 18-inch diameter steel casing in an approximately 26-inch diameter borehole to approximately 4,200 ft bls.
- 12.25-inch open borehole to approximately 8,000 ft bls.

Inside the 18-inch diameter steel casing, 8.85-inch inner diameter fiberglass reinforced piping (FRP) would be grouted in place using a cement-filled annulus. The lower 500 ft of the outer borehole and the cement-filled annulus would be grouted with CO_2-resistant cement.

In order for the well to be used for CO_2 injection for the proposed project, there would be two main differences in the design of IW-1 and IW-2. These differences would include the use of a polished borehole receptacle (PBR) and a stainless steel tubing and packer system. The PBR would consist of a short 10- to 20-ft segment of corrosion-resistant, high-performance alloy pipe placed at the bottom (lowest/last casing portion) of the FRP (Figure 2-7). The PBR would provide a smooth metal surface wherein the bottom packer system would be seated for the smaller diameter stainless steel tubing through which the CO_2 would be injected. Details of the final design of IW-2 would be determined in the approved UIC Class V experimental technology well construction permit.

The proposed well design of IW-2 would allow for the CO_2 injection zone to be: (1) vertically isolated from the USDW by a laterally continuous stratigraphic unit that is more than 1,000 ft thick and contains numerous layers with vertical permeabilities that are less than 10^{-8} centimeters per second (cm/sec); and (2) horizontally isolated from the USDW by four (one stainless steel, one FRP, two carbon steel) casings, one fluid-filled annulus, and approximately 9 inches of cement. The lower 500 ft of the outer borehole and the cement-filled annulus would be grouted with CO_2-resistant cement.

Figure 2-8 provides an illustration of the proposed well design for DZMW-2. A series of telescoping steel casings would be designed to isolate selected intervals throughout the USDW above a substantial confining unit. These casings would include:

- 24-inch diameter steel casing in an approximately 30-inch diameter borehole to approximately 300 ft bls.
- 16-inch diameter steel casing in an approximately 23-inch diameter borehole to approximately 1,100 ft bls (upper DZMW).
- 6.21-inch diameter FRP casing in an approximately 15-inch diameter borehole to approximately 2,800 ft bls.
- 6-inch open borehole to approximately 2,850 to 2,900 ft bls (lower DZMW).

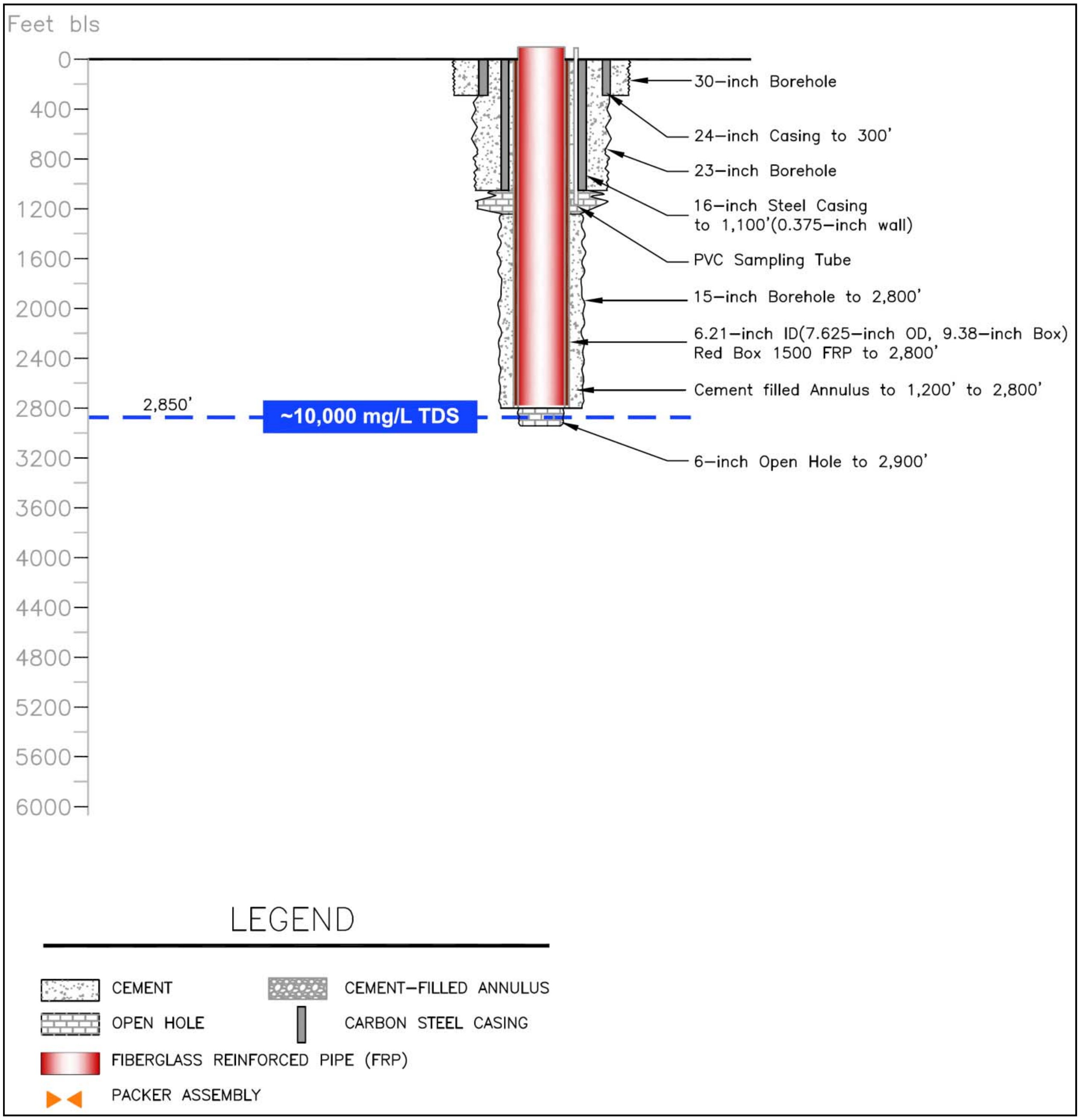

Figure 2-8. Dual Zone Monitoring Well DZMW-2 Design Details
Source: ECT, 2011.

The two zones within the DZMW would be used to measure various parameters including selected water quality constituents, temperature, and pressure to detect for potential leakage of either CO_2 or wastewater through the confining unit and into the USDW.

Figure 2-9 presents an illustration of the proposed well design for the injection zone monitoring well, IZMW-2. The purpose of this well would be to support the evaluation of and accounting for the CO_2 injected into the subsurface as part of the proposed project. For this well, a series of telescoping steel casings would be designed to isolate selected intervals throughout the USDW above a substantial confining unit. These casings include:

- 36-inch diameter steel casing in an approximately 42-inch diameter borehole to approximately 300 ft bls.
- 24-inch diameter steel casing in an approximately 32-inch diameter borehole to approximately 1,200 ft bls.
- 16-inch diameter steel casing in an approximately 23-inch diameter borehole to approximately 3,300 ft bls.
- 6.21-inch diameter FRP casing in an approximately 15-inch diameter borehole to approximately 4,200 ft bls.
- 12.25-inch open borehole to approximately 8,000 ft bls.

The proposed well design of IZMW-2 would allow for the CO_2 injection interval to be: (1) vertically isolated from the USDW by a laterally continuous stratigraphic unit that is more than 1,000 ft thick; and (2) horizontally isolated from the USDW by two (one FRP and one carbon steel) casings and approximately 8.5 inches of cement. The lower 500 ft of the outer borehole would be grouted with CO_2-resistant cement.

Similar to the IW-1 well drilling, the IW-2 well would be drilled using the largest electric drilling rig operational in the southeastern United States. The drill rig would be equipped with fluid containment systems to handle all drilling fluids and muds to minimize potential impacts in the vicinity of the well site. Mud rotary methods would be used to set the casing at the 300-ft depth interval, but the drilling method would be switched to reverse air rotary drilling methods to complete the drilling to the 1,200-ft depth and set the next casing. Using the reverse air drilling method would minimize the amount of water required to support the drilling operations. The drilling fluids and produced waters would be contained in metal drilling pad and mud tanks, and groundwater in proximity to the well site and drilling pad would be monitored weekly using a series of perimeter monitoring wells. This drilling rig has the torque necessary

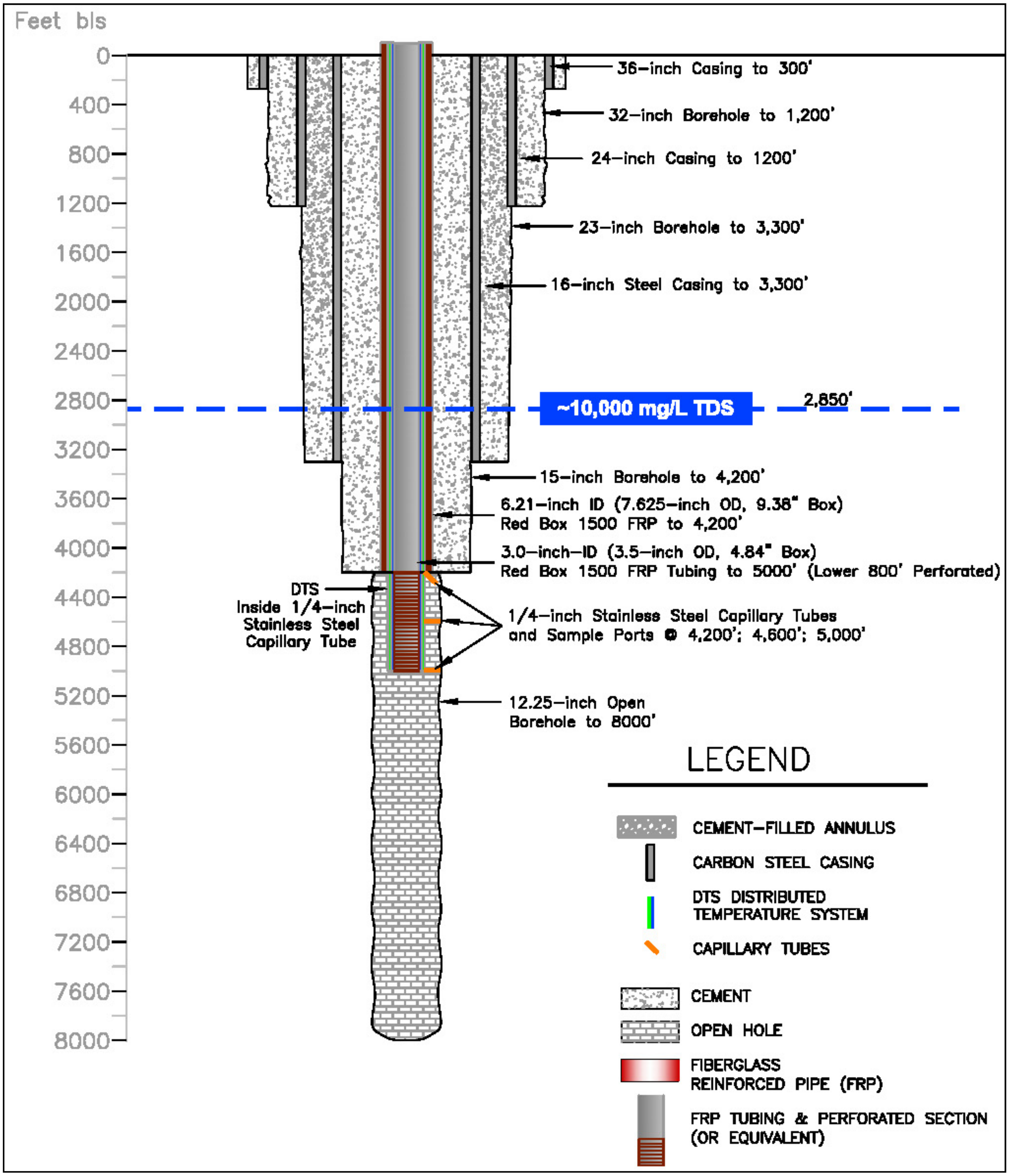

Figure 2-9. Injection Zone Monitoring Well IZMW-2 Design Details

Source: ECT, 2011.

to drill the large diameter boreholes required for the project plus top head capacity to manage 8,000+ ft of drill string.

2.2.5.4 Operations and Maintenance Plans

For the proposed project, CO_2 capture and sequestration activities would take place over approximately an 18-month period targeted to start in the third quarter of calendar year 2013. During this period, the proposed project would be expected to inject and sequester CO_2 at a rate of approximately 300,000 tpy into the more than 4,200-ft-bls deep saline carbonate formation.

Some of the anticipated routine injection well operational monitoring requirements are described in the subsequent section. During the CO injection and UIC Class V experimental technology well operation, the fluid filled annulus between the FRP and stainless steel tubing (described in the preceding section) would also be monitored and its associated equipment maintained. Details of the operating and monitoring requirements would be determined in the final approved UIC permit.

2.2.5.5 Monitoring, Verification, and Accounting Program

The DOE (2009) NETL Best Practices Manual for "Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations" provides a detailed list of different monitoring, verification, and accounting (MVA) techniques either previously tested or proposed to be tested at various carbon capture and sequestration projects. The MVA program developed for this proposed project would use information presented in this document, including the formatting style from some of its tables. A summary of the proposed MVA program is provided in the following discussion, and the detailed program will be included as an appendix to the UIC Class V experimental technology well permit application for IW-2 and the associated monitoring wells.

The overall goals of the MVA program would be to demonstrate: (1) implementation of the proposed carbon capture and sequestration project would be safe; (2) the capture and storage aspects would provide effective CO_2 control and would not create adverse environmental impacts; (3) and the project and MVA program would be compliant with the applicable regulations.

The fundamental goals and objectives of the proposed MVA program would be as follows (DOE, 2009):

- Understand the CO_2 storage processes and demonstrate their effectiveness.
- Evaluate the geochemical interactions of CO_2 with and mobility through the injection zone formation solids and brine fluids.

- Assess the potential for environmental, health, and safety impacts as a result of the CO_2 injection and in case of a leak to the atmosphere.
- Evaluate and monitor required corrective actions in the event a leak should occur.

The intent of the MVA plan would be to present and explain the specific approach, technologies, and methodologies developed for this site (see Table 2-2).

Table 2-2. Summary of Pre-, During, and Post-CO_2 Monitoring Program

Proposed MVA Program
Pre-CO_2 injection period
Geophysical well logs
Wellhead pressure
Formation pressure
Injection rate testing
Seismic survey (VSP walk-out survey)
Atmospheric CO_2 monitoring
Pressure and water quality within and above storage formation
During CO_2 injection period
Geophysical well logs
Wellhead pressure
Formation pressure
Annulus pressure
Injection rate
Seismic survey (VSP walk-out survey)
CO_2 and oxygen flux monitoring
Pressure and water quality within and above storage formation
Active source thermal logging
Post-CO_2 injection (closure) period
Seismic survey (VSP walk-out survey)
Pressure and water quality within and above storage formation
Routine UIC monitoring for wastewater injection

Sources: DOE, 2009.
ECT, 2011.

Table 2-3 summarizes the main environmental monitoring zones and the different proposed MVA techniques for the proposed project. Figure 2-10 illustrates the surface locations for these various monitoring stations. Table 2-3 provides a brief description of the key monitoring objectives for each of the different monitoring zones and provides a distinction as to whether the methods proposed are considered primary, secondary, or potential additional MVA technologies. In short, the primary technologies would be proven methods associated with carbon capture and sequestration projects that typically require the direct placement of monitoring equipment or collection of data through invasive techniques (well drilling, sample coring, etc.) and, as such, would be generally constrained to fixed locations. However, the secondary and potential additional technologies would be less proven methods for carbon capture and sequestration projects but could often be used in less invasive or noninvasive applications. As such, the secondary and potential additional technologies would be used to compliment the information obtained from the primary technologies and help to better assess the CO_2 plume location and areas of potential leakage over larger spatial scales.

Table 2-3. Monitoring Zones and Technology Stages Proposed for RTI's Proposed Project at the Tampa Electric Polk Power Station

Objectives	Primary Technologies	Secondary Technologies	Potential Additional Technologies
Atmospheric monitoring *Objectives*: • Ambient CO_2 concentration • Leak detection	CO_2 Detection CO_2 detectors (Ambient CO_2 *concentration*)		CO_2 Detection Isotopes
Near surface monitoring *Objectives*: • Groundwater monitoring • Fluid chemistry • Soil gas monitoring • Crustal deformation • Leak detection • Vadose zone characterization	Geochemical analysis *(Groundwater monitoring)* *(Fluid chemistry)*	Advanced Water Quality Analysis • Inorganics and organics • Isotopes • Total organic and inorganic carbon Soil-Vadose Zone Gas Monitoring	Tracers (*Leak Detection*) • Noble gases/isotopes/perfluorocarbons Remote sensing (*Crustal Deformation*) • Synthetic aperture radar and InSAR
Subsurface monitoring *Objectives*: • Groundwater monitoring • Soil gas monitoring • Leak detection • Subsurface-reservoir characterization • Plume tracking • Well integrity testing	Water Quality Analysis • Injection fluid monitoring • Formation fluid monitoring • Water level Caprock integrity (Characterization) • Geomechanical analysis • Core collection *Wireline Logging (Well Integrity)* • Temperature • Noise • Cement bond • Density • Gamma ray • Sonic (acoustic) *Physical Testing (Well Integrity)* • Annulus pressure • Injection volume/rate • Wellhead pressure • Downhole pressure • Downhole temperature	Seismic Surveying • VSP Geochemistry • Brine/fluid composition • Tracer injection/monitoring Injection well logging • Temperature logging • Reservoir saturation tool • Optical	Geophysical Techniques • Wireline logging o Resistivity o Specialty logging

Sources: DOE, 2009.
ECT, 2011.

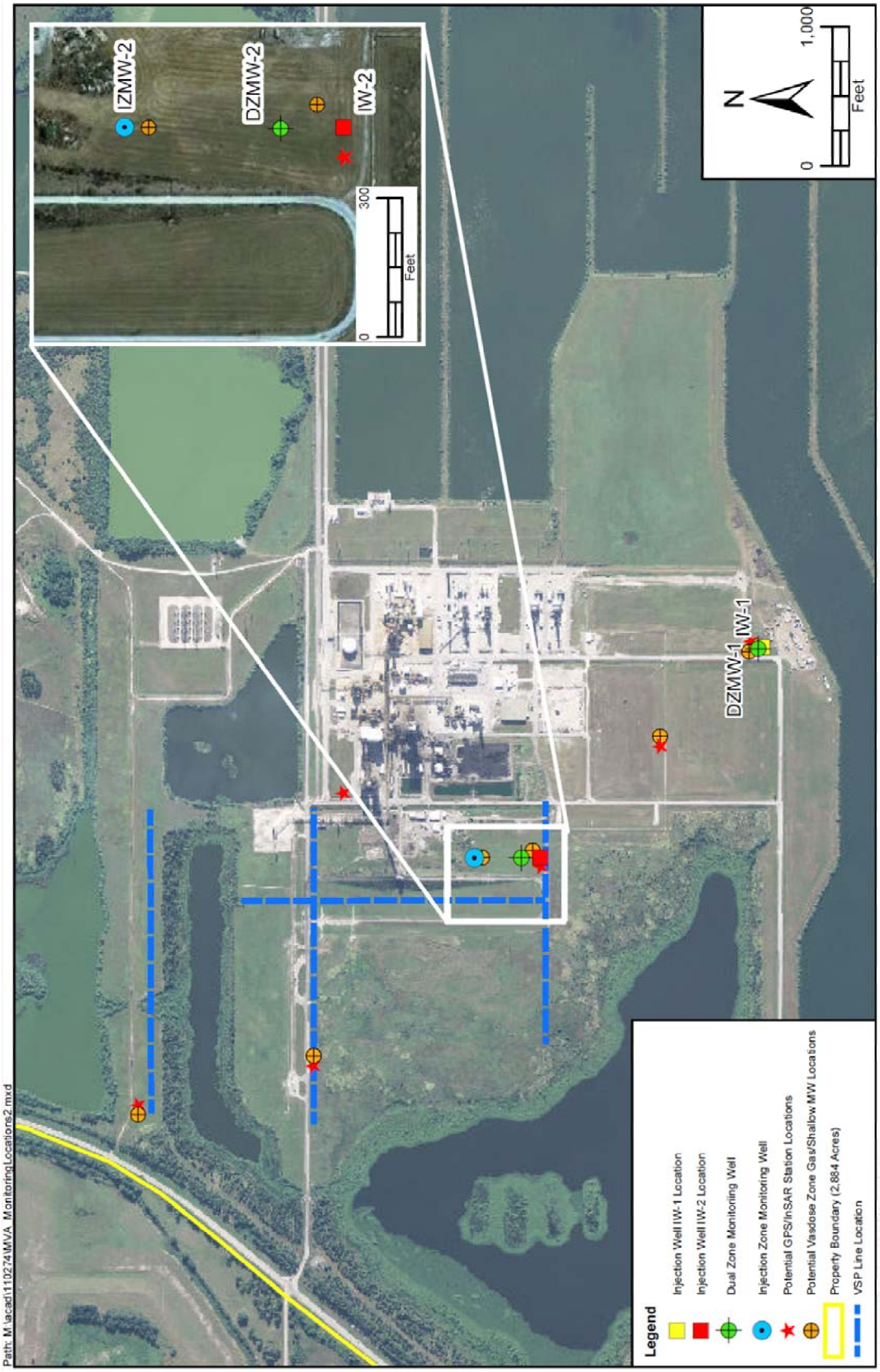

Figure 2-10. MVA Monitoring Locations
Sources: SWFWMD Aerial Photography, 2009.
ECT, 2011.

In summary, the proposed MVA technologies would likely include the following:

- Atmospheric monitoring:
  - CO_2 detectors.
  - Tracers (isotopes/injected compounds such as perfluorocarbon tracers [PFTs]).
- Near-surface monitoring:
  - Geochemical/advanced groundwater monitoring.
  - Soil-vadose zone gas monitoring.
  - Tracers (isotopes/injected compounds such as PFTs).
  - Remote sensing-interferometric synthetic aperture radar (InSAR) monitoring (test for viability prior to sitewide deployment).
- Subsurface monitoring:
  - Physical monitoring of injection pressures, volumes, rates, and temperatures.
  - Caprock integrity (via cores and geomechanical analysis).
  - Wireline geophysical logging (including some specialty logs).
  - Water quality, geochemistry, and fluid level/pressure monitoring.
  - Vertical seismic profiling (walkout surveys).
  - Tracer injection monitoring (within wastewater and possibly CO_2 gas).

Based on site-specific conditions, plus the different types and level of proposed monitoring activities, the proposed MVA program would be expected to satisfy the primary MVA goals and fundamental objectives associated with the proposed demonstration project. Ultimately, details of the MVA requirements would be determined in the final approved UIC permit.

2.3 NO-ACTION ALTERNATIVE

Under the no-action alternative, DOE would not provide cost-shared funding to RTI for the proposed project. In the absence of DOE funding, DOE assumes that RTI would not proceed with the proposed project, and any potential environmental impacts of the project would not occur, except that Tampa Electric would proceed with its plans to construct deep injection well IW-2 for disposal of wastewater from its existing power plant operations. Further, under the no-action alternative, DOE's efforts to advance clean energy technologies, improve energy security using domestic resources, and reduce GHG levels would be delayed.

3.0 AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This chapter provides descriptions of the affected environment and analyses of the environmental consequences of the proposed project and the no-action alternative for the following resource areas:

- Air quality.
- Geology and soils.
- Water resources.
- Socioeconomics.
- Transportation.
- Waste management.
- Human health and safety.

3.1 AIR QUALITY

3.1.1 AFFECTED ENVIRONMENT

3.1.1.1 Climatology and Meteorology

The proposed project site at the Polk Power Station in Polk County, Florida, lies within the Northern Hemisphere's humid subtropical climate zone. This zone is noted for long, hot, and humid summers and mild and wet winters. The central Florida climate is also affected by maritime influences from the Atlantic Ocean and the Gulf of Mexico.

Table 3-1 provides a summary of monthly mean and extreme temperatures based on National Weather Service (NWS) data collected at Wauchula, Florida, for the period of record from 1971 through 2000. The Wauchula weather station is located in Hardee County, approximately 19 miles southeast of the Polk Power Station site, and is the nearest representative NWS surface observation station with available temperature and precipitation data. A slightly closer station is located in Bartow, approximately 15 miles to the northeast. However, the area surrounding the Wauchula station is more rural and, therefore, more similar to the proposed project site. As shown in Table 3-1, monthly mean temperatures vary by only 20°F. Temperatures above 90°F have occurred in every month except January, which had a highest recorded temperature of 88°F. From 1971 through 2000, there were only 5 days with below-freezing temperatures.

Based on historical records, rainfall in the vicinity of the site varies widely from month to month. Table 3-2 presents 30-year rainfall records from the Wauchula weather station. Average rainfall is greatest during the summer months, when convective thunderstorms are likely, and lower for the remainder of the year, especially in the winter months. Table 3-2 also shows daily and monthly extremes.

The maximum daily rainfall has ranged from 2.74 to 7.6 inches. Monthly precipitation has varied from 0 to more than 15 inches.

Table 3-1. Ambient Temperatures Measured at Wauchula, Florida

	Daily				Monthly		
Month	Mean Maximum	Mean Minimum	Highest	Lowest	Lowest Mean	Mean	Highest Mean
January	72.8	48.5	88	20	51.0	60.7	69.5
February	74.3	49.2	93	25	54.6	61.8	68.2
March	78.7	53.2	94+	23	61.9	66.0	71.0
April	83.1	57.4	97	34	65.7	70.3	73.5
May	88.3	63.7	101+	44	72.3	76.0	79.6
June	90.7	69.6	102	51	77.5	80.2	83.4
July	91.6	71.2	100+	57	79.3	81.4	83.5
August	91.7	71.7	98+	58	80.4	81.7	83.3
September	89.9	70.7	99	55	78.7+	80.3	82.1
October	85.1	64.2	95+	39	71.4	74.7	79.0
November	79.3	56.8	90+	24	63.6	68.1	74.7
December	74.2	50.7	92	21	57.5	62.5	68.4
Annual	83.3	60.6	102	20	51.0	72.0	83.5

Note: Highest and lowest daily temperatures based on complete station record (i.e., 1948 to 2001).
Mean temperatures based on years 1971 through 2000.
Temperatures are degrees Fahrenheit.

Sources: National Climatic Data Center (NCDC), Climatography of the United States: No. 20, 1971-2000.
ECT, 2011.

Table 3-2. Normal and Extreme Precipitation Measured at Wauchula, Florida

	Monthly Normals		Extremes		
Month	Mean	Median	Highest Daily	Highest Monthly	Lowest Monthly
January	2.30	1.85	2.74	7.84	0.00
February	2.63	2.07	4.40	8.82	0.00
March	3.27	2.47	5.75	12.14	0.30
April	2.37	1.92	5.55	6.60	0.00
May	3.83	3.13	5.72	8.39	0.00
June	7.92	7.52	6.05	15.96	1.69
July	7.85	8.35	4.73	12.46	2.21
August	7.37	7.32	6.94	12.76	2.66
September	6.17	5.62	5.33	11.56	1.44
October	2.68	1.75	6.32	10.36	0.00
November	2.05	1.24	7.60	11.18	0.12
December	2.00	1.51	3.96	6.29	0.28
Annual	50.44	51.47	7.60	15.96	0.00

Note: Precipitation is in inches.

Sources: NCDC, Climatography of the United States: No. 20, 1971-2000.
ECT, 2011.

The nearest representative station with detailed wind data is located at the Orlando International Airport, approximately 63 miles northeast of the Polk Power Station. There are a number of other weather stations closer to the site, but they were not considered to be as representative because of their coastal locations. The observations at these other stations could be expected to be affected more by the Gulf of Mexico, and thus experience routine on- and off-shore breezes. Therefore, the Orlando International Airport is expected to have wind patterns more representative of the proposed project site's inland location. Figure 3-1 provides a 5-year annual wind rose based on wind speed and direction observed for the years 1996 through 2000. Figure 3-2 depicts 5-year seasonal wind roses for the same station. The information presented in these figures represents the percentage of time the wind blows from a particular direction at a given speed. Although there is no single prevailing wind direction throughout the year, the winds are slightly more predominant from the easterly direction (56 through 101 degrees), which occurs approximately 15 percent of the time, with another 7+ percent from the north and 6+ percent from the south. Winds in the spring predominate from the southern sector, and southwesterly winds are common during summer months. In the fall, winds mostly occur from the northeast quadrant, and there is a strong northerly wind component in the winter. The average wind speed over the 5-year period was 7.5 miles per hour (mph). Spring has the highest winds at 8.4 mph. The lowest average winds are in the summer at 6.3 mph.

3.1.1.2 Ambient Air Quality Conditions

Ambient air quality in an area can be characterized in relation to the National Ambient Air Quality Standards (NAAQS). NAAQS have been established for six common air pollutants selected because of their prevalence and importance to human health and welfare: CO, nitrogen dioxide (NO_2), SO_2, ozone, particulate matter less than 10 and 2.5 microns in aerodynamic diameter (PM_{10} and $PM_{2.5}$, respectively), and lead. These are also commonly referred to as criteria pollutants, because the limits are largely based on health criteria. Primary NAAQS were established to protect human health, and secondary NAAQS were designed to protect the environment and physical property.

Table 3-3 shows the primary NAAQS. The secondary standards are the same as the primary NAAQS for most pollutants. However, there are no secondary standards for CO or for the NO_2 and SO_2 1-hour averaging times. Also, there is a 3-hour secondary standard for SO_2, but no primary standard associated with that averaging time. Except for establishing slightly lower SO_2 standards for the annual and 24-hour averaging periods, Florida has adopted the NAAQS.

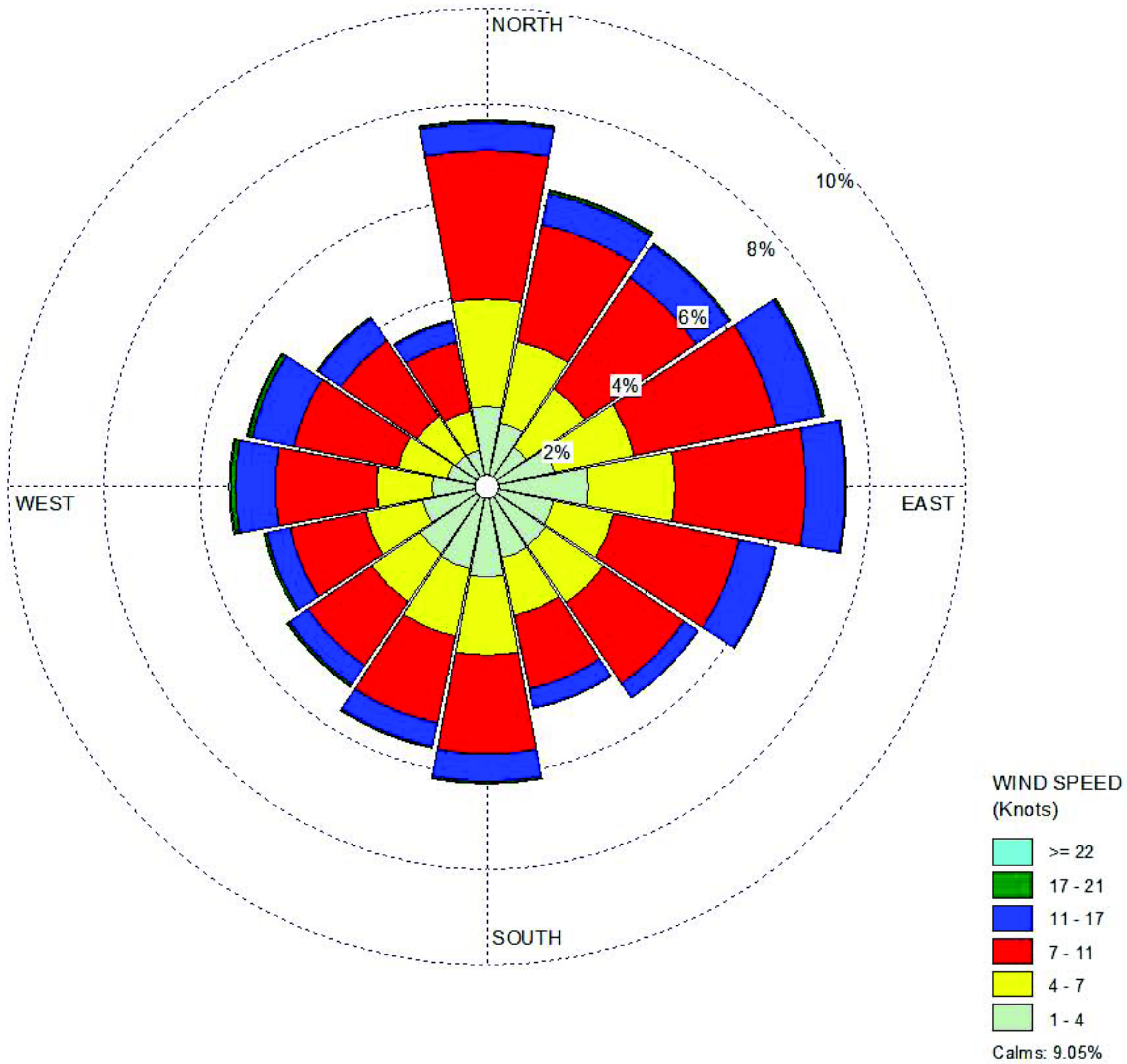

Figure 3-1. 5-Year Annual Wind Rose, Orlando International Airport, 1996 through 2000

Source: NCDC, 2002.

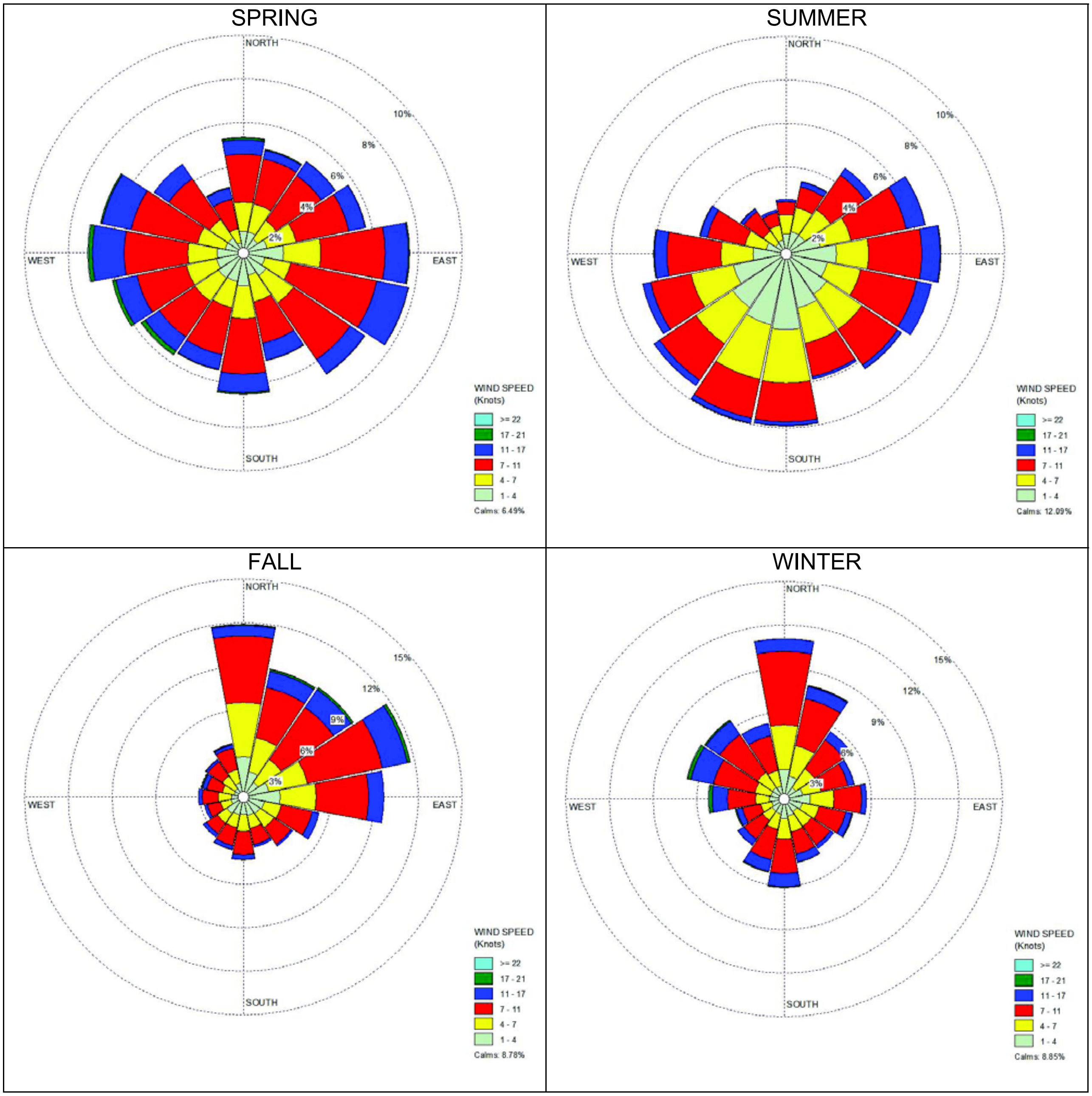

Figure 3-2. 5-Year Seasonal Wind Roses, Orlando International Airport, 1996 through 2000

Source: NCDC, 2002.

Table 3-3. NAAQS and Monitored Air Quality Concentrations

Pollutant and Averaging Time	Primary NAAQS[1]	2010 Monitored Data[2]		Location of Monitor City	County
CO				Valrico	Hillsborough
8-hour*	9 ppm	0.9 ppm	2nd Maximum		
1-hour*	35 ppm	1.0 ppm	2nd Maximum		
NO_2				Tampa	Hillsborough
Annual†	53 ppb	6 ppb	Arithmetic mean		
1-hour§	100 ppb	38 ppb	3-year average of daily 98th percentile		
PM_{10}					
24-hour*	150 µg/m^3	47 µg/m^3	2nd Maximum	Mulberry	Polk
24-hour*	150 µg/m^3	51 µg/m^3	2nd maximum	Lakeland	Polk
$PM_{2.5}$				Lakeland	Polk
Annual†	15 µg/m^3	7.71 µg/m^3	Arithmetic mean		
24-hour‡	35 µg/m^3	15.7 µg/m^3	3-year average of 98th percentile		
Ozone				Lakeland	Polk
8-hour (1997 standard)£	0.080 ppm	0.069 ppm	3-year average of annual 4th maximum		
8-hour (2008 standard) £	0.075 ppm	0.069 ppm	4th Maximum		
1-hour*	0.12 ppm	0.079 ppm	2nd Maximum		
8-hour£	0.075 ppm	0.066 ppm	3-year average of annual 4th maximum		
1-hour*	0.12 ppm	0.078 ppm	2nd maximum		
SO_2				Valrico	Hillsborough
Annual†	0.03 ppm	0.001 ppm	Arithmetic mean		
24-hour*	0.14 ppm	0.003 ppm	2nd Maximum		
1-hour¥	75 ppb	17 ppb	3-year average of 99th percentile		
Lead				Tampa	Hillsborough
Rolling 3-month average	0.15 µg/m^3	0.011 µg/m^3	Maximum daily		

*Not to be exceeded more than once per year. Standard has been revoked for 24-hour SO_2.
†Arithmetic mean.
‡The 3-year average of the 98th percentile of 24-hour concentrations.
§The 3-year average of the 98th percentile of the daily maximum 1-hour average concentration is less than or equal to the standard.
£Standards attained when the 3-year average of the annual 4th highest daily maximum 8-hour average concentration is less than or equal to the standard.
¥The 3-year average of the 99th percentile of the daily maximum 1-hour average concentration is less than or equal to the standard.

Sources: [1]40 CFR 50.1-50.12.
[2] FDEP, 2011; 2008 through 2010 data used for 3-year averages. http://www.dep.state.fl.us/air/air_quality/techrpt/quicklook.htm.
ECT, 2011.

With the exception of the lead standard, all areas of Florida have air quality designated as being better than the NAAQS or unclassifiable/attainment by 40 CFR 81.310. There is a localized area (less than 2 square kilometers) in Tampa surrounding an industrial facility that is nonattainment for the 2008 lead standard. This area is more than 25 miles from the proposed project site and is not relevant to the evaluation of this project.

In addition to the NAAQS, Table 3-3 lists recent data (i.e., 2010) from selected monitoring stations located in Polk and Hillsborough Counties. The Polk County monitors are considered to be representative of the rural Polk Power Station site. PM_{10} data were collected at the Mulberry station located approximately 8 miles northwest of the project site. As shown in Table 3-3, the second highest 24-hour PM_{10} concentration at the Mulberry site was 47 micrograms per cubic meter ($\mu g/m^3$), which is well below the primary standard of 150 $\mu g/m^3$. Another Polk County site at 1015 Sikes Boulevard in Lakeland, which is 21 miles to the north northwest of the project site, recorded a second high 24-hour PM_{10} concentration of 51 $\mu g/m^3$. $PM_{2.5}$ was monitored at the Sikes Boulevard Lakeland monitor location and recorded 24-hour and annual values of 15.7 and 7.71 $\mu g/m^3$, respectively. The 24-hour concentration is the 3-year average of the 98th percentile of 24-hour concentrations. The measured $PM_{2.5}$ at this site is approximately half of the standards and is similar to values (e.g., a difference of 0.5 $\mu g/m^3$ or less) obtained at the Valrico (formerly Plant City) monitor located approximately 21 miles northwest of the project site in Hillsborough County.

Ozone data were collected at two monitoring stations in Lakeland located approximately 15 and 21 miles north of the site. As shown in Table 3-3, the second highest measured 1-hour ozone concentrations of 0.79 and 0.78 ppm are well below the 1-hour standard of 0.12 ppm. It should be noted that the 1-hour ozone standard has been revoked. The ozone values of 0.069 part per million (ppm) measured at the Sikes Boulevard monitoring station and 0.066 ppm measured at the Sheperd Road site are within approximately 90 percent of the current 8-hour standard of 0.075 ppm. From 2008 through 2011, the ambient ozone air quality has been variable, showing improvement in 2009 and 2010, but was somewhat higher in 2011.

The lead value shown in Table 3-3 is the highest concentration measured in 2010 at the Valrico site. This concentration is only 7 percent of the standard and is a good indication that lead values in this area of Florida are very low.

Data from the Valrico monitor were used to determine ambient air quality for CO and SO_2. As shown in Table 3-3, the measured second high 1- and 8-hour CO concentrations were 3 and 10 percent of the 1- and

8-hour standards, respectively. High CO levels are generally associated with high volume intersections, roadways, and parking areas.

As shown in Table 3-3, the SO_2 values measured at the Valrico monitor are well below the NAAQS. The measured values of 0.001 ppm annual concentration and 0.003 ppm 24-hour concentration are less than 5 percent of the NAAQS. These values are also 5 percent or less of the Florida ambient air quality standards for those averaging times. The 3-year average of the daily 99^{th} percentile hourly SO_2 values was 17 ppb, which is much less than the standard of 75 ppb.

The NO_2 data shown in Table 3-3 for the Tampa monitor site on Gandy Boulevard approximately 50 km west of the Polk Power Station indicate the annual ambient levels are well below the standard (i.e., approximately 11 percent of the standard). The 3-year average of the daily 98^{th} percentile concentrations was 38 parts per billion (ppb), well below the 100-ppb standard.

3.1.2 ENVIRONMENTAL CONSEQUENCES

3.1.2.1 Proposed Project

Construction activities for the proposed project would start in April 2012 and be completed in March 2013. The CO_2 capture and sequestration activities would take place over an approximate18-month period targeted to start in the third quarter of 2013.

Due to the limited duration of the construction and operation phases, the proposed project would have short-term minor air quality impacts. Emissions during construction and operation would not exceed major new source review (NSR) air permitting applicability thresholds, have a regionally significant impact, or contribute to violations of federal, state, or local air regulation or ambient air quality standards. In summary, the proposed project would conform to the EPA-approved Florida State Implementation Plan (SIP) due to the minimal level of the emissions. Discussions of air quality impacts during construction and operation of the proposed project are provided in the following sections.

Construction

Construction of the proposed project would result in three general categories of air emissions. First, site preparation and vehicle movement would generate fugitive dust emissions. Second, internal combustion engines in construction equipment would release NO_x, CO, and other motor fuel combustion products. And third, construction worker travel to and from the Polk Power Station would result in vehicular emissions.

The quantity of emissions released during the construction process would generally be low but would vary due to weather conditions and would fluctuate on an hourly and daily basis as construction progresses. Fugitive dust emissions would be greatest during the site preparation phase. Fugitive dust emissions would also be greater during the more active construction periods as a result of increased vehicle traffic on the construction site.

Fugitive dust emissions from the construction site would be minimized using appropriate dust suppression control methods. Standard control methods include the application of environmentally approved dust-suppressing chemicals or water to unpaved roads and other exposed surfaces and the seeding of exposed areas. Construction-related fugitive dust emissions would be temporary and would cease once construction is completed.

Emissions from internal combustion engines would occur during site preparation and construction because of the use of onsite construction equipment for site grading, concrete placement, and structural steel and major equipment installation. In addition to the pollutants associated with the combustion of motor fuel by the construction equipment engines, the following construction activities would result in minor emissions of volatile organic compounds (VOCs):

- Evaporative losses from onsite painting.
- Refueling of construction equipment.
- Application of adhesives, waterproofing chemicals, and cleaning solvents.

Also, to potentially reduce GHG and other emissions from construction equipment and vehicles, DOE would encourage RTI to consider the use of best management practices and clean energy options, such as clean diesel technologies and alternative fuel vehicles, to the extent practicable.

There would be an estimated 107 construction workers on a monthly average basis. While not readily quantifiable, the temporary net changes in vehicle-miles traveled (VMT) in the area would be minimal, as would any temporary net changes in areawide vehicular emissions due to the relatively low number of construction workers anticipated.

Air quality impacts caused by construction activity would vary from day to day as a function of the level of activity, specific nature of the activity, weather conditions while the activity occurs, and emissions controls applied to the activity. However, even under worst-case conditions, maximum ambient impacts caused by construction emissions are expected to be modest, temporary, and limited to the general area of the construction site. Additionally, there is a substantial buffer between the project construction site and the nearest point of public exposure; i.e., approximately 0.65 mile (3,400 ft).

In summary, based on the type and nature of the construction-related emissions sources, air quality impacts caused by construction-related emissions would be minor and localized, primarily limited to the immediate onsite area of the construction activity, and well within the Polk Power Station property boundaries.

Operation

During the approximate 18-month operation phase, the proposed project would have minimal impacts on ambient air quality due to the small number and size of the project's emissions sources. Emissions sources associated with operation of the proposed project include the following continuous and intermittent sources:

- 23.75-million-British-thermal-units-per-hour (MMBtu/hr) propane-fired HTDP unit startup heater (intermittent combustion emission source; would operate for approximately 32 percent of the time; i.e., 2,820 hours per year [hr/yr]).
- 2.1-MMBtu/hr propane-fired DSRP tailgas recycle heater (continuous combustion emission source).
- HTDP unit adsorber sorbent hopper (intermittent particulate matter [PM] emission source - would operate for approximately 1.2 percent of the time; i.e., 104 hr/yr).
- Amine (aMDEA) surge drum (intermittent VOC emission source; would operate for approximately 0.02 percent of the time; i.e., 12 hr/yr).
- HTDP unit regenerator system regenerator fines bin (intermittent PM emission source; would operate for approximately 1.2 percent of the time; i.e., 104 hr/yr).

In addition to the emission sources described, the existing Polk Power Station flare would be used to oxidize intermittent emissions associated with startup and shutdown of the demonstration high-temperature syngas cleanup process.

Due to the temporary, intermittent, and minor level of emissions associated with operation of the proposed project, impacts on ambient air quality would be minimal and would not contribute to violations of federal, state, or local ambient air quality standards. As discussed in Subection 3.1.1, Polk County is presently designated as in attainment with respect to NAAQS.

In addition to having minimal impacts on ambient air quality, during the operation phase of the demonstration, the proposed project is expected to inject and sequester CO_2 that would otherwise have been released to the atmosphere at a rate of approximately 300,000 tpy. Operation of the proposed project would require approximately 9 MW of electric power, which would be provided by Tampa Electric, similar to the existing operations. Assuming that this power would be generated by the Polk Unit 1 IGCC plant and the proposed project would operate for approximately 8,000 hours over the 18-month demonstration period, the estimated GHG emissions from this additional power generation would be approximately 72,730 tons. Therefore, the proposed project would result in a net decrease in GHG emissions. The demonstration high temperature syngas cleanup process would also result in reductions of SO_2 and trace metal (arsenic, selenium, and mercury) emissions compared to the current Polk Power Station syngas cleanup process. Therefore, additional analyses of the potential impacts of these pollutants, such as deposition analyses, are not warranted for this proposed project.

3.1.2.2 No-Action Alternative

Under the no-action alternative, DOE would not provide RTI with cost-shared funding for the proposed project, and the project would not be constructed nor operated. Therefore, no impacts to air quality due to the proposed project would occur.

3.2 GEOLOGY AND SOILS

3.2.1 AFFECTED ENVIRONMENT

3.2.1.1 Subsurface Geology

In general, the Polk Power Station site and surrounding region contain surficial layers of unconsolidated sands plus clays and consolidated carbonate strata to depths of roughly 250 to 300 ft. These stratigraphic units are underlain by a thick sequence of sedimentary carbonate (limestone and dolomite) rocks. A summary of the geologic and hydrogeologic framework for the central Florida phosphate district of west-central Florida is presented in Table 3-4 and illustrated on Figure 3-3.

In the vicinity of the site, the Upper Cretaceous Pine Key Formation is present at the anticipated UIC well completion depth of 8,000 ft bls. The Upper Cretaceous Lawson limestone (which may correlate to the Upper Pine Key Formation) occurs above this and is present between roughly 4,600 to 4,800 ft bls. Overlying this stratigraphic unit is the lower unit of the Cedar Keys Formation, which is still of the Late Cretaceous age and present between depths of 4,200 to 4,600 ft bls. The Lower Cedar Keys Formation, Lawson limestone, and Pine Key Formation (units greater than 4,200 ft bls) comprise the targeted injection zone for this project. Vertical permeability testing performed on samples taken from a core collected from between 4,767 and 4,774 ft bls from IW-1 indicated permeabilities ranging from 1.5×10^{-5}

Table 3-4. Hydrogeological Framework for West-Central Florida

System	Series	Stratigraphic Unit		General Lithology	Major Lithologic Unit	Hydrogeological Unit	
Quarternary	Holocene and Pliestocene	Undifferentiated surficial deposits		Predominantly fine quartz sand; shell interbedded clay, marl, peat, dolostone, sandstone, and phosphorite	Sand	Surficial aquifer system	
		Fort Thompson Formation		Shelly quartz sand, unfossiliferous quartz sand, and thin limestone beds			
		Caloosahatchee Formation		Shelly quartz sand; thin, shelly limestone beds, and marl	Clastic	Confining unit	Intermiediate aquifer system
Tertiary	Pliocene	Tamiami Formation		Sandy limestone, clayey and pebbly sand; clay, marl, shell, phosphatic	Carbonate and clastic		
	Miocene	Hawthorn Group	Peace River Formation*	Clayey, phosphatic, sandy beds; silty and sandy phosphatic clay beds, and clayey phosphatic quartz sand		Aquifer	
			Arcadia Formation†	Dolomite and clay, and limestone, silty, phosphatic		Confining unit	
	Oligocene	Suwannee Limestone		Limestone, sandy limestone, fossiliferous	Carbonate	Floridan aquifer system	
	Eocene	Ocala Group		Limestone, chalky, foraminiferal, dolomitic, near bottom			
		Avon Park Formation		Limestone and hard brown dolomite; intergranular evaporite in lower part in some areas		Upper Floridan aquifer Middle confining unit Lower Floridan aquifer	
		Oldsmar Formation		Dolomite and limestone, with intergranular gypsum in most areas			
	Paleocene	Upper and Middle Units Cedar Keys Formation		Dolomite and limestone with beds of anhydrite	Carbonate with evaporites	Sub-Floridan confining unit	
		Lower Unit Cedar Keys Formation		Dolomite and limestone with some anhydrite	Carbonates with minor evaporites	Targeted injection interval	
		Lawson Limestone/ Pine Key Formation		Dolomite and limestone with some anhydrite and traces of shale			

*Peace River Formation includes Bone Valley Member and undifferentiated deposits.
†Arcadia Formation includes undifferentiated deposits, Tampa Member, and Nocatee Member.

Sources: Ryder, 1985.
Johnson, 1989.

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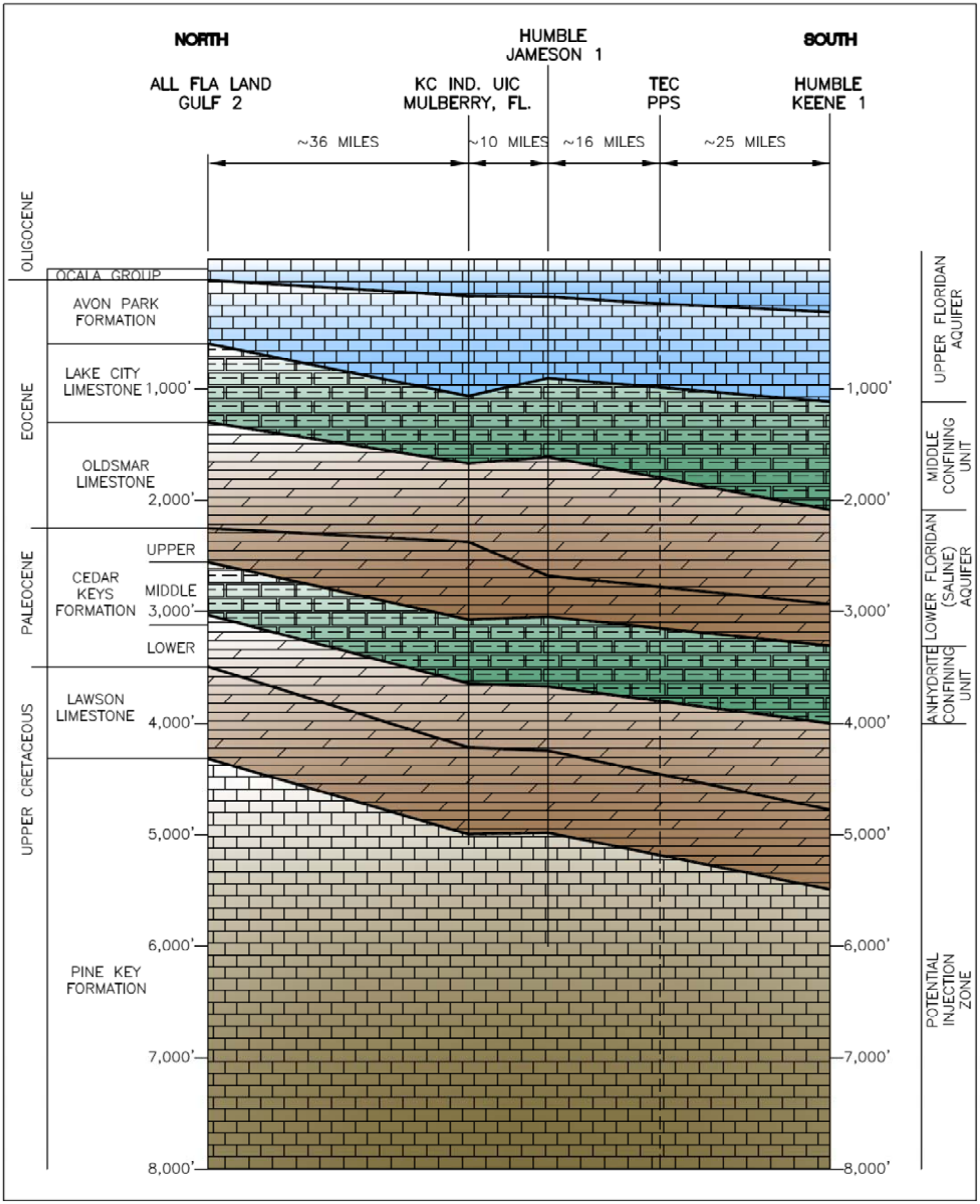


Figure 3-3. North-South Geologic Cross-Section of West-Central Florida

Sources: Kaiser, 1973. ECT, 2011.

to 6.8×10^{-4} cm/sec (0.04 to 1.9 feet per day [ft/day]) (Ardaman, 2010). It should be noted that, for sedimentary rock, the vertical permeability is typically thought to range between one-tenth and one-hundredth of the horizontal permeability. Also, the total porosity of these cores ranged from 23 to 32 percent (Ardaman, 2010). The Upper and Middle units of the Paleocene Cedar Keys Formation overlie these Upper Cretaceous units, and these strata occur at or below depths of approximately 3,150 ft.

The Upper and Middle units of the Cedar Keys Formation, along with the lowermost portion of the overlying Oldsmar Formation, comprise the primary confining unit exceeding 1,300 ft in thickness and overlying the proposed CO_2 injection zone. The majority of the pore space within these Cedar Keys units is filled with anhydrite and these units also include numerous layers of strata that are predominantly anhydrite. With the anhydrite filling the pore space, the vertical permeability and total porosities will be reduced, as is evident from the test results performed on several core samples. Vertical permeability testing performed on core samples collected from the confining unit during the drilling of IW-1 indicated low permeabilities ranging from 1.8×10^{-8} to 5.6×10^{-9} cm/sec (1.6×10^{-5} to 6.2×10^{-6} ft/day) (Ardaman, 2010). Additionally, the average total porosity of the cores tested from the confining unit was 3.5 percent with an average effective porosity, measured by a helium pyncometer, of 0.132 percent (Ardaman, 2010). The substantial thickness (greater than 1,300 ft) and extremely low vertical permeability would provide a suitable seal against the potential vertical migration of CO_2.

Above these Cretaceous age units is the Eocene Series, which includes the Oldsmar Formation, Avon Park limestone, and Ocala Group. The Avon Park limestone is the lower of two highly productive units of the Upper Floridan aquifer. The Suwannee limestone of Oligocene age overlies the Ocala Group. At the project site, the Suwannee limestone is encountered between 300 to 420 ft bls, but this unit pinches out to the northeast portion of Polk County. The Suwannee limestone is the top of two highly productive units of the Upper Floridan aquifer and is overlain by strata comprising the Hawthorn Group.

The Hawthorn Group consists of the Arcadia and Peace River Formations, in ascending order. The Arcadia Formation contains, in ascending order, the Nocatee and Tampa Members plus an unnamed member. The Arcadia Formation consists of dolomite, sand, clay, and silty, phosphatic limestone. The Peace River Formation is comprised of clayey phosphatic sand beds, which comprise the Bone Valley Member, which is the primary unit mined for phosphate (Scott, 1986). The Hawthorn Group is present from approximately 40 to 200 ft bls at the Polk Power Station site but varies from absent to approximately 300 ft across Polk County. The most recent deposits are undifferentiated sands and terrace deposits, which may range in thickness from 0 to approximately 40 ft.

The nearest offsite penetration into the Lower Cedar Keys Formation is the KCI Mulberry UIC well located in Mulberry, Florida, roughly 10 miles straight north of the Polk Power Station site. The KCI Mulberry UIC well began operation in the mid-1970s and injects acidic wastes into the subsurface.

Regarding its physiographic setting, the site is located within the geomorphic province known as the Polk Upland (White, 1970). There are no known or mapped regional faults or fractures within the injection zone or overlying confining unit within a 25-mile radius of the site.

As part of the original SCA (ECT, 1992) for Tampa Electric's Polk Power Station, a detailed sinkhole evaluation report was prepared for the facility. The following summary information is taken primarily from that document and includes of some updated information specifically related to the proposed RTI project. Based on information from this report, sinkholes are a natural and common geologic feature in areas underlain by geologic layers comprised of carbonate rock and other rock types that are soluble in natural water, such as those present essentially beneath all of Florida. The dissolution of these carbonate rocks is typically influenced by concentrated horizontal and vertical zones of weathering associated with groundwater movement. Ancient shorelines created discrete horizontal zones and developed geologic unconformities, erosional surfaces, or other related geologic features. Vertical faults, fractures, and/or joints in underlying bedrock are often evident as linear features visible on aerial photographs and satellite images. These subsurface vertical features, where present, can create zones of concentrated dissolution of the rock. Figure 3-4 illustrates areas of different sinkhole types and development potential throughout Florida (Sinclair *et at.*, 1985). As can be seen from review of this figure, the Polk Power Station site is located in an area where the cover materials exceed 200 feet (ft), and cover-collapse sinkhole occurrence is unlikely, although possible. The potential for sinkhole development is readily apparent in the number and size of sinkholes present within any given area in Polk County (see Figure 3-5).

Based on the fracture trace studies described in the 1992 sinkhole evaluation report plus the scarcity and small size of any closed depressions, the Polk Power Station site is thought to be relatively free of any major joints or fractures and has experienced only minor sinkhole activity to date. The dissolution of relatively shallow carbonate materials (shell deposits, limestone, and dolomite) to form solution cavities, particularly in the upper part of the intermediate aquifer system, is thought to be the most probable cause of the small land-surface depressions observed at the site. This does not mean that larger cavities may not exist in the carbonate formations comprising the Florida aquifer system, but rather that the thick section of relatively cohesive sandy clay, clay, and carbonate rock that overlie these cavities appears to have sufficient bearing strength to bridge any existing cavities.

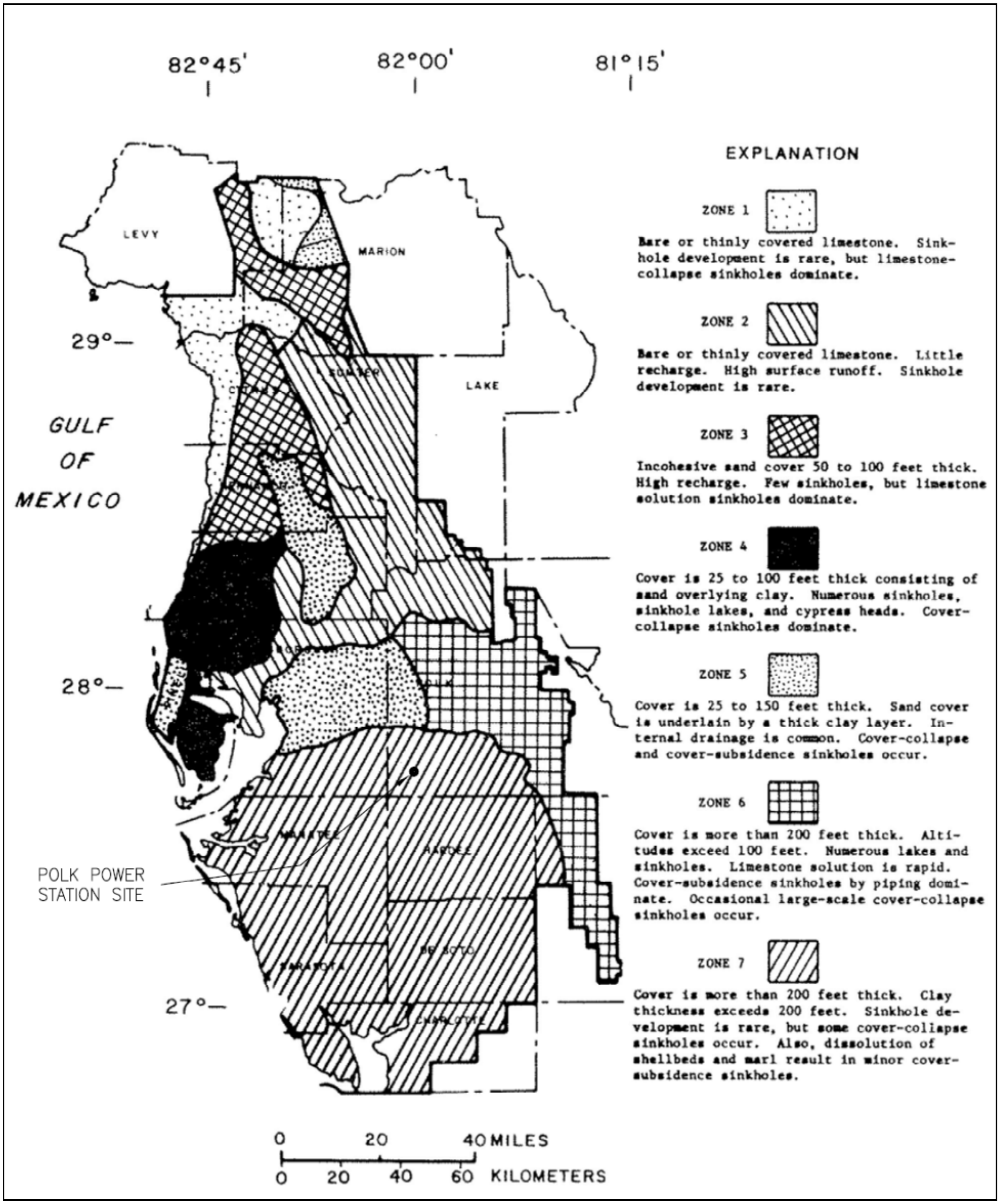


Figure 3-4. Zones of Different Types of Sinkhole Development

Source: Sinclair *et al.*, 1985.

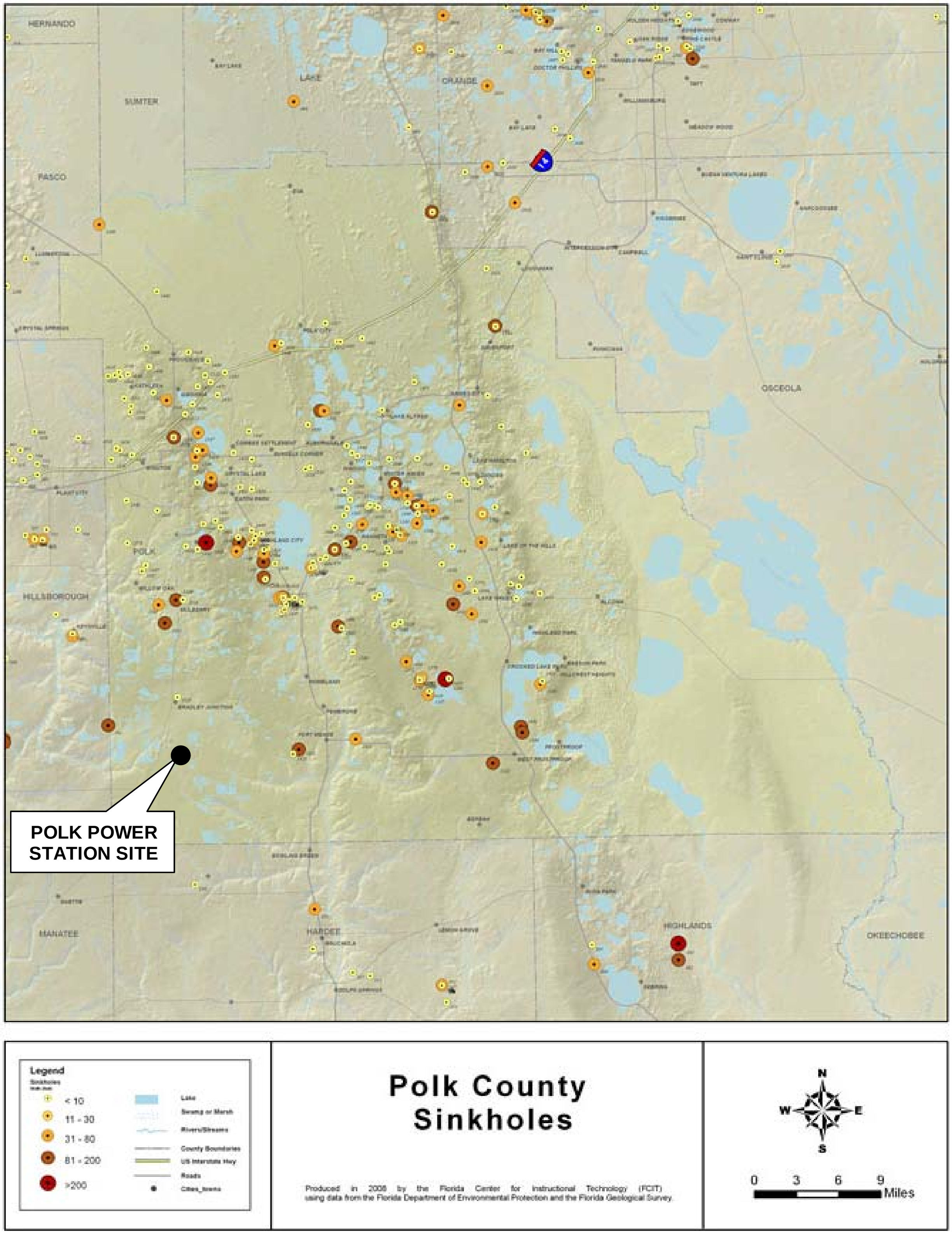


Figure 3-5. Polk County Sinkholes (2008)
Source: University of South Florida, 2008.

3.2.1.2 Soils

Soil types have been mapped by the U.S. Department of Agriculture (USDA) in cooperation with the Polk County Soil Conservation Services (SCS) (1990). The Polk Power Station site is situated primarily on Smyrna-Myakka, Arents-Water, and Ona soil types (Figure 3-6). Seventeen other soil types occur across the site but cover significantly less area.

The Smyrna-Myakka soil complex consists primarily of fine sands that cover broad areas of flatwoods. These soils are somewhat poorly drained with the water table typically within 0 to 1 ft of the land surface for 1 to 4 months in most years. The Smyrna soils have an organic matter content of 1 to 5 percent, and the Myakka soils have an organic matter content of 2 to 5 percent (SCS, 1990).

The Arents-Water complex is a soil type resulting from mining activities. The Arents consists of overburden soil piles (various slopes) created during phosphate mining activities. The water portion of the complex is the groundwater, which subsequently flows into and fills the mine cuts that typically remain open.

The Ona fine sands are also found in broad areas of flatwoods. The Ona soils are also somewhat poorly drained with the water table typically within 0 to 1 ft of the land surface for 1 to 4 months in most years.

3.2.2 ENVIRONMENTAL CONSEQUENCES

3.2.2.1 Proposed Project

The main potential adverse effects of the proposed project on geology and soils would result from the injection of approximately 300,000 tpy of CO_2 over 18 months. These impacts are presented in the following paragraphs with a brief discussion including their likelihood of occurrence.

A sudden unplanned or uncontrolled release of CO_2 to the surface would be considered unlikely because of the well design plus the operational and monitoring technologies, which would be used. If a release were to occur at or from the well/wellhead, such an event would have minimal impacts on the soil resources surrounding the well. Most effects would be localized mainly to nearby low-lying areas surrounding the well and could be readily remediated.

The operation of injection well IW-2 for injection of CO_2 in its supercritical fluid state for the proposed project is not expected to contribute to or increase the probability for the formation of sinkholes. The reasons behind this conclusion are presented and discussed in the following paragraphs.

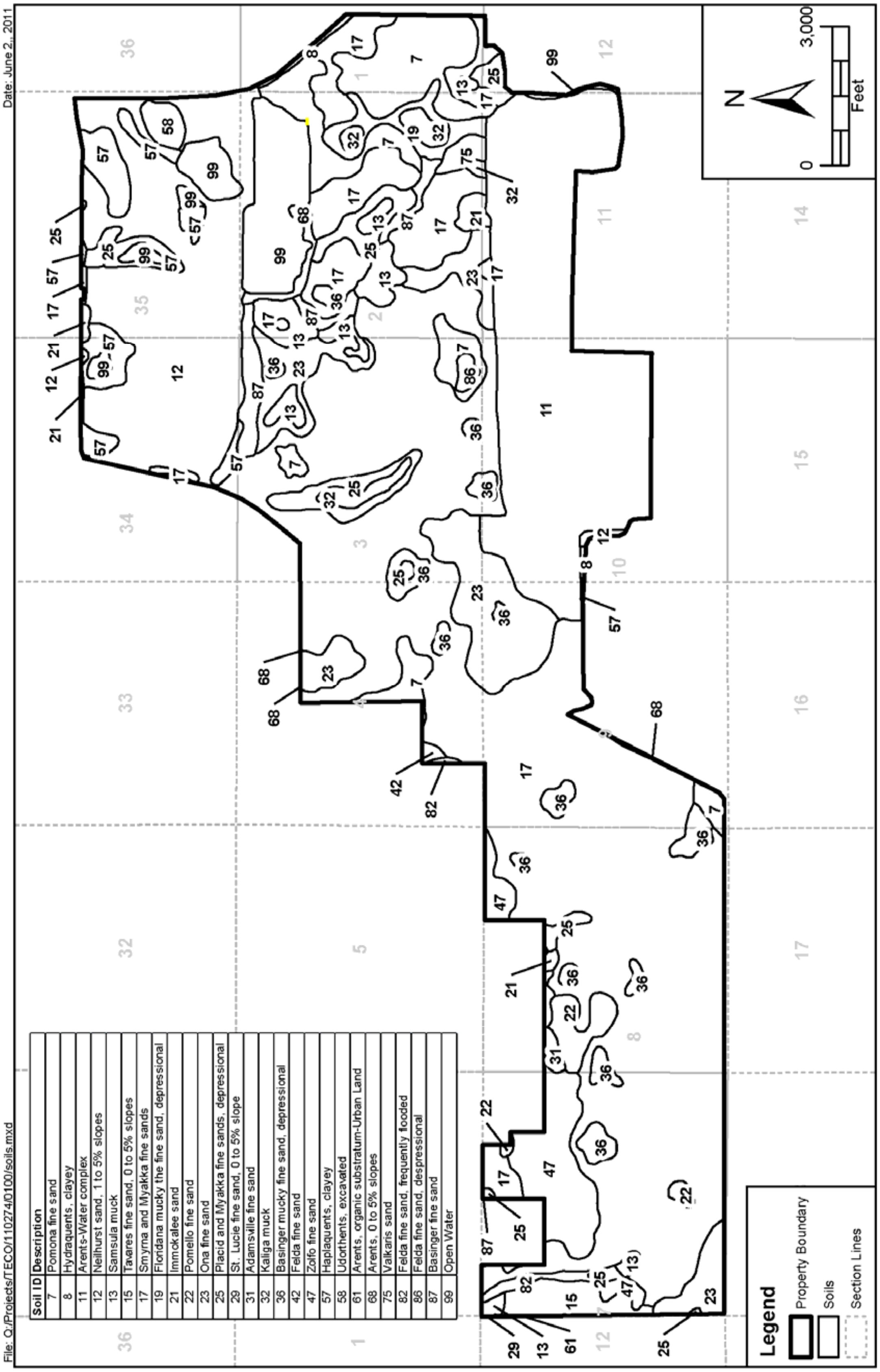


Figure 3-6. Soils Map for Polk Power Station Site

Sources: USDA NRCS, 2002. Amato *et al.*, 1986. Chen, 1965. Winston, 1994. ECT, 2011.

First, the targeted injection zone extends between 4,200 to 8,000 ft bls and would include portions of the Cedar Key Formation, Lawson Limestone, and Pine Formation. The depth of this injection zone lies beneath several thousand feet of carbonate rock formations (see Table 3-4 and Figure 3-3), as well as several thousand feet below the depths of the ancient shorelines (horizontal weathering zones) described previously. The drilling and geophysical logs collected during the recent drilling of IW-1 revealed no evidence of solution cavities attributable to potential sinkhole development in this targeted zone. Furthermore, the substantial thickness of competent rock units overlying this zone should provide more than adequate bearing strength to prevent the collapse of such cavities, should they exist.

Second, the upper and middle units of the Cedar Key Formation comprise a more than 1,000-ft-thick confining unit, which has and will restrict the vertical movement of groundwater and CO_2. This confining unit is laterally continuous, plus it and the proposed injection zone are expected to be free of any major faults, fractures, or joints. Therefore, the presence of vertical zones of concentrated groundwater movement is not expected and, as such, the likelihood or probability of sinkhole development is not expected to increase.

Third, based on geochemical modeling of the injected CO_2 and wastewater (injectate) interaction with the subsurface brine and formation performed by the University of South Florida (Stewart, 2011), the preliminary modeling results indicated that, following the CO_2 (IW-2) and wastewater injection (IW-1 and IW-2), there is a potential for a minor amount of deposition and precipitation of minerals (fluorapatite and dolomite) in proximity to the injection wells, not dissolution. The anticipated change in porosity would be quite small (a fraction of 1 percent); so, although overtime this may influence the injection pressures slightly, it should not plug the pore space enough to preclude continued injection.

Fourth, also based on the geochemical modeling, it is predicted that the CO_2 gas saturation plume (or pure supercritical CO_2 plume) will not remain in the subsurface beyond roughly 1 to 2 years after converting IW-2 to inject wastewater, which is equivalent to 2 to 3 years after starting wastewater injection at IW-1. After this time, the CO_2 is essentially either dissolved into the brine or has reacted with the formation material within the injection interval (via solubility and mineral trapping). Thus shortly after the CO_2 injection period, the CO_2 will no longer be acidic in nature nor have a buoyant density exerting upward vertical pressures or seeking upward vertical migration pathways contributing to dissolution of formation materials.

Therefore, DOE believes that the storage of CO_2 for the proposed project would not affect or contribute to an increased potential for sinkhole formation.

A sudden unplanned or uncontrolled release of CO_2 vertically through the geologic materials adjacent to the injection well up to the surface soils or near surface geologic units would also be considered unlikely. The reasons for this include the lateral continuity, substantial thickness, and low vertical permeability of the confining (caprock) unit plus the lack of other nearby well/borehole penetrations or fractures/faults through the confining unit. Relatively slow leakage from the well bores due to casing and/or cement problems would be detected ahead of time by mechanical integrity testing to be conducted as part of the monitoring anticipated to be required under the UIC permit. If a release were to occur, such an event would not be expected to reach or have adverse impacts on the surface soils or near surface geologic units due to the presence of additional confining units within the overlying 2,500- to 3,000-ft vertical distance. Additionally, the released CO_2 would continue to react geochemically with the carbonate materials and most likely be geochemically converted and dissolved within the formation fluids via solubility and mineral trapping.

Due to the highly unlikely nature of the previously described effects, the proposed project would be expected to have minimal impacts due to leakage of CO_2 from the storage formation to the surface or into another area in the subsurface.

3.2.2.2 No-Action Alternative

Under the no-action alternative, DOE would not provide funding to RTI, and the proposed project would not proceed. Therefore, no impacts to geology or soils would occur due to the project construction and operation. However, under the no-action alternative, Tampa Electric would proceed with its plans to drill and construct the deep injection well IW-2 and associated monitoring well and use the injection well for disposal of wastewater from the power plant operations.

3.3 WATER RESOURCES

3.3.1 AFFECTED ENVIRONMENT

3.3.1.1 Surface Water

The eastern portion (i.e., east of SR 37) of the Polk Power Station site, which includes the existing power plant facilities and would contain the proposed project site, is located within the headwaters of the Little Payne Creek drainage basin. Little Payne Creek flows approximately 10 miles southeast from the site to Payne Creek. Payne Creek is a tributary of the Peace River, which flows into Charlotte Harbor and the Gulf of Mexico in southwest Florida. According to Chapter 62-302, F.A.C., these surface waters are classified as Class III fresh waters with designated uses for recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife.

Key surface water features located on the eastern portion of the Polk Power Station site include the 755-acre cooling reservoir, a 26-acre stormwater retention pond, several areas of reclaimed wetlands, an old water-filled mine cut, and a reclaimed, unnamed lake (see Figure 2-3).

The existing Polk Power Station operations use the cooling reservoir for once-through cooling for the Polk Unit 1 IGCC plant and also for the discharge of treated plant wastewaters. Stormwater runoff from the existing power plant facility areas is collected, treated as needed, and routed to the stormwater retention pond. Under NPDES Permit No. FL0043869-Major, the Polk Power Station is permitted to have two external outfalls to the Little Payne Creek system. Outfall D-001 discharges from the cooling reservoir to the unnamed lake along the eastern boundary of the site, which flows to Little Payne Creek. Outfall D-002 discharges stormwater from the retention pond to an old mine cut, which flows to the unnamed lake. Tampa Electric monitors and reports the water quality of these two external outfalls in accordance with the NPDES permit conditions.

3.3.1.2 Groundwater

The groundwater aquifer systems in Polk County include, shallowest to deepest, the surficial (usually unconfined), intermediate (usually semi-confined to confined), and Floridan aquifers (usually confined). Table 3-4 and Figure 3-3 present the general geologic and hydrogeologic framework for these aquifer systems in west-central Florida.

Figure 3-7 illustrates the distribution and presence of the surficial aquifer system (SAS) in Florida and Polk County (Copeland *et al.*, 2009). At the project site, the SAS is composed of the undifferentiated sands and clays, plus the upper sandy section of the Bone Valley Member of the Peace River Formation. At the proposed project location, this unit is approximately 40 to 50 ft thick (ECT, 1992). The average annual precipitation at the site is approximately 53 inches per year, and the amount of recharge entering the surficial aquifer is affected by runoff and evapotranspiration. The SAS is not used as a significant source of water in Polk County nor in the vicinity of the project site (Copeland *et al.*, 2009).

Figure 3-8 illustrates the distribution and presence of the intermediate aquifer system (IAS) in Florida and Polk County (Copeland *et al.*, 2009). The IAS consists of portions of the Peace River and Arcadia Formations of the Hawthorn Group. At the site, the intermediate aquifer has two producing zones that are separated by different semiconfining to confining units. At the proposed project location, this aquifer with its associated confining units is approximately 220 to 250 ft thick (ECT, 1992). The primary

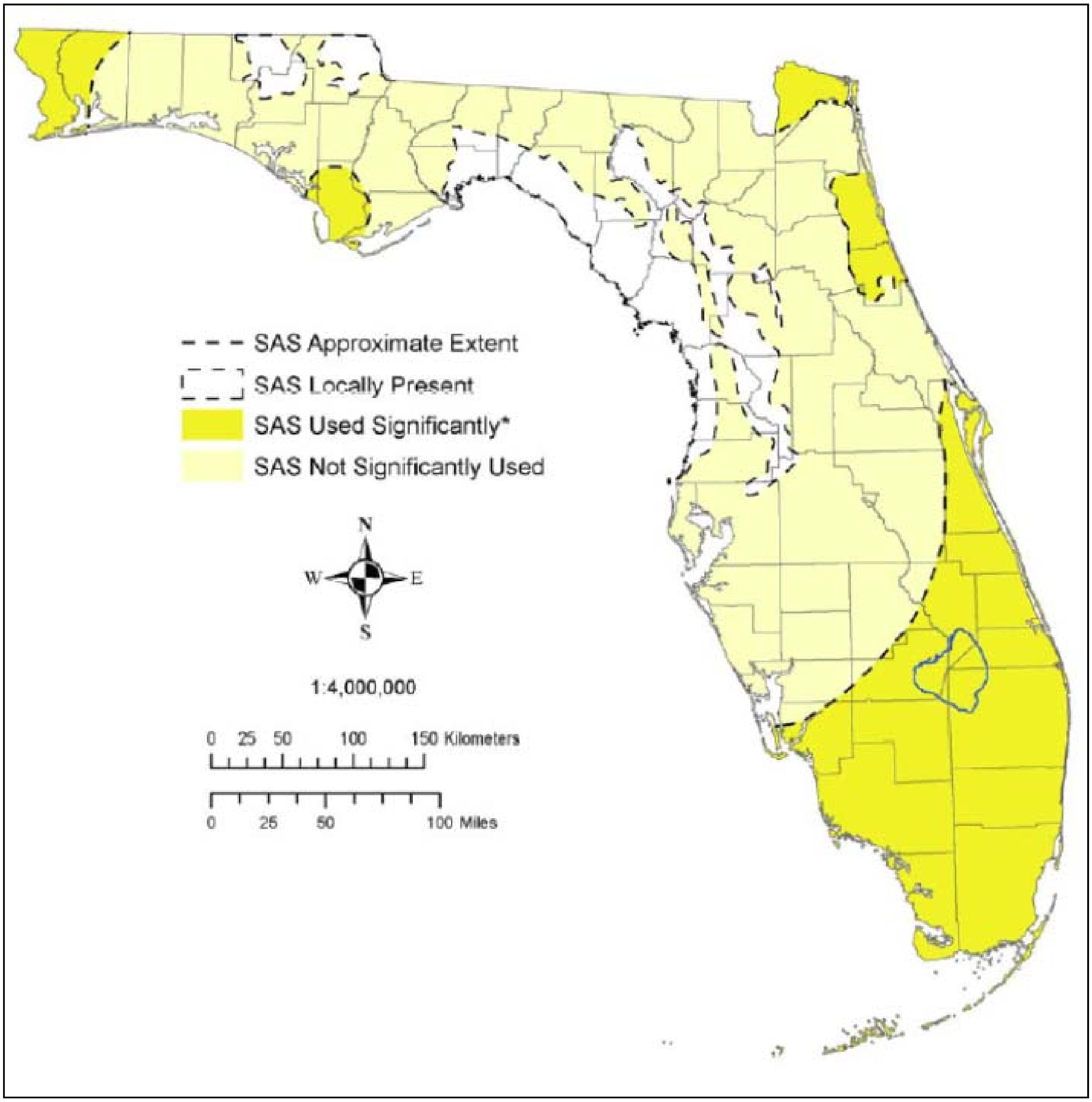


Figure 3-7. Distribution and Presence of the Surficial Aquifer System in Florida
Source: Copeland *et al.*, 2009.

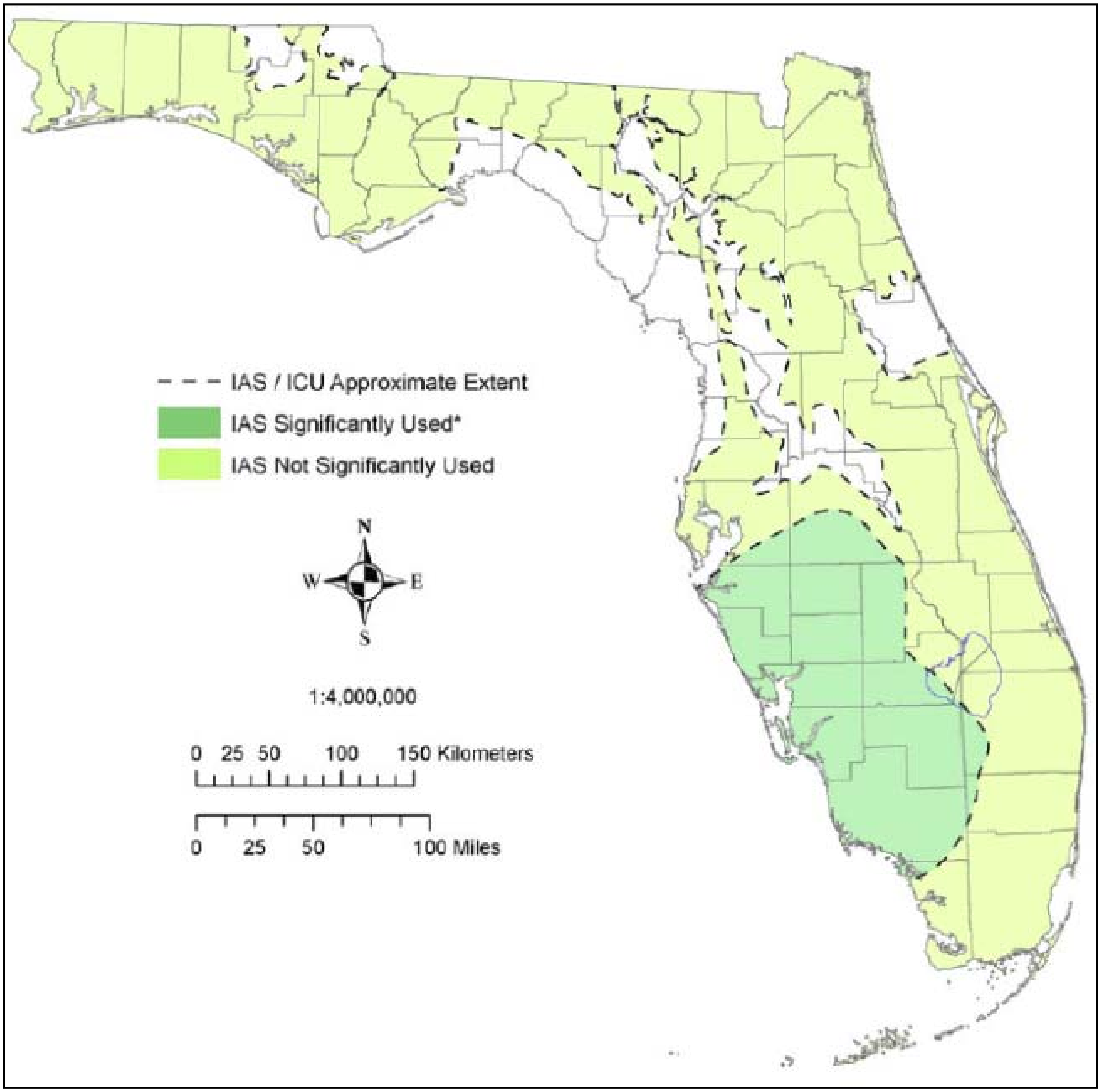


Figure 3-8. Distribution and Presence of the Intermediate Aquifer System in Florida

Source: Copeland *et al.*, 2009.

recharge to the upper intermediate aquifer is leakage from the SAS. The IAS is used as a source of water in Polk County primarily for agricultural and residential purposes (Arthur *et al.*, 2008).

The Upper Floridan aquifer system (UFAS) includes the Suwannee Limestone, Ocala Group, and upper portion of the Avon Park Formation. Figure 3-9 illustrates the distribution and presence of the UFAS in Florida and Polk County (Copeland *et al.*, 2009). At the proposed project location, the UFAS is approximately 700 to 750 ft thick (ECT, 1992). In proximity to the site, the UFAS has two highly transmissive and producing zones, which include the Suwannee Limestone and Avon Park Formation. Primary recharge to the UFAS comes from the physiographic ridge areas to the north and east of the Polk Power Station site, with some additional recharge coming from the lower IAS. The UFAS is one of the major sources of drinking water supply for this area in west-central Florida.

The Lower Floridan aquifer system (LFAS) is separated from the UFAS by the middle confining unit that coincides with the lower portion of the Avon Park Formation (formerly known as the Lake City Limestone), beneath which lies the Oldsmar Formation, which is the main producing zone in this aquifer. However, due to the occurrence of more transmissive, productive units at shallower depths, the LFAS is not commonly used as a water source in the west-central portion of Florida (Southwest Florida Water Management District [SWFWMD 2011]). Also, the LFAS has poorer water quality with total dissolved solids concentrations ranging from 2,000 to 10,000 milligrams per liter, which would require additional treatment prior to use as drinking water.

In February 2011, the SWFWMD water use permit electronic database was screened for all permitted wells within a 2-mile radius of the Polk Power Station site (located east of SR 37). The results of this search indicated 33 existing wells were permitted for withdrawals and reportedly used for industrial-, agricultural-, or mining-related purposes. Of these 33 permitted wells, 4 are used for industrial or commercial purposes with up to a 6.99-million-gallons-per-day (MGD) permitted use (all at Polk Power Station), 14 were used for mining and sealing water-related purposes with up to a 7.08-MGD permitted use, plus 15 were used for irrigation with up to a 1.08-MGD permitted use.

The deepest water supply wells drilled in the vicinity of the site are the four water supply wells installed for the existing power plant. These wells were drilled to a depth of approximately 900 ft bls and do not penetrate to the bottom of the USDW nor approach the depth to the top of the confining unit (approximately 2,900 ft bls) above the proposed injection zone. Currently, Tampa Electric is authorized to withdraw up to 5.24 MGD on an annual average daily basis from these wells in the UFAS. Otherwise, most of the other water wells in the vicinity of the site penetrating into the UFAS have depths ranging

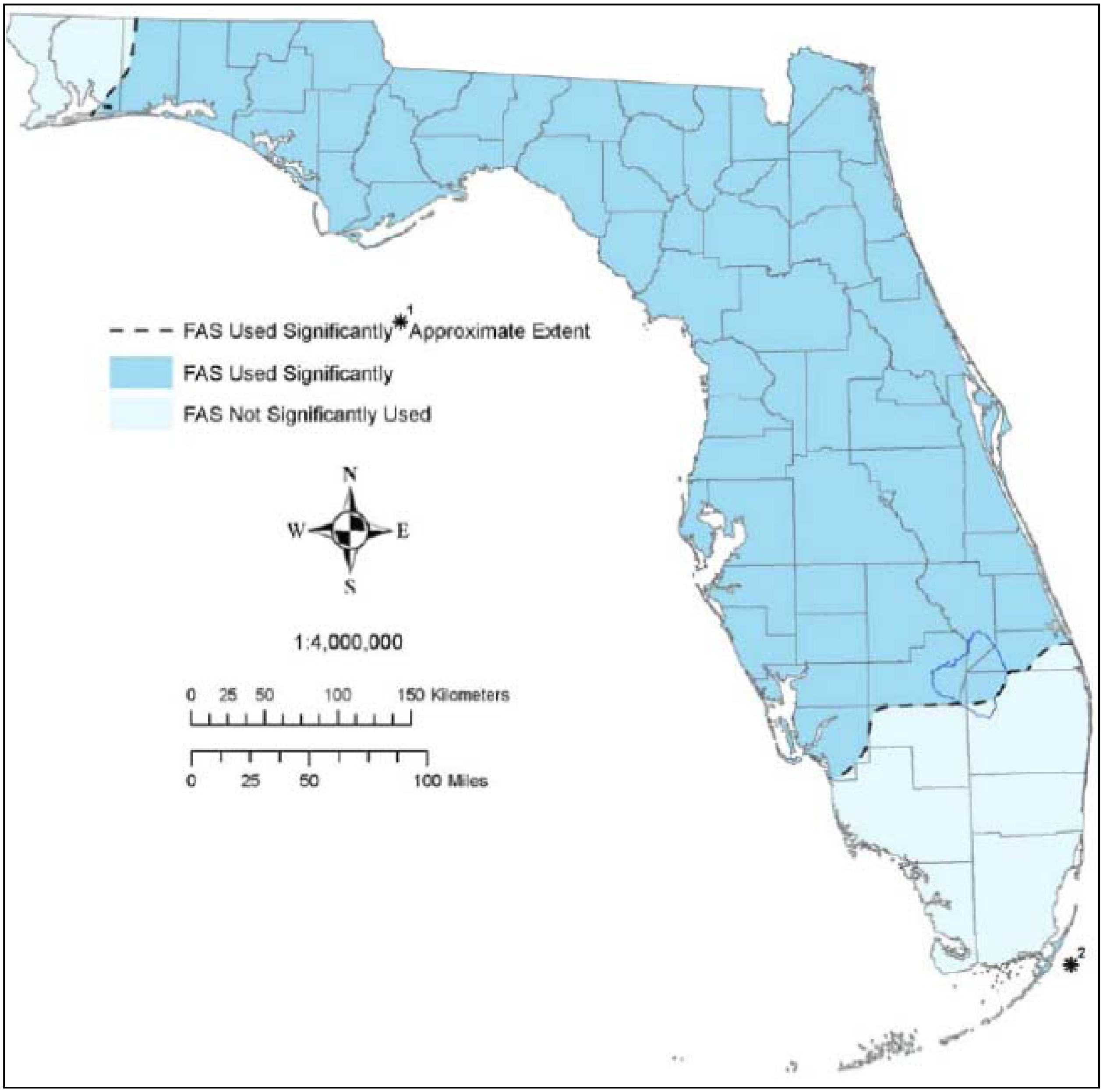


Figure 3-9. Distribution and Presence of the Upper Floridan Aquifer System in Florida

Source: Copeland *et al.*, 2009.

between 300 to 500 ft bls or are completed into one of the shallower overlying aquifers (intermediate or SAS).

As previously mentioned, the nearest offsite deep well penetration into the Lower Cedar Keys Formation is the KCI Mulberry UIC well located in Mulberry, Florida, roughly 10 miles straight north of the Polk Power Station site. This UIC well has been in operation since the mid-1970s and injects acidic wastes.

3.3.2 ENVIRONMENTAL CONSEQUENCES

3.3.2.1 Proposed Project

Surface Water

During construction of the proposed project, the primary surface water resource concerns would be soil erosion and stormwater runoff from the proposed project facility area and construction laydown/parking areas. These areas are relatively level, covered in grass, and within existing drainage infrastructure areas for the existing power plant. During construction, appropriate erosion control and stormwater management measures would be used to minimize potential impacts. These measures would be implemented in accordance with the requirements of a generic permit for stormwater discharge from large and small construction activities, under Chapter 62-621, F.A.C., which would be required for the proposed project. Based on these measures, the potential impacts on surface water resources during construction of the proposed project would be minimal and temporary.

During operations, stormwater runoff from the proposed project facility area would be directed to and integrated with the stormwater drainage system for the existing power plant facilities. The existing drainage system and stormwater retention pond have sufficient capacity to detain and appropriately treat the additional project-related runoff. Therefore, no potential impacts to surface water resources are anticipated.

Also, during operations, the proposed project would require cooling and process water and would produce a process wastewater. Figure 3-10 provides the water balance for the proposed project.

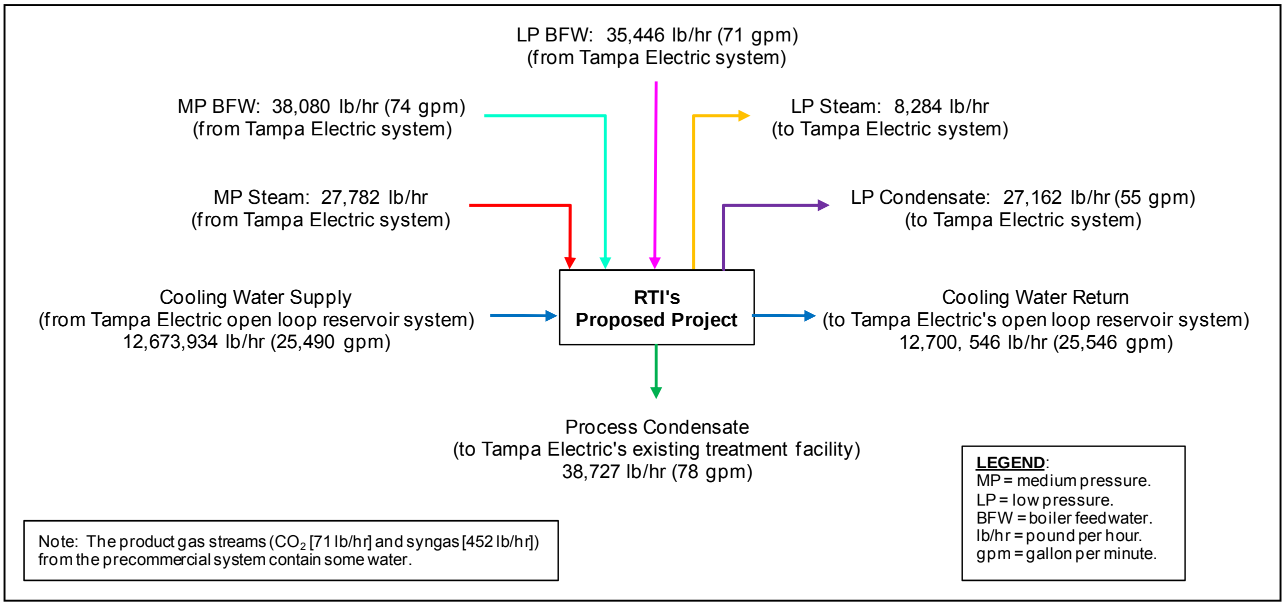


Figure 3-10. Water Balance for RTI's Proposed Project
Sources: RTI, 2011. ECT, 2011.

As shown in Figure 3-10, the largest water use for the proposed project would be process cooling water. The cooling water would be supplied by tying into the supply headers of Tampa Electric's existing open loop cooling reservoir system. The cooling water would be returned to the existing system. The existing circulating water flow rate for the cooling reservoir is approximately 250 MGD; therefore, the proposed project water use would increase the flow rate by approximately 15 percent. The cooling reservoir has sufficient existing capacity to supply the additional cooling water needs of the proposed project without the use of additional surface water or groundwater resources.

The primary source of wastewater from the proposed project would be process condensate generated in the low-temperature gas cooling unit and the CO_2 compression and drying system. This process condensate would be recycled within the proposed project systems to the extent possible. The remaining process condensate would be routed to Tampa Electric's existing wastewater treatment facilities and/or treated and routed to the existing cooling water system. Effluent from Tampa Electric's existing wastewater treatment facilities is discharged to the cooling reservoir. The potential impacts of the additional condensate wastewater discharge from the proposed project on the cooling reservoir or other surface waters would be minimal.

Groundwater

The UIC program in Florida is regulated jointly by FDEP using Chapter 62-528, F.A.C., and EPA Region 4 using 40 CFR 146. The primary regulatory purpose of the FDEP and EPA regulations is to protect the quality of Florida's underground sources of drinking water from inappropriate injection operations and to prevent degradation of the quality of other aquifers adjacent to the injection zone that may be used for other purposes. Currently there are six main regulatory categories for UIC wells, which include:

- Class I—wells used for disposal of municipal and industrial wastewater below the USDW.
- Class II—oil and gas injection wells.
- Class III—solution mining injection wells.
- Class IV—hazardous waste injection wells (banned in Florida).
- Class V—other types of injection wells, including experimental wells.
- Class VI—carbon capture and sequestration.

At present, and as it pertains to these different UIC well classifications, FDEP has primacy for Classes I, III, IV, and V, while EPA has primacy over Classes II, with involvement from the Florida Geological Survey. Presently, EPA has primacy over the new Class VI category for geological carbon sequestration wells, as the state of Florida has not decided whether it will pursue primacy over these wells at this time.

Both state and federal regulations applicable to UIC permitting include multiple provisions for safeguarding and preventing injected fluid movement into USDWs. The injection well for the proposed project is expected to be permitted as a Class V experimental technology well that would meet the more stringent Class I industrial injection well design standards. For most of the previous carbon capture and sequestration projects performed in the United States, the UIC wells were permitted under either Class I, II, V, or some combination of these regulatory criteria.

Injection wells used for carbon capture and sequestration pilot projects may be permitted as Class V experimental technology wells if their design and operation are experimental in nature, plus all applicable Safe Drinking Water Act and UIC permitting requirements are met. Once, or if, the experimental technology well is no longer considered experimental, the well would need to be permitted for the most applicable class of UIC wells, if it is expected to continue in operation. For the proposed project, Tampa Electric intends to permit injection well IW-2 as a Class V experimental technology well for CO_2 injection during the demonstration period. After that period, Tampa Electric plans to change the well to a Class I UIC well for the injection of wastewater.

A sudden unplanned or uncontrolled release of CO_2 vertically through the subsurface adjacent to the injection well up into the overlying aquifers would be considered unlikely. The reasons for this include the lateral continuity, substantial thickness, low vertical permeability of the confining (caprock) unit, plus the lack of other nearby well/borehole penetrations or fractures/faults through the confining unit. Relatively slow leakage from the well bores due to casing and/or cement problems would be detected ahead of time by mechanical integrity testing to be conducted as part of the monitoring typically required under the UIC permit. If a release were to occur, such an event would not be expected to reach or have a significant impact on the primary drinking water aquifers due to the presence of additional low permeability confining units within the 2,000- to 2,400-ft vertical distance.

Preliminary geochemical modeling analyses for the proposed project are being performed by Dr. Stewart from the University of South Florida, and those efforts will be more thoroughly described in supporting documentation provided for the UIC permit application. However, the preliminary geochemical modeling results, which account for CO_2 injection followed by subsequent wastewater injection at IW-2, indicate the CO_2 plume would react with and completely dissolve into the brine within the injection zone within a relatively short period of time (less than 5 years), long before the CO_2 plume would possibly be able to move horizontally and reach the Polk Power Station property boundaries (Stewart, 2011, verbal communication). This rapid dissolution and mineral trapping would also reduce the likelihood that CO_2 would exist long enough to migrate very far vertically as well.

However, should a slow release or small amount of CO_2 escape through the injection zone's confining unit, no adverse consequences would be expected. The CO_2 in the released solution would continue to react geochemically with the substantial thickness of carbonate materials during its upward migration between the confining unit and much shallower overlying aquifers. The CO_2 solution would most likely continue to geochemically react and dissolve via solubility and mineral trapping before reaching the overlying shallow aquifers more commonly used for potable purposes.

The injection well drilling and CO_2 injection process for the proposed project would not require substantial volumes of water. After drilling and setting the first well casing using mud rotary drilling methods, the drilling method used for the remainder of the borehole would be switched to reverse air, which requires little makeup water.

As shown in Figure 3-8, medium- and low-pressure boiler feedwater for the proposed project would be supplied from Tampa Electric's existing boiler feedwater treatment and supply system. Tampa Electric's existing process water is provided through groundwater withdrawals from the Floridan aquifer. The additional feedwater for the proposed project would potentially increase overall groundwater use by up to 145 gallons per minute or 208,800 gallons per day during the 18-month demonstration period. However, this relatively minor increase in groundwater use would not cause an increase in Tampa Electric's authorized water use of 5.2 MGD for the Polk Power Station. Therefore, potential impacts of this additional groundwater use for the proposed project would be minimal and short-term. The proposed project would not adversely impact groundwater resources of the area.

3.3.2.2 No-Action Alternative

Under the no-action alternative, DOE would not provide funding to RTI, and the proposed project would not proceed. Therefore, no impacts to surface water and groundwater would occur due to the project construction and operation. However, under the no-action alternative, Tampa Electric would proceed with its plans to drill and construct the deep injection well IW-2 and use the well for disposal of wastewater from the power plant operations.

3.4 SOCIOECONOMICS

The following subsections describe the existing socioeconomic conditions, including population, employment, income, housing, and public facilities and services in Polk County, Florida, and the potential impacts of the proposed project and no-action alternative.

3.4.1 AFFECTED ENVIRONMENT

3.4.1.1 Population

The Polk Power Station and proposed project site are located in an unincorporated area of Polk County in west-central Florida. Table 3-5 provides population trends for Polk County, select cities in Polk County, and the state of Florida. According to the 2010 Census data, the population of Polk County was 602,095 on April 1, 2010. The population in Polk County grew at a rate of slightly lower than the state in the 1990 to 2000 period and higher than the state in between 2000 and 2010. In 2010, Polk County was the 9th most populous of the 67 counties in Florida and ranked 19th in population density.

Table 3-5. Population Trends for Polk County, Select Cities, and Florida

Area	Population			Percent Change	
	1990	2000	2010	1990 to 2000	2000 to 2010
Polk County	405,382	483,924	602,095	19.4	24.4
Bartow	14,716	15,340	17,298	4.2	12.8
Lakeland	70,576	78,452	97,422	11.2	24.2
Florida (state)	12,938,071	15,982,824	18,801,310	23.5	17.6

Sources: Bureau of Economic and Business Research (BEBR), Florida Statistical Abstract, 2010.
U.S. Census Bureau, 2011.

3.4.1.2 Employment and Income

In 2009, Polk County had an estimated labor force of 272,831 persons, of which 254,530 were employed (Bureau of Economic and Business Research [BEBR], Florida Statistical Abstract, 2010). Unemployed persons in 2009 totaled 18,301, for an unemployment rate of 6.7 percent. The statewide unemployment rate in 2009 was estimated at 6.2 percent. Table 3-6 presents the five largest major industry groups in terms of employment in Polk County in 2009. The largest group was government (federal, state, and local), followed by health care, social assistance, and retail trade.

Table 3-6. Polk County Major Industry Groups

Industry	Number of Persons Employed	Percent of Total Persons Employed
Government (federal, state, and local)	29,177	15.2
Health care and social assistance	24,722	12.9
Retail trade	24,004	12.5
Administration and support	15,459	8.0
Manufacturing	14,780	7.7

Source: BEBR, Florida Statistical Abstract, 2010.

Per capita personal income in Polk County in 2008 was $32,572, and median household income was $44,350. Both of these figures were lower than the state of Florida average income figures or $39,064 and $47,802, respectively.

3.4.1.3 Housing

The 2010 U.S. Census data indicate that there were 281,214 total housing units in Polk County, of which 227,485 units or 80.9 percent were occupied. Of the occupied housing units, 160,442 units or 70.5 percent were owner-occupied and 67,043 units or 29.5 percent were renter-occupied. In 2010, the vacancy rates for homeowner units in Polk County was 4.3 percent and rental units was 15.7 percent, compared to the statewide average rates of 3.8 and 13.2 percent, respectively.

3.4.1.4 Public Facilities and Services

According to Polk County Public School District information, Polk County has 160 school sites and centers, including 66 elementary schools, 19 middle schools, and 17 high schools, plus charter and alternative schools, with a total enrollment of approximately 92,000 students in the fall of 2010. The nearest schools to the Polk Power Station site are located in the cities of Mulberry and Fort Meade.

The nearest fire station to the Polk Power Station site is located in Bradley Junction, approximately 4.4 miles to the north. This station is manned by two fulltime firefighters and eight to twelve volunteer firefighters and is equipped with a pumper truck, tanker truck, and rescue truck. Police services for the site area are provided by the Polk County Sheriff's Department. Sheriff's deputies patrolling the area are based out of the Southwest Regional Substation, located in south Lakeland. The Florida Highway Patrol also patrols the area. Access roads to the Polk Power Station are gated, and access is controlled by onsite security personnel.

The nearest hospitals to the Polk Power Station site are Bartow Memorial and Polk General, both located in Bartow approximately 13 miles northwest of the site. Both hospitals are equipped with emergency rooms. The emergency medical service that would respond to the Polk Power Station site is located at the Fort Meade Fire Station.

The Polk Power Station site is located in rural Polk County in an area that is not provided with public potable water supply or sanitary sewerage services. Water and sanitary services for the existing power plant are provided by onsite facilities operated by Tampa Electric.

3.4.2 ENVIRONMENTAL CONSEQUENCES

3.4.2.1 Proposed Project

The proposed project would have minor impacts on socioeconomic resources in the project area. The proposed project would not induce population growth or adversely impact housing in the Polk County area. During construction, the proposed project would create a monthly average of 107 jobs and a peak of 160 jobs on the site over the 13-month construction period and would involve various expenditures for materials, equipment, and services. During the 18-month operational period, the project would create 12 jobs. The creation of jobs and project-related expenditures would provide some short-term benefits to the local economy.

The proposed project would not adversely impact or create the need to expand public facilities and services, such as schools, police and fire protection services, and medical facilities. Any potential effects of the proposed project on socioeconomic resources would be short-term during the approximately 2.5-year period for construction and operation of the project.

3.4.2.2 No-Action Alternative

The no-action alternative would have no impacts on socioeconomic resources since the proposed project would not be constructed. However, under the no-action alternative, the short-term benefits to the local economy of project-related jobs and expenditures would also not occur.

3.5 TRANSPORTATION

3.5.1 AFFECTED ENVIRONMENT

Transportation facilities in the vicinity of the Polk Power Station site include roadways and a railroad. As shown in Figure 2-2, the eastern portion of the Polk Power Station site is bordered by SR 37 on the west, County Road (CR) 630 on the north, and CR 663 (Fort Green Road) on the east. SR 674/Wimauma Road is located just to the southwest of the eastern portion of the site. The main entrance road to the site is from SR 37, which runs southwest to northeast in the site area. This entrance has a manned security gate located approximately 250 ft from SR 37. SR 37 is a two-lane highway classified as a minor arterial that functions at an acceptable level of service (LOS) B from the Manatee County line to CR 640 based on 2009 traffic counts of 260 peak hour, peak direction trips (Polk Transportation Planning Organization, 2010). Polk County's minimum LOS standard for rural arterial and collector roads is LOS D.

SR 674 is also a two-lane highway classified as a rural major collector from the Hillsborough County line to SR 37 that operates at LOS B with 101 peak hour, peak direction trips in 2009. CR 630, which runs east from SR 37 on the northern site boundary, is a two-lane highway classified as a minor arterial that functions at LOS B with 154 peak hour, peak direction trips. CR 663 (Fort Green Road) is a two-lane highway classified as a minor collector running north-south along the eastern site boundary. There is a secondary access road to the Polk Power Station facilities from Fort Green Road. The roadways in the vicinity of the Polk Power Station site currently function at acceptable LOS.

The Polk Power Station site also has a rail spur from the CSX Railroad, an existing north-south rail line running along Fort Green Road on the east side of the site. The rail line has been used for delivery of some of the equipment during construction of the existing power plant units. Rail is not routinely used for the ongoing operations. Coal and petroleum coke fuels for Polk Unit 1 and other materials are delivered by truck. There are no private or public aviation facilities located within a 5-mile radius of the site. Further, the rural site area is not served by public transit services.

3.5.2 ENVIRONMENTAL CONSEQUENCES

3.5.2.1 Proposed Project

Some short term, minor transportation impacts may be expected due to the movement of construction workers and equipment and material deliveries to and from the Polk Power Station site during construction of the proposed project. These potential impacts would involve minor traffic congestion and delays in the immediate vicinity of the access road entrances to the site on SR 37 and Fort Green Road. These entrances are currently gated, and access to the site is controlled.

As part of the previous environmental licensing/permitting efforts for the Polk Power Station, detailed transportation analyses were conducted to assess impacts of construction- and operation-related traffic associated with development of the power plant facilities. For the original SCA (ECT, 1992), the analysis considered the trips generated by an average construction workforce of 400 workers and a peak of 600 workers. For the Polk Unit 6 SCA (ECT, 2007), the analysis considered a construction workforce average of 600 workers and peak of 1,700 workers. The results of both of these transportation analyses found that the roadway links and intersections within the traffic impact area would operate at acceptable LOS with the existing geometry of the facilities, and no improvements were needed. Also, during the initial development of the Polk Power Station, the roadway entrances were designed and constructed with appropriate geometric improvements, such as deceleration, acceleration, and turn lanes, based on Florida Department of Transportation (FDOT) standards, to accommodate the anticipated construction and operation traffic.

Since the construction workforce for RTI's proposed project of an average of 107 workers and peak of 160 workers would be significantly less than the workforces considered in the previous transportation analyses, the construction traffic for the project would not be expected to adversely impact the surrounding roadway network or cause the roads to function at unacceptable LOS.

Potential transportation impacts are not expected during the operational phase of the proposed project due to the small number of workers needed to operate the facilities (i.e., three workers per shift).

3.5.2.2 No-Action Alternative

Under the no-action alternative, no impacts to transportation would occur since the proposed project would not be constructed.

3.6 SOLID WASTE AND BYPRODUCT MANAGEMENT

3.6.1 AFFECTED ENVIRONMENT

Various nonhazardous solid wastes and byproducts are generated by the existing Polk Unit 1 IGCC operations on the Polk Power Station site. These wastes and byproducts include:

- Slag byproduct.
- Sulfuric acid byproduct.
- Used oils and oily wastes.
- Water treatment media.
- Worn gasifier refractory and brick.
- Miscellaneous solid wastes.

The slag and sulfuric acid byproducts are temporarily stored onsite and are sold by Tampa Electric for offsite commercial uses. In general, for the existing operations, the nonhazardous solid wastes are periodically collected, characterized, and transported offsite for appropriate recycling or disposal.

The Polk Power Station is currently classified as a large-quantity generator under applicable Resource Conservation and Recovery Act (RCRA) regulations outlined in 40 CFR 260 through 279. The materials with potentially hazardous properties that are generated by the existing Polk Unit 1 IGCC operations include:

- Spent sulfuric acid plant catalysts.
- Acid gas removal solvent and filters.
- Deactivated carbon filter media.
- Vent sorbents.
- Sulfuric acid byproduct.

These potentially hazardous wastes are managed by Tampa Electric in accordance with RCRA and state requirements. The current Polk Power Station Integrated Contingency Plan (ICP) addresses emergency procedures to be implemented in case of an accidental release of these wastes. These wastes are periodically collected, characterized, and transported offsite by a licensed hauler for appropriate disposal at RCRA-permitted facilities.

3.6.2 ENVIRONMENTAL CONSEQUENCES

3.6.2.1 Proposed Project

The proposed project would use and store various chemicals and materials and generate various waste products. These materials and wastes would be managed by RTI in accordance with the same procedures and programs used by Tampa Electric for the existing Polk Power Station operations. RTI has a large-quantity generator license for handling RCRA wastes. RTI would obtain a specific license to cover the Polk Power Station site and would arrange for an appropriately licensed hauler to transport any potentially hazardous wastes offsite for disposal at a RCRA-permitted facility.

In the HTDP unit, circulation of the sorbent would result in attrition and generation of fines, which would be separated from the treated syngas by filters. These sorbent fines would be periodically removed from the filters. The fines would be accumulated in a lock hopper system, which is sized for approximately 30 days or 17,000 pounds of fines. Toxicity characteristic leaching procedure (TCLP) testing of the fines generated from the pilot testing of RTI’s syngas cleanup technologies at the Eastman Chemical plant indicated that the fines were not considered hazardous. For the proposed project, the fines would be characterized by TCLP testing, collected in storage drums, and transported offsite for appropriate disposal.

Another waste generated during the proposed project operations would be the arsenic, selenium, and mercury sorbents from the TCRP unit. It is anticipated that these sorbents, which total approximately 34,000 pounds, would be changed out at least once during the 8,000 hours of operation. TCLP testing of these sorbents when used in syngas cleanup has not been performed; therefore, it is currently uncertain whether or not these sorbent wastes would be considered hazardous. For the proposed project, these sorbent wastes would be collected, characterized by TCLP testing, and transported offsite for appropriate disposal.

It is anticipated that the catalysts in the DSRP unit and water gas shift reactors would be used for the duration of the proposed project operations. If at the end of operations these systems are decommissioned, these catalysts would be characterized and appropriately handled and shipped offsite for disposal. Other used and unused solvents, such as aMDEA, would be either sold for reuse or characterized for offsite disposal at an appropriately permitted facility.

The proposed project is not expected to create adverse impacts due to the generation and handling of solid wastes, including potentially hazardous wastes. Wastes would be managed, controlled, stored, and disposed in accordance with applicable federal and state regulations. Persons responsible for the operations of the proposed project facilities would be properly trained and informed on the safety and emergency response procedures in the Polk Power Station ICP, similar to current Tampa Electric employees at the site. Further, potential impacts due to waste generation and management would be short-term over the 18-month operational period for the proposed project.

3.6.2.2 No-Action Alternative

Under the no-action alternative, no impacts due to the generation and management of wastes would occur since the proposed project would not be constructed nor operated.

3.7 HUMAN HEALTH AND SAFETY

3.7.1 AFFECTED ENVIRONMENT

Potential human health and safety impacts may result from air pollution releases, accidental spills or release of hazardous materials or toxic gases, and worker injuries due to accidents. Air pollution can cause human health problems. NAAQS were established to protect human health and welfare with a reasonable margin of safety. As discussed in Section 3.1, air quality in the area of the Polk Power Station is designated as attainment for NAAQS pollutants.

As discussed in Section 3.6, the Polk Power Station operations generate potentially hazardous wastes and materials. These wastes are controlled, managed, and disposed in accordance with applicable RCRA and state regulations to minimize potential spills and releases and protect human health and safety. Further, in case of an accidental release, workers at the Polk Power Station have been trained in the emergency response procedures contained in Tampa Electric's RCRA ICP for the Polk Power Station to minimize human health risks.

The acid gas removal process in the existing syngas cleanup system for the Polk Unit 1 IGCC facility produces a gas stream with a high concentration of H_2S. H_2S is a colorless, flammable gas with a characteristic foul odor of rotten eggs. Human exposure to lower concentrations of H_2S can result in eye irritation, sore throat, nausea, shortness of breath, and fluid in the lungs. At higher concentrations (i.e., 300 to 500 ppm), inhalation of H_2S can result in pulmonary edema with the possibility of death. To minimize the potential release of H_2S gas, Tampa Electric conducts routine inspections of the equipment and piping in the acid gas removal system for Polk Unit 1. Also, the facility is equipped with gas detectors set to sound alarms if H_2S is detected at very low concentrations.

Tampa Electric's worker safety program for the Polk Power Station includes training and adherence to applicable Occupational Safety and Health Administration (OSHA) procedures to minimize injuries due to accidents.

3.7.2 ENVIRONMENTAL CONSEQUENCES

3.7.2.1 Proposed Project

As discussed in Section 3.1.2.1, the potential air quality impacts caused by construction of the proposed project would be short-term and localized to the immediate onsite area of the construction activity. During operations, the proposed project would have minor, intermittent air emissions and would not contribute to exceedance of NAAQS. Therefore, the construction and operation of the proposed project would have negligible impacts to human health and safety due to air pollution.

Similar to the existing Polk Power Station operations, potentially hazardous wastes generated by the proposed project operations would be controlled, managed, and disposed in accordance with applicable RCRA and state regulations to minimize potential releases and human health risks. Also, similar to the existing operations, applicable OSHA procedures would be followed to minimize the potential for worker injuries due to potential accidents.

Similar to the existing Polk Power Station operations, the high H_2S gas stream from the HTDP for the proposed project would be oxidized to produce elemental sulfur and sulfuric acid and would not be vented to the atmosphere. Again, similar to the existing operations, to minimize the potential impacts from an accidental release of H_2S gas, the facilities and piping would be routinely inspected and equipped with detectors set to sound alarms if H_2S is detected at low concentrations. Based on these safety procedures, coupled with the significant distance between the proposed project site and nearest residences, odor is not expected to be a problem to surrounding residences or the community.

For the proposed project, potential concerns to human health and safety related to the CO_2 capture and sequestration aspects of the project could result from CO_2 leaks to the air and CO_2 migration to underground aquifers used for drinking water. CO_2 is heavier than ambient air, colorless, and odorless, which makes it an invisible hazard (DOE, 2007). CO_2 is normally present in the atmosphere at a concentration of approximately 0.03 percent. However, if humans are exposed to high concentrations of CO_2 for extended periods of time, health risks, such as suffocation and permanent brain injury from lack of air, can occur (DOE, 2007). Headache, impaired vision, labored breathing, and mental confusion can also occur from CO_2 exposure. Generally, the pooling and large, rapid releases of CO_2 are the situations of concern for human health and safety, instead of small gradual leaks (DOE, 2007). No general CO_2 exposure standards currently exist for the general public (DOE, 2007).

However, OSHA and the National Institute for Occupational Safety and Health (NIOSH) have established CO_2 exposure limits to protect workers against health effects due to exposure to high concentrations of CO_2. OSHA has set the permissible exposure limit for CO_2 of 5,000 ppm or 9,000 milligrams per cubic meter based on an 8-hour time-weighted exposure (Centers for Disease Control and Prevention [CDC], 2011). OSHA permissible exposure limits are regulatory limits on the amount or concentrations of a substance in the air to prevent adverse human health effects. NIOSH has established immediately dangerous to life or health (IDLH) values that the exposure to airborne contaminants is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment (CDC, 2011). The NIOSH IDLH value for CO_2 is 40,000 ppm based on a 30-minute exposure. Extended exposure to such high concentrations of CO_2 would normally only occur due to a large, rapid release of CO_2 or if a release were contained within an enclosure. For the proposed project, the presence of these conditions would be considered unlikely. Based on the proposed project design, any release of CO_2 would occur to the ambient atmosphere and would be expected to quickly dissipate.

After injection underground, CO_2 migration in high concentrations can cause human health issues in aquifers used for drinking water. If CO_2 migrates to drinking water aquifers in high concentrations, the groundwater can become contaminated, because CO_2 can cause the mobilization of elements in the soil, such as metals, into the aquifers. Similar to air leaks of CO_2, gradual releases of CO_2 into underground drinking water sources typically do not cause substantial harm to human health due to contamination, but rapid releases could (DOE, 2007).

For the proposed project, the equipment, vessels, and piping systems for the CO_2 capture and compression processes, as well as the injection wellhead, well casing, and grouting/packing systems, would be designed and constructed to minimize the risks for potential CO_2 leaks. The proposed project's MVA program would be designed and implemented in accordance with applicable UIC permitting requirements to avoid, detect, and correct unintended CO_2 leaks to minimize risks to human health. The program would include regular equipment and pipeline inspections and monitoring detectors to reduce the risks of failures leading to CO_2 releases. All operational personnel would also be trained in emergency procedures in case of an accidental CO_2 release to minimize human health and safety risks.

The injection well would be designed, drilled, and constructed to make migration of CO_2 to drinking water aquifers highly unlikely. Based on available geologic formation sources and site-specific information collected during the drilling of IW-1 at the Polk Power Station site, the targeted CO_2 injection zone is vertically isolated from the closest drinking water aquifer by a more than 1,300-ft-thick, low-permeability confining unit. The proposed IW-2 well design would include four casings, one fluid-filled annulus, and approximately 9 inches of CO_2-resistant cement to horizontally isolate the injected CO_2 from the underground source of drinking water. Therefore, potential human health risks due to CO_2 migration in high concentrations are expected to be minimal. These risks would be further mitigated by the short-term operational period for the proposed project and the MVA program, which includes monitoring of groundwater quality. The final operational and MVA requirements would be detailed in the approved UIC permit.

3.7.2.2 No-Action Alternative

Under the no-action alternative, no risks to human health or safety would occur due to construction or operation of the proposed project, including no risks due to CO_2 capture and sequestration.

3.8 RELATIONSHIP BETWEEN SHORT-TERM USES OF THE ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

The CEQ regulations that implement the procedural requirements of NEPA require consideration of the relationship between short-term uses of man's environment and the maintenance and enhancement of long-term productivity (40 CFR 1502.16). Construction and operation of the proposed project would require short-term uses of land, energy, water, and other resources. In the context of the CEQ regulations, short-term uses of the environment involve those uses during the life of the proposed project, whereas long-term productivity refers to the period of time after which the project has ceased operations and the equipment has been decommissioned and removed. Under the funding agreement with DOE, the proposed project would be operated for approximately 18 months, ending by the third quarter of 2015. Currently, it is uncertain whether the proposed project facilities would cease operations and be decommissioned or would continue to be operated by Tampa Electric without further DOE funding. In either case, at some time in the future when the project facilities have reached their useful life, the equipment could be removed, and the site land could be restored to its predisturbance condition or used for other purposes for the Polk Power Station operations. As discussed in Section 1.4, the deep injection well IW-2 would be used by Tampa Electric to dispose of wastewater for its existing power plant operations after the CO_2 capture and sequestration aspects of the proposed project have been completed. Therefore, the short-term use of the land and other resources for the proposed project would not impact the long-term productivity of the area.

3.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Construction of the proposed project facilities would cause the irreversible and irretrievable commitment of materials, such as concrete and steel, and fuels. During operation, the project would cause the irretrievable commitment of electrical energy, fuels, water, and certain chemicals and solvents. When the project facilities are decommissioned, some of the materials, equipment, and chemicals would be recycled, to the extent practicable.

3.10 UNAVOIDABLE ADVERSE IMPACTS

Construction and operation of the proposed project would cause small unavoidable impacts due to emissions of some air pollutants. These small air impacts would be short-term, localized, and would not adversely impact ambient air quality in the general region. The project would also cause short-term traffic congestion impacts due to construction workers accessing the site. These unavoidable impacts are not expected to be significant.

4.0 CUMULATIVE IMPACTS

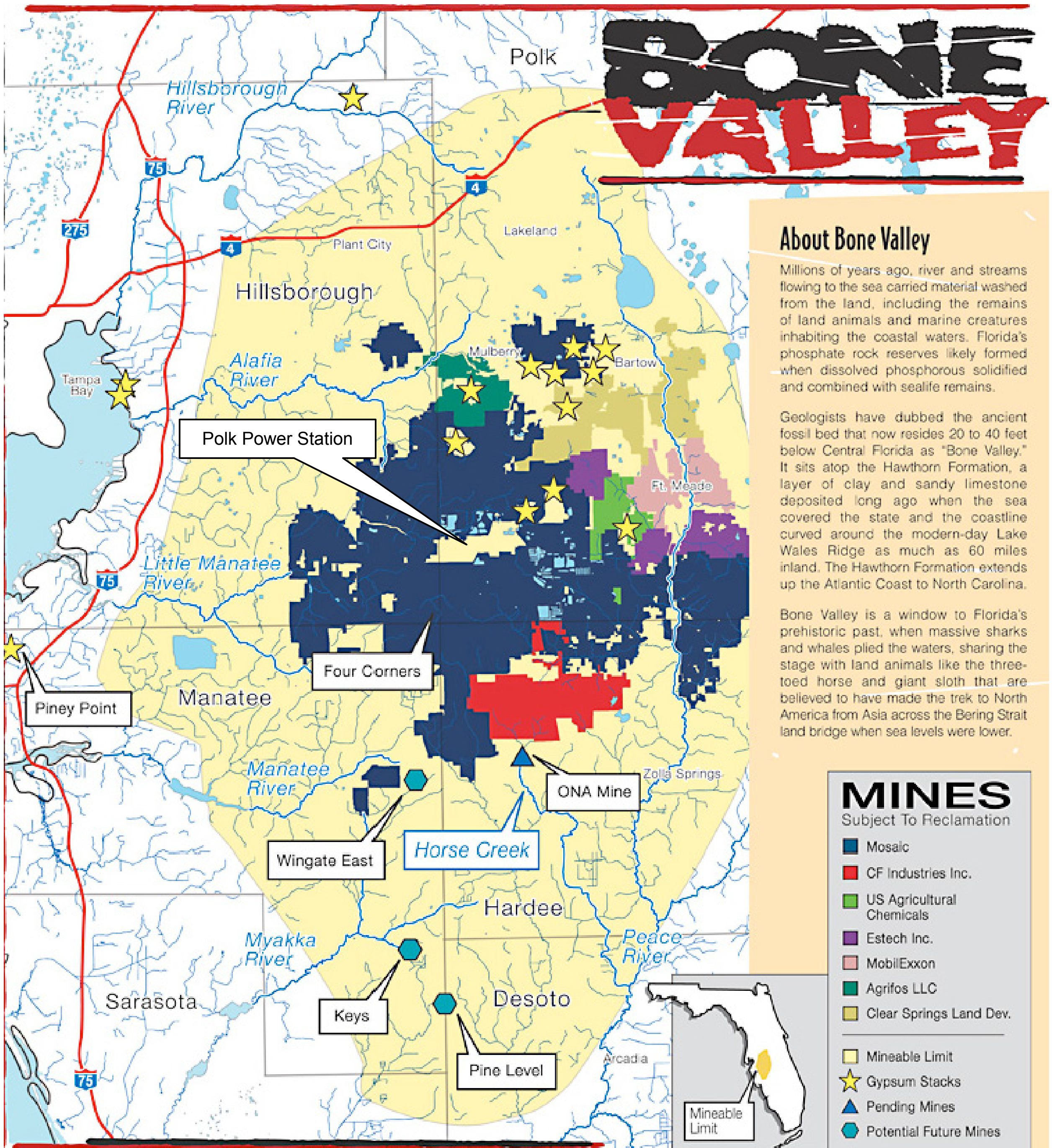
CEQ NEPA implementing regulations require an analysis of the cumulative impacts that could result from the incremental impact of a proposed project when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such actions (40 CFR 1508.7). The purpose of this analysis is to determine if, even though the impacts from a proposed project may be minor and localized, combining those impacts with the effects of other projects could result in significant impacts. This chapter describes the past, present, and reasonably foreseeable actions or activities at the Polk Power Station site and the cumulative impacts of the proposed project in combination with these other activities.

4.1 PAST, PRESENT, AND REASONABLY FORESEEABLE ACTIONS

Conditions resulting from past activities on and in the vicinity of the Polk Power Station site are included in the descriptions of the affected environment in Chapter 3.0 of this EA. The Polk Power Station site is located within an area known as the Bone Valley Central Florida Phosphate District (see Figure 4-1). A significant portion of the rural lands within this district has been mined to recover phosphate or disturbed by mining-related activities, which began in the late 1800s and continue today. Some of the lands comprising the Polk Power Station site were mined prior to 1940, and mining activities continued on the western portion of the site until 1994. The specific area of the site containing the existing power plant and where RTI's proposed project would be located was not mined but was disturbed by adjacent mining activities. Tampa Electric began construction of the Polk Power Station in November 1994, and the Polk Unit 1 260-MW IGCC plant began commercial operation in 1996. In conjunction with development of the power plant facilities, Tampa Electric also was required to reclaim some of the lands (i.e., lands mined after July 1, 1975) in accordance with state and county requirements.

Since Polk Unit 1 was constructed, Tampa Electric expanded the electric generating capacity at the Polk Power Station by adding four simple-cycle combustion turbine generating units. Polk Units 2 and 3 started commercial operation in July 2000 and May 2002, respectively. Unit 4 was placed into service in March 2007 and Unit 5 in May 2007.

Cumulative impacts on air quality could result from the combination of air emissions from the existing Polk generating units with emissions from the proposed project. As part of the environmental permitting efforts for the existing units, dispersion modeling was conducted to demonstrate that the emissions would not adversely impact ambient air quality or exceed NAAQS. The existing units are also subject to



The above map includes lands mined for phosphate since 1975, subject to mandatory reclamation. Reclamation of lands mined prior to 1975 (not included here) is voluntary. Although several companies are referenced in the legend, only three phosphate mining companies remain in Florida: Mosaic, CF Industries, and PCS Phosphates, located in northern Hamilton County. Only a few potential future mines are identified. In almost all cases, wherever a gypsum stack is noted, there is a fertilizer processing plant.

Figure 4-1. Bone Valley Central Florida Phosphate District

Source: www.baysoundings.com, 2005.

emissions monitoring, testing, and reporting requirements to ensure the units are operating within permitted emissions limits.

In the reasonably foreseeable future, it is anticipated that Tampa Electric could construct additional electric generating units at the Polk Power Station site. The site offers sufficient available land area, and the configuration of the existing facilities would allow for development of additional units. According to Tampa Electric's 10-year Site Plan for Electrical Generating Facilities and Associated Transmission Lines, January 2011 – December 2020 (Tampa Electric, 2011), the company forecasts that approximately 480 MW of additional combustion turbine peaking generation capacity will be needed in the 2013 to 2018 timeframe to meet its customers' electric needs. Some of these combustion turbine units could be located at the Polk Power Station. Beyond 2018, Tampa Electric's forecasts indicate that additional intermediate generation capacity will be needed and that capacity could be provided by converting Polk Units 2 through 5 to combined-cycle units. The addition of any of these future generating units at the Polk Power Station would result in additional air emissions. As part of the permitting requirements for the units, dispersion modeling analyses would be required to demonstrate that the additional air emissions would not adversely impact air quality. Also, in the foreseeable future, upon completion of the project and if the demonstration results were favorable, Tampa Electric may consider the option of continuing the operation of all or some portion of the syngas cleanup system.

As discussed in Section 1.4, prior to agreeing to provide the host site for RTI's proposed project, Tampa Electric initiated efforts and is presently proceeding with efforts to permit, drill, and construct two deep injection wells at the Polk Power Station site. Tampa Electric plans to use these wells for the disposal of wastewaters from its existing power plant operations. These efforts are part of Tampa Electric's overall plan to use reclaimed water from the city of Lakeland for cooling reservoir makeup water to reduce groundwater use. The injected wastewater would primarily consist of reverse osmosis brine effluent resulting from the treatment of the reclaimed water prior to use as makeup water. Use of reclaimed water would also allow Tampa Electric to permit and construct additional generation capacity at the site since any additional groundwater use may not be allowed by SWFWMD.

For the proposed project, DOE would provide partial funding for the drilling and construction of one of the planned deep injection wells (i.e., IW-2), which would initially be used to inject and sequester CO_2 during the demonstration period. Upon completion of the proposed project, Tampa Electric plans to use the IW-2 well for injection of wastewater. Tampa Electric's future use of the injection well is considered a future action that could result in cumulative effects on geologic and groundwater aquifer resources even after completion of the proposed project.

4.2 GREENHOUSE GAS AND GLOBAL WARMING

According to the International Panel on Climate Change (IPCC) (2007a), a worldwide environmental issue is the likelihood of changes in the global climate as a consequence of global warming produced by increasing atmospheric concentrations of GHGs. The atmosphere allows a large percentage of incoming solar radiation to pass through to the earth's surface, where it is converted to heat energy (infrared radiation) that is more readily absorbed by GHGs such as CO_2 and water vapor than incoming solar radiation. The heat energy absorbed near the earth's surface increases the temperature of the air, soil, and water.

GHGs include water vapor, CO_2, methane, nitrous oxide, ozone, and several chlorofluorocarbons. The GHGs constitute a small percentage of the earth's atmosphere. Water vapor, a natural component of the atmosphere, is the most abundant GHG. The second-most abundant GHG is CO_2, which remains in the atmosphere for long periods of time. Due to man's activities, atmospheric CO_2 concentrations have increased approximately 35 percent over preindustrial levels. Fossil fuel burning is the primary contributor to increasing concentrations of CO_2 (IPCC, 2007a).

According to the IPCC fourth assessment report, "[w]arming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC, 2007b). The IPCC report finds that the global average surface temperature has increased by approximately 0.74 degrees Celsius (°C) in the last 100 years; global average sea level has risen approximately 150 millimeters over the same period; and cold days, cold nights, and frosts over most land areas have become less frequent during the past 50 years. The report concludes that most of the temperature increase since the middle of the twentieth century "is very likely due to the observed increase in anthropogenic [GHG] concentrations."

The IPCC 2007 report estimates that, at present, CO_2 accounts for approximately 77 percent of the climate change potential attributable to anthropogenic releases of GHGs, with the vast majority (74 percent) of this CO_2 coming from the combustion of fossil fuels.

IPCC and the U.S. Climate Change Science Program (CCSP) examined the potential environmental impacts of climate change at global, national, and regional scales. IPCC's report states that, in addition to increases in global surface temperatures, the impacts of climate change on the global environment may include:

- More frequent heat waves, droughts, and fires.
- Rising sea levels and coastal flooding; melting glaciers, ice caps, and polar ice sheets.
- More severe hurricane activity and increases in frequency and intensity of severe precipitation.
- Spread of infectious diseases to new regions.
- Loss of wildlife habitats.
- Heart and respiratory ailments from higher concentrations of ground-level ozone (IPCC, 2007b).

On a national scale, average surface temperatures in the United States have increased, with the last decade being the warmest in more than a century of direct observations (CCSP, 2008). Impacts on the environment attributed to climate change that have been observed in North America include:

- Extended periods of high fire risk and large increases in burned area.
- Increased intensity, duration, and frequency of heat waves.
- Decreased snow pack, increased winter and early spring flooding potentials, and reduced summer stream flows in the western mountains.
- Increased stress on biological communities and habitat in coastal areas (IPCC, 2007b).

In the southeast region of the United States where the proposed project would be located, the average temperatures have declined from 1901 to 1970; then temperatures increased strongly since 1970. Over the last century, Florida has experienced decreased precipitation overall, and in all seasons except winter. In the area where the proposed project would be located, precipitation has increased approximately 10 to 15 percent in the winter months. During the next century, Florida's climate may change even more; however, IPCC predicts that the largest increases in future temperatures are likely to occur in the northern latitudes (IPCC, 2007b).

Because climate change is a cumulative phenomenon produced by releases of GHGs from industry, agriculture, and land use changes around the world, it is generally accepted that any successful strategy to address it must rest on a global approach to controlling these emissions. In other words, imposing controls on one industry or in one country is unlikely to be an effective strategy. And because GHGs remain in the atmosphere for a long time and industrial societies will continue to use fossil fuels for at least 25 to 50 years, climate change cannot be avoided. As IPCC report states, "[s]ocieties can respond to climate change by adapting to its impacts and by reducing [GHG] emissions (mitigation), thereby reducing the rate and magnitude of change" (IPCC, 2007b).

According to the IPCC, there is a wide array of adaptation options. While adaptation will be an important aspect of reducing societies' vulnerability to the impacts of climate change over the next two to three decades, "adaptation alone is not expected to cope with all the projected effects of climate change, especially not over the long term as most impacts increase in magnitude" (IPCC, 2007). Therefore, it will also be necessary to mitigate climate change by stabilizing the concentrations of GHGs in the atmosphere. Because these gases remain in the atmosphere for long periods of time, stabilizing their atmospheric concentrations will require societies to reduce their annual emissions. The stabilization concentration of a particular GHG is determined by the date that annual emissions of the gas start to decrease, the rate of decrease, and the persistence of the gas in the atmosphere. The IPCC report predicts the magnitude of climate change impacts for a range of scenarios based on different stabilization levels of GHGs. "Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk" (IPCC, 2007b).

On February 18, 2010, the CEQ issued "Draft National Environmental Policy Act of 1969 (NEPA) Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions" (CEQ, 2010). The draft guidance discusses when and how federal agencies should consider GHG emissions and climate change in their proposed actions. Specifically, the guidance indicates that, as an indicator threshold, if a proposed action would cause emissions of 25,000 metric tons or more of CO_2-equivalent GHG emissions on an annual basis, the agency should conduct a quantitative and qualitative assessment of GHG emissions and climate change.

During the demonstration period, the proposed project would capture and sequester up to 300,000 tons of carbon dioxide (CO_2), which would otherwise have been released to the atmosphere. Therefore, the proposed project is expected to result in a net reduction of GHG emissions, and DOE believes the EA is consistent with the CEQ guidance.

4.3 CUMULATIVE IMPACT SUMMARY

The specific land area where the proposed project facilities would be located was previously disturbed by phosphate mining-related activities, as well as the construction activities for the existing power plant facilities. The proposed project facilities would be relatively similar to the existing facilities on the Polk Power Station site and integrated with the existing operations. Therefore, the cumulative impacts of the proposed project on the local land use would be negligible.

As discussed in Subsection 3.1.2, the proposed project would have four air emissions sources. Three of these sources would operate intermittently over the 18-month demonstration period. Only the propane-fired DSRP tailgas recycle heater emissions source would operate continuously. Based on the temporary, intermittent, and minor level of emissions from the proposed project operations, the cumulative impacts on local air quality in combination with the existing power plant emissions sources would be minimal. Further, if Tampa Electric places any future generating units in service during the demonstration period, the cumulative impacts on air quality due to the proposed project would be minimal due to the minor level of emissions from the project.

During the 18-month demonstration period, the proposed project would reduce GHG emissions by capturing and sequestering approximately 300,000 tpy of CO_2, which would otherwise have been released to the atmosphere.

Following the completion of the CO_2 sequestration aspects of the proposed project, Tampa Electric intends to terminate CO_2 injection, remove the CO_2 tubing and packer system from IW-2, and initiate wastewater injection using the same well. This subsequent wastewater injection in IW-2 as well as in IW-1 is anticipated to continue for the duration of the power plant operations, or at least as long as the plant continues to receive and reuse reclaimed water as part of its water supply. As discussed in Subsection 2.2.5.2, FDEP has approved a Class V exploratory boring UIC permit for IW-2 for the injection of wastewater. Tampa Electric intends to submit a Class V experimental technology UIC well permit application in late June 2011 for the injection of CO_2 for the proposed project. Upon completion of the proposed project, Tampa Electric plans to obtain and operate IW-2 under a subsequent Class I industrial UIC permit for wastewater injection.

Preliminary geochemical modeling results indicate that even after 50 years of subsequent wastewater injection (at rates up to 1.7 MGD), the combined CO_2 and wastewater plumes are unlikely to migrate much more than approximately 1.5 miles away from the point of injection at the injection wells (Stewart, 2011). Also, the preliminary geochemical modeling results, which account for the initial CO_2 injection followed by subsequent wastewater injection in IW-2, indicate the CO_2 plume would react with and completely dissolve in the brine wastewater within the geological injection zone within a relatively short period of time (i.e., less than 5 years). This dissolution would occur before the CO_2 plume would be able to move horizontally and reach the Polk Power Station property boundaries or migrate vertically to reach a drinking water aquifer.

Although neither the CO_2 nor the wastewater plumes are predicted to migrate a long distance offsite, the resulting pressure front caused by injection of these two materials may extend some distance away from the site, with the greatest pressures occurring onsite at the injection wells and dissipating with distance away from the point of injection. However, these pressures are not expected to cause the migration of brine wastewater into overlying aquifers due to the substantial thickness and low vertical permeability of the primary overlying confining unit. Furthermore, the confining unit is known to be laterally continuous, and its closest penetrations from other deep drilling activities are located at least 10 miles or farther away from the project site (Chen, 1965). Therefore, the cumulative impacts of Tampa Electric's use of IW-2 for wastewater disposal after the well would be used for CO_2 injection are expected to be minimal.

5.0 CONCLUSIONS

DOE's Proposed Action would provide $171.8 million in cost-shared funding to RTI for the construction and demonstration of the precommercial scale-up of its high-temperature syngas cleanup and CO_2 capture and sequestration technologies. RTI's proposed project would be located on approximately 2.4 acres of previously disturbed land at Tampa Electric's existing Polk Power Station electric generating facilities in Polk County, Florida. RTI's proposed project would treat a slipstream, equivalent to approximately 66 MW of electricity, of syngas from the Polk Unit 1 IGCC plant to remove 99.9 percent of the sulfur, reduce trace contaminant concentrations, and convert SO_2 to elemental sulfur. Also, up to 90 percent of the CO_2 in the cleaned syngas would be captured and sequestered in a deep geologic formation.

DOE prepared this EA to comply with the requirements and procedures of NEPA. This EA provides evaluations of the potential environmental impacts of DOE's Proposed Action of providing funding to RTI, RTI's proposed project, and the no-action alternative. The impact evaluations considered environmental resource areas typically included in NEPA documents. Some of the resource areas were not carried forward for detailed analysis, because DOE determined the proposed project would not impacts these resources, or the potential impacts would be negligible. The following discussion provides DOE's conclusions regarding the potential impacts of RTI's proposed project.

During preparation of this EA, DOE consulted with the Florida SHPO, the Seminole Tribe of Florida, and the Seminole Nation of Oklahoma regarding potential impacts of the proposed project on historic and tribal resources or properties. Based on initial evaluations, DOE determined that no resources or properties would be affected by the proposed project. The Florida SHPO and the Seminole Tribe of Florida THPO concurred with DOE's determination.

Construction of the proposed project would result in fugitive dust air emissions from site preparation activities and the release of NO_x, CO, and other fuel combustion emissions from equipment and vehicles. Operation of the proposed project would also result in the release of PM and other minor air emissions. Due to the temporary, intermittent, and minor level of emissions associated with the construction and operation of the proposed project, potential impacts on air quality would be minimal and not contribute to exceedances of NAAQS. During the 18-month demonstration period, the proposed project would reduce GHG emissions by sequestering 300,000 tpy of CO_2, which would otherwise have been released to the atmosphere.

During construction and operation of the proposed project, appropriate stormwater management and erosion control measures would be implemented to minimize or avoid potential impacts to surface water resources. Also, the proposed project would use minor amounts of additional water resources and discharge minimal amounts of wastewater. Water would be provided from the existing Polk Power Station water supply system, and discharged wastewater would be returned to the existing wastewater treatment system; therefore, potential impacts on water resources would be minimal.

The proposed injection of CO_2 into the deep geologic formation at the Polk Power Station site would not adversely impact underground sources of drinking water due to the presence of a low permeability, laterally continuous confining unit that exceeds 1,300 ft in thickness and the proposed design of the injection well with multiple casings and cement packings through and below the drinking water aquifer. Further, should a slow release of CO_2 occur, preliminary geochemical modeling analyses indicate the CO_2 solution would geochemically react with carbonate materials within the target injection zone and be dissolved via solubility and mineral trapping before vertically migrating into drinking water aquifers. A comprehensive MVA program would be implemented to assure the safe operation of the proposed CO_2 capture and sequestration activities. The well used for CO_2 injection would be covered by a Class V experimental technology UIC permit. Tampa Electric submitted the permit application in August 2011. FDEP has reviewed and concurred with this permitting approach.

The proposed project would have minimal impacts on socioeconomic resources in the project area. Construction of the proposed project would have short-term benefits to the local economy due to the creation of jobs and project-related expenditures for materials, equipment, and services. Also, construction of the proposed project would have short-term, minor impacts to traffic congestion due to the movement of workers and equipment to and from the Polk Power Station site. However, these potential traffic impacts would not cause surrounding roads to function at unacceptable LOS.

The proposed project would generate moderate quantities of solid waste, some of which may be potentially hazardous. These wastes would be managed, controlled, and disposed in accordance with applicable federal and state regulations and would not be expected to cause adverse impacts. Also, the proposed project would have minimal impacts to human health and safety. Applicable OSHA procedures would be followed to minimize the potential for worker injuries due to accidents.

Under the no-action alternative, DOE would not provide funding to RTI, and it is assumed the proposed project would not be constructed. Therefore, no impacts would occur to environmental resources, and no short-term benefits to the local economy would occur.

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APPENDIX A
DISTRIBUTION LIST

This appendix contains the list of persons and agencies who received a copy of this environmental assessment.

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APPENDIX B
CONSULTATIONS

This appendix contains the consultation correspondence between DOE and the Florida State Historic Preservation Office, Seminole Tribe of Florida, and Seminole Nation of Oklahoma.

Note: The figure attachments to the letters sent to the tribal contacts are identical and are not duplicated for all of the letters.

APPENDIX C
PUBLIC COMMENTS AND RESPONSES

This appendix contains comments received on the Draft EA from the Florida State Historic Preservation Office and the U.S. Environmental Protection Agency (EPA), Region 4, and the summary of DOE's responses to the EPA comments.

SHPO Comment Letter

FLORIDA DEPARTMENT OF STATE
Kurt S. Browning
Secretary of State
DIVISION OF HISTORICAL RESOURCES

August 15, 2011

Mr. Mark Lusk
U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880, MS B07
Morgantown, West Virginia 26507-0880

Re: SHPO #: 2011-3324/ Received by SHPO: August 1, 2011
U.S. Department of Energy: NEPA
RTI International Scale-Up of High-Temperature Synthesis Gas Cleanup and Carbon Capture and Sequestration Technologies
Project located at Tampa Electric Company's Existing Integrated Gasification Combined-Cycle (IGCC) Power Plant at Polk Power Station in Polk County

Dear Mr. Lusk:

This office reviewed the referenced project for possible impact to historic properties listed, or eligible for listing, in the *National Register of Historic Places*. The review was conducted in accordance with Section 106 of the *National Historic Preservation Act of 1966*, as amended in 1992, *36 CFR Part 800: Protection of Historic Properties*.

Due to the nature of the above referenced undertaking no historic properties will be affected.

If there are any questions concerning our comments or recommendations, please contact Katherine Peterson, Historic Preservationist, by phone at 850.245.6333, or by electronic mail at kdpeterson@dos.state.fl.us.

Sincerely,

Laura A. Kammerer

Laura A. Kammerer
Deputy State Historic Preservation Officer
For Review and Compliance

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EPA Comment Letter

We appreciate your coordination with us, and are transmitting the results of our expedited review. Due to time constraints, the review focused on comments from our media programs with technical reviewers available during the comment period.

August 19, 2011

SUBJ: EPA Comments on Draft Environmental Assessment (EA) for
RTI International Scale-up of High-temperature Syngas Cleanup
and Carbon Capture and Sequestration Technologies
Polk County, Florida

The U.S. Environmental Protection Agency (EPA) reviewed the referenced Environmental Assessment (EA) in accordance with Section 309 of the Clean Air Act and Section 102(2)(C) of the National Environmental Policy Act (NEPA).

The DOE proposes to provide cost-shared funding for RTI International's (RTI) project to treat coal-derived synthesis gas (syngas) from the existing Tampa Electric Company's Polk Unit 1 at the existing Polk Power Station, and to capture and sequester carbon dioxide (CO_2) via injection into a deep well. The EA describes DOE's Proposed Action, RTI's proposed project, and the no-action alternative. DOE would provide partial funding, authorized pursuant to the American Recovery and Reinvestment Act of 2009, for the drilling, construction, and modification of a deep well (IW-2) to be temporarily used to inject and sequester CO_2.

Up to 90 percent of the CO_2 in the cleaned syngas would be captured and sequestered via a deep injection well in a saline geologic formation beneath the Polk Power Station site. The proposed project would demonstrate the technologies for a period of 18 months, with the goal of advancing cost-effective technologies focusing on clean energy production and the use of U.S. domestic fossil energy resources.

Based on the information provided in the EA, we support the project and believe the proposed facility and its operation do not appear to represent a significant impact to human health and the environment. However, appropriate worker protection measures and adherence to OSHA standards will be important measures during construction and operation of the facility, as the most likely receptors of any adverse impacts to public health would be experienced by on-site employees. Based on our review of the EA, we offer the following comments for your consideration as this project proceeds:

Climate Change

On February 18, 2010, the Council on Environmental Quality (CEQ) proposed four steps to modernize and reinvigorate NEPA. In particular, CEQ issued draft guidance for public comment on, among other issues, when and how Federal agencies must consider greenhouse gas (GHG) emissions and climate change in their proposed action

For example, equipment and vehicles that use conventional petroleum (e.g., diesel) should incorporate clean diesel technologies and fuels to reduce emissions of GHGs and other pollutants, and should adhere to anti-idling policies to the extent possible. Alternate fuel vehicles (e.g., natural gas, electric) are also possibilities. We recommend that the project team identify activities to reduce mobile source emissions. These reduction strategies can be incorporated into construction bid specifications and contracts.

Community Impacts

The EA does not address how neighboring communities (i.e., businesses and residences) may be affected by the proposed action's operation. It does state (p. 2-4) that *"Several areas with low-density, scattered residential uses are located more than 1.7 miles west of the project site. These areas are located north of the western portion of the site along Bethlehem and Albritton Roads and west of the site along SR 674 in Hillsborough County. The only other areas of residential development in the site vicinity are located in the unincorporated community of Bradley Junction, approximately 4 miles north of the site."*

It is unclear whether noise or odor will be a problem for surrounding residences, businesses, etc. The document (p. 3-33) states: *"The acid gas removal process in the existing syngas cleanup system for the Polk Unit 1 IGCC facility produces a gas stream with a high concentration of H_2S. H_2S is a colorless, flammable gas with a characteristic foul odor of rotten eggs."*

We note that hydrogen sulfide has a variable odor threshold, and that at high concentrations (150 ppm) H_2S can paralyze the olfactory nerve. Therefore, odor may not be a reliable indicator of the presence of this gas. Also, it is unclear whether the odor (if present at a level where it may be smelled) will be sufficiently controlled (i.e., mitigated) to avoid impacting the surrounding community.

Sinkhole Potential

The process to clean the coal-derived syngas involves the use of CO_2 in a supercritical fluid form. i.e., where the temperature and pressure are raised to the critical point where CO_2 as a gas exists in a fluid state where CO_2 becomes a "supersolvent." More over for deep well disposal, CO_2 is generally injected in a supercritical phase at pressures above 6.9 MPa (1,000 psig) to minimize the injected volume. Consequently, injection formations must be deeper than approximately 1,000 m to ensure that CO_2 will remain in a supercritical state. In its supercritical state, CO_2 represents the potential to dissolve, weaken, or transform the minerals contained in the formation it is injected into.

Because South Florida region, including Polk County, is known for its sinkhole formations, please reference the Polk County sinkhole map: http://fcit.usf.edu/florida/maps/pages/11100/f11153/f11153.htm.

The EA does not discuss the potential for facilitating sinkhole formation, nor the potential cumulative effect of this proposed action with that of droughts in sinkhole formation.

(see: http://www.whitehouse.gov/sites/default/files/microsites/ceq/20100218-nepa-consideration-effects-ghg-draft-guidance.pdf).

The draft guidance explains how Federal agencies should analyze the environmental impacts of greenhouse gas emissions and climate change when they describe the environmental impacts of a proposed action under NEPA. It provides practical tools for agency reporting, including a presumptive threshold of 25,000 metric tons of carbon dioxide equivalent ($C0_2e$) emissions from the proposed action to trigger a quantitative analysis, and instructs Federal agencies how to assess the effects of climate change on the proposed action and their design. The draft guidance does not apply to land and resource management actions and does not propose to regulate greenhouse gases.

While this guidance is not yet final (and thus, not required), we recommend that the assessment explicitly reference the draft guidance, describe the elements of the draft guidance, and to the relevant extent, provide the assessments suggested by the guidance.

Ambient Air Quality Conditions

The 1997 8-hour ozone standard of 0.08 ppm should be included in Table 3-3 (page 3-6). The 2008-2010 design value at Polk County monitors is 0.069 ppm. The "£" footnote next to 8-hour ozone (Table 3-3) should state that it is the three-year average of the annual 4th maximum.

As a general comment, Table 3-3 should show the design value for each pollutant based on the most recent data (in this ozone example, it is 0.069 ppm based on 2008-2010). The entire table should be reviewed for accuracy (for example, there are two ozone monitors in Polk County, rather than the implied one monitor listed in the table).

Page 3-7 discusses the air quality data. As noted previously, there are more recent ozone monitoring data than 2008 (2009 and 2010 ozone monitoring data are available). Also, the statement *"From 2006 through 2008, the ambient ozone air quality has generally been improving, and long-term attainment with the ozone standard is expected,"* needs to be updated to reflect additional data from 2009 and 2010.

Clean Diesel Recommendations

As noted in Section 3.1.2. (page 3-8), the primary mobile source emissions will occur during the construction phase. It is noted that the impact of the estimated 107 construction workers commuting to the site is minimal, and that previous projects with approximately four times the construction workers had very little impact on the roads around the site.

While it is anticipated that the *"air quality impacts caused by construction-related emissions would be minor and localized, primarily limited to the immediate onsite area of the construction activity, and well within the Polk Power Station property boundaries,"* it would be useful to have an approximate list of the types and number of construction equipment that will be used. This would help provide a sense of the amount of these construction related emissions.

EPA also recommends a discussion of best management practices (BMPs) to reduce GHGs and other air emissions during construction and operation of the facility. Specifically, clean energy options such as energy efficiency and renewable energy should

The document discusses the Safe Drinking Water Act's (SDWA) Underground Control Injection (UIC) program compliance. However, the UIC program is focused on protecting potential underground sources of drinking water (USDWs) and insuring the integrity of the injection well. For example, injection wells are classified and regulated according to the type of fluid injected and the injection interval in relation to USDWs.

While the UIC program requires testing on formation materials to ensure that injection pressures will not fracture rock formations in the injection interval, this is not the same as insuring that the injection does not impact sinkhole formations (or seismic activity in tectonically active areas). For example, the UIC regulations are aimed at protecting USDWs. One way is by preventing formation of transmissive faults and fractures that may allow injected fluids to migrate vertically and reach underground sources of drinking water. A sinkhole issue may be an effect associated with the storage of the CO_2 in its supercritical state, not its actual injection. For example, 40CFR146.13 states:

> *"Except during stimulation, injection pressure at the wellhead shall not exceed a maximum which shall be calculated so as to assure that the pressure in the injection zone during injection does not initiate new fractures or propagate existing fractures in the injection zone. In no case shall injection pressure initiate new fractures or propagate existing fractures in the injection zone. In no case shall injection pressure initiate fractures in the confining zone or cause the movement of injection or formation fluids into an underground source of drinking water."*

Therefore, the EA should discuss the potential for storage of CO_2 in its supercritical fluid state in deep geological formations, and potential to affect or contribute to existing factors (e.g., drought periods) of sinkhole formation.

Energy Use – CO_2 Emissions

The document states that the proposed CO_2 capture and sequestration technology would capture up to 300,000 tons per year, or 90%, of the CO_2 in the cleaned syngas, and sequester the CO_2 by deep well injection. However, it is unclear how much power would be required to operate the technology, or what the power source would be.

It is important to quantify the degree to which the capture and sequestration of CO_2 is offset by combustion emissions including GHGs (e.g., CO_2, CH_4, and N_2O) as well as criteria pollutants (e.g., CO, NO_x, SO_2, etc.) that may be produced through powering of the capture and sequestration technology.

Miscellaneous

The document does not mention air deposition of emitted pollutants, (particularly mercury), and should cover this issue.

We appreciate the opportunity to comment on this project. We are available to assist you in implementing any of the measures described in our comments to help in addressing the potential impacts of the proposed action. Please contact Ramona McConney at (404) 562-9615 if you have questions.

SUMMARY OF DOE RESPONSES TO EPA COMMENTS

The U.S. Department of Energy (DOE) received comments on the Draft Environmental Assessment (EA) from the U.S. Environmental Protection Agency (EPA), Region 4.

The correspondence from EPA, dated August 19, 2011, stated that, based on the information provided in the Draft EA, the agency supports the project and believes the proposed facility and its operation do not appear to represent a significant impact to human health and the environment. The EPA correspondence also included several comments on the Draft EA for consideration as the project proceeds. The following summarizes EPA's comments and DOE's responses to these comments.

CLIMATE CHANGE

EPA pointed out that, on February 18, 2010, the Council on Environmental Quality (CEQ) issued "Draft National Environmental Policy Act of 1969 (NEPA) Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions." The draft guidance discusses when and how federal agencies should consider greenhouse gas (GHG) emissions and climate change in their proposed actions. Specifically, the guidance indicates that, as an indicator threshold, if a proposed action would cause emissions of 25,000 metric tons or more of carbon dioxide-equivalent (CO_2e) GHG emissions on an annual basis, the agency should conduct a quantitative and qualitative assessment of GHG emissions and climate change.

During the demonstration period, RTI International's (RTI's) proposed project would capture and sequester up to 300,000 tons of carbon dioxide (CO_2), which would otherwise have been released to the atmosphere. The proposed project is expected to result in a net reduction of GHG emissions. Therefore, DOE believes the EA is consistent with the CEQ guidance.

AMBIENT AIR QUALITY CONDITIONS

EPA commented that the discussion and Table 3-3 in Section 3.1.1.2, Ambient Air Quality Conditions, of the Draft EA needed several changes and updates. DOE revised Section 3.1.1.2 of the Final EA to address EPA's comments.

CLEAN DIESEL RECOMMENDATIONS

To reduce GHG and other emissions from mobile sources during construction, EPA recommended the consideration of best management practices and clean energy options, such as the use of clean diesel technologies and alternative fuel vehicles. DOE will encourage RTI to consider EPA's recommendations related to clean diesel technologies for construction vehicles and equipment to the extent practicable.

COMMUNITY IMPACTS

EPA commented that it is unclear in the Draft EA whether noise or odor will be a problem for surrounding residences and communities, particularly the odor of hydrogen sulfide (H_2S). As discussed in the Draft EA, Tampa Electric Company's (Tampa Electric's) Polk Power Station, the site for the proposed RTI project, is located in a rural area of Polk County. The nearest residences are located more than 1.7 miles from the site, and the nearest community is located approximately 4 miles from the site. Tampa Electric has operated the Polk Power Station for more than 15 years and has had no complaints from its neighbors regarding noise or odors.

The existing Polk Unit 1 integrated gasification combined-cycle (IGCC) facility includes an acid gas removal process, similar to the high-temperature desulfurization process (HTDP) process for the proposed project, which produces a gas stream with a high concentration of H_2S. For the existing operations, this acid gas stream is oxidized to produce sulfuric acid. For the proposed project, a small portion of the acid gas stream will be oxidized to produce elemental sulfur. The high-concentration H_2S gas stream is not vented to the atmosphere. Further, to minimize the potential impacts from an accidental release of H_2S gas, the existing facilities and piping are routinely inspected and equipped with detectors set to sound alarms if H_2S is detected at low concentrations. Also, employees are routinely trained in emergency response procedures contained in Tampa Electric's Resource Conservation and Recovery Act (RCRA) integrated contingency plan (ICP) for the Polk Power Station. Similar procedures and monitoring would be implemented for the proposed project.

Therefore, DOE believes that neither noise nor odor will be a problem to the surrounding residences or community.

SINKHOLE POTENTIAL

EPA commented that the Draft EA should discuss the potential for the storage of CO_2 in its supercritical fluid state in deep geologic formations to affect or contribute to the formation of sinkholes.

As part of the original site certification application (SCA) (ECT, 1992) for Tampa Electric's Polk Power Station, a detailed sinkhole evaluation report was prepared for the facility. The following summary information is taken primarily from that document and includes of some updated information specifically related to the proposed RTI project.

Sinkholes are a natural and common geologic feature in areas underlain by geologic layers comprised of carbonate rock and other rock types that are soluble in natural water, such as those present essentially beneath all of Florida. The dissolution of these carbonate rocks is typically influenced by concentrated horizontal and vertical zones of weathering associated with groundwater movement. Ancient shorelines created discrete horizontal zones and developed geologic unconformities, erosional surfaces, or other related geologic features. Vertical faults, fractures, and/or joints in underlying bedrock are often evident as linear features visible on aerial photographs and satellite images. These subsurface vertical features, where present, can create zones of concentrated dissolution of the rock. Figure A illustrates areas of different sinkhole types and development potential throughout Florida (Sinclair *et at.*, 1985). As can be seen from review of this figure, the Polk Power Station site is located in an area where the cover materials exceed 200 feet (ft), and cover-collapse sinkhole occurrence is unlikely, although possible. The potential for sinkhole development is readily apparent in the number and size of sinkholes present within any given area in Polk County (see Figure B).

Based on the fracture trace studies described in the 1992 sinkhole evaluation report plus the scarcity and small size of any closed depressions, the Polk Power Station site is thought to be relatively free of any major joints or fractures and has experienced only minor sinkhole activity to date. The dissolution of relatively shallow carbonate materials (shell deposits, limestone, and dolomite) to form solution cavities, particularly in the upper part of the intermediate aquifer system, is thought to be the most probable cause of the small land-surface depressions observed at the site. This does not mean that larger cavities may not exist in the carbonate formations comprising the Floridan aquifer system, but rather that the thick section of relatively cohesive sandy clay, clay, and carbonate rock that overlie these cavities appears to have sufficient bearing strength to bridge any existing cavities.

The operation of the injection wells for either wastewater injection or CO_2 injection for the proposed demonstration project is not expected to contribute to or increase the probability for the formation of sinkholes. The reasons behind this conclusion are presented and discussed in the following paragraphs.

First, the targeted injection zone extends between 4,200 to 8,000 feet below land surface (ft bls) and would include portions of the Cedar Key Formation, Lawson Limestone, and Pine Formation. The depth of this injection zone lies beneath several thousand feet of carbonate rock formations (see Draft EA Table 3-4 and Figure 3-3), as well as several thousand feet below the depths of the ancient shorelines (horizontal weathering zones) described previously. The drilling and geophysical logs collected during the recent drilling of IW-1 revealed no evidence of solution cavities attributable to potential sinkhole

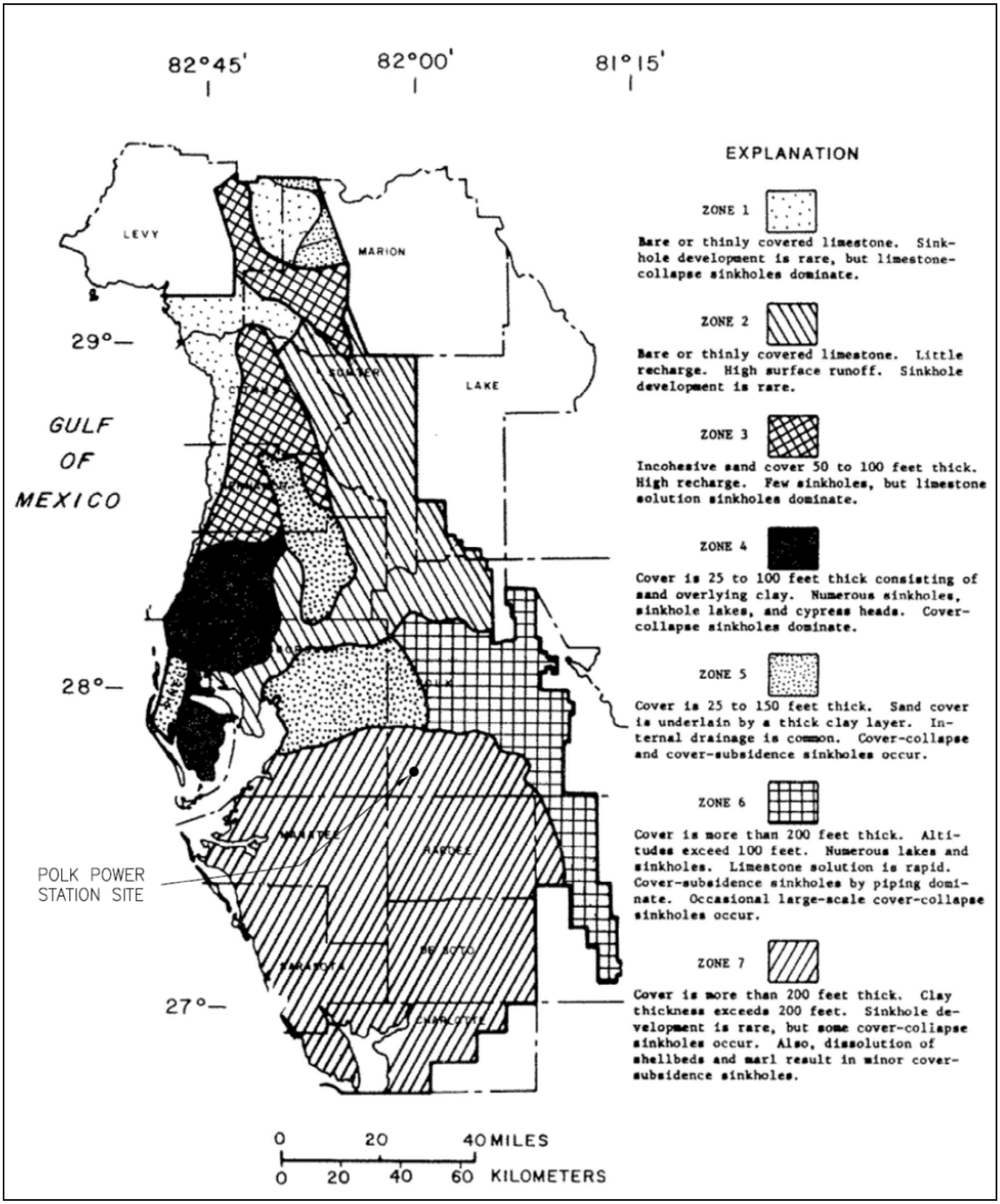

Figure A. Zones of Different Types of Sinkhole Development
Source: Sinclair *et al.*, 1985.

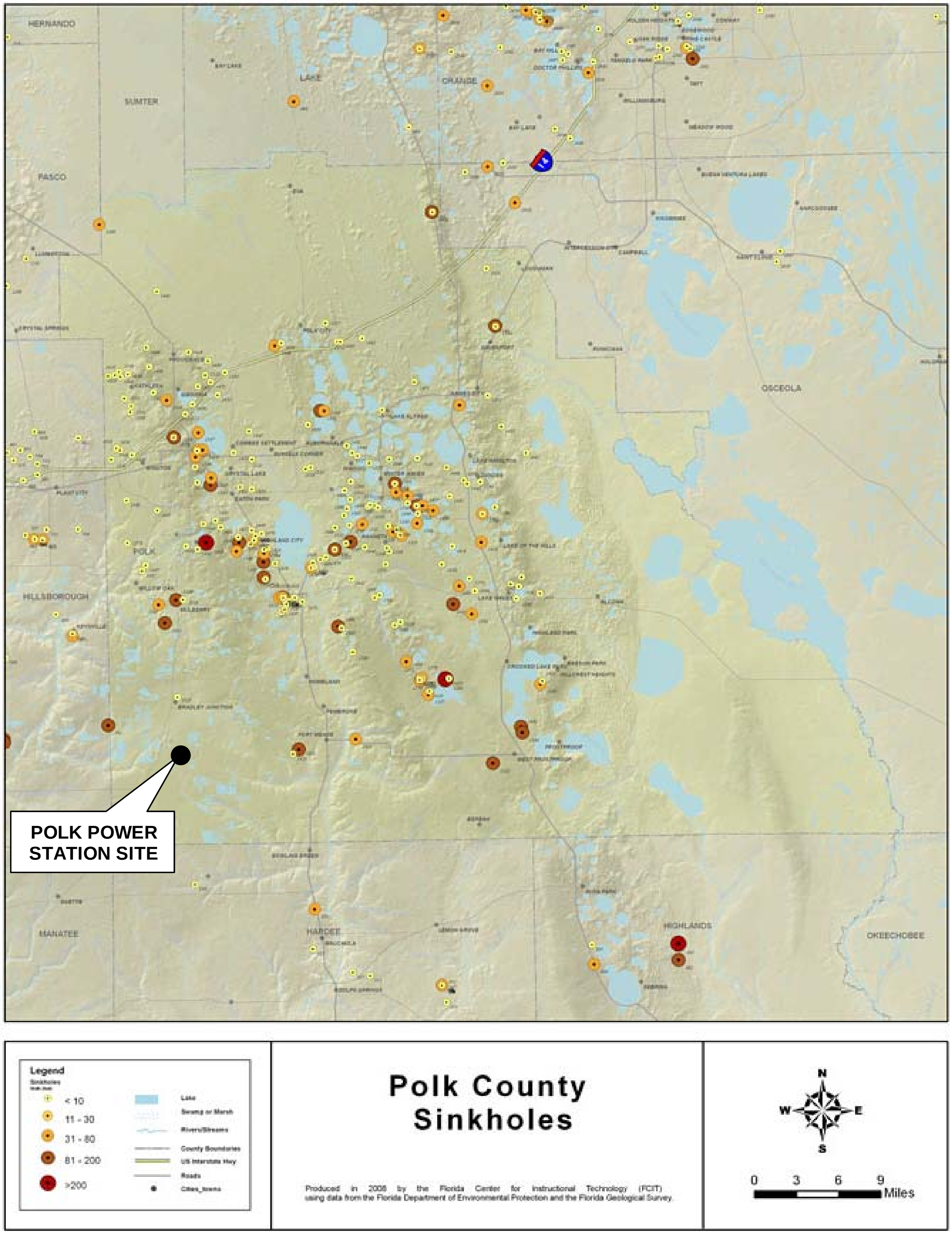

Figure B. Polk County Sinkholes (2008)

Source: University of South Florida, 2008.

development in this targeted zone. Furthermore, the substantial thickness of competent rock units overlying this zone should provide more than adequate bearing strength to prevent the collapse of such cavities, should they exist.

Second, the upper and middle units of the Cedar Key Formation comprise a more than 1,000-ft-thick confining unit, which has and will restrict the vertical movement of groundwater and CO_2. This confining unit is laterally continuous, plus it and the proposed injection zone are expected to be free of any major faults, fractures, or joints. Therefore, the presence of vertical zones of concentrated groundwater movement is not expected and, as such, the likelihood or probability of sinkhole development is not expected to increase.

Third, based on geochemical modeling of the injected CO_2 and wastewater (injectate) well interaction with the subsurface brine and formation performed by the University of South Florida (Stewart, 2011), the preliminary modeling results indicated that, following the CO_2 (IW-2) and wastewater injection (IW-1 and IW-2), there is a potential for a minor amount of deposition and precipitation of minerals (fluorapatite and dolomite) in proximity to the injection wells, not dissolution. The anticipate change in porosity would be quite small (a fraction of 1 percent); so, although overtime this may influence the injection pressures slightly, it should not plug the pore space enough to preclude continued injection.

Fourth, also based on geochemical modeling, it is predicted that the CO_2 gas saturation plume (or pure supercritical CO_2 plume) will not remain in the subsurface beyond roughly 1 to 2 years after converting IW-2 to inject wastewater, which is equivalent to 2 to 3 years after starting wastewater injection at IW-1. After this time, the CO_2 is essentially either dissolved into the brine or has reacted with the formation material within the injection interval (via solubility and mineral trapping). Thus shortly after the CO_2 injection period, the CO_2 will no longer be acidic in nature nor have a buoyant density exerting upward vertical pressures or seeking upward vertical migration pathways contributing to dissolution of formation materials.

Therefore, DOE believes that the storage of CO_2 for the proposed project would not affect or contribute to an increase potential for sinkhole formation.

ENERGY USE—CO_2 EMISSIONS

EPA commented that the degree to which the capture and sequestration of CO_2 for the proposed project is offset by combustion emissions of GHGs, as well as criteria pollutants from generating the power required to operate the technologies should be quantified. RTI estimates that the operation of the proposed project would require approximately 9 megawatts (MW) of power, primarily for the CO_2 compressors. This power would be provided by Tampa Electric, similar to the power supply for the existing power plant operations. Table A provides the estimated GHG and criteria pollutant emissions produced from the generation of 9 MW of power based on the assumptions that the power would be provided from the Polk Unit 1 IGCC plant, and the proposed project would operate for approximately 8,000 hours over the 18-month demonstration period.

Table A. Estimated GHG and Criteria Pollutant Emissions from Power Generated for the RTI Project

Pollutant	Estimated Emissions (Tons for Demonstration Period)
GHGs	
Carbon dioxide (CO_2)	72,435
Methane (CH_4)	30
Nitrous oxide (N_2O)	266
Total GHGs	72,731
Criteria Pollutants	
Nitrogen oxides (NO_x)	18.3
Sulfur dioxide (SO_2)	49.4
Carbon monoxide (CO)	13.6
Particulate matter (PM_{10}/$PM_{2.5}$)	2.4
Volatile organic compounds (VOCs)	0.4

Source: ECT, 2011.

These estimated emissions are considered conservative (i.e., higher than actually expected), since the calculations are based on Polk Unit 1 firing syngas produced in the existing processes. During the proposed project demonstration period, a slipstream of this syngas would be treated to remove 90 percent of the CO_2 and 99.9 percent of the sulfur. This treated syngas would be recombined with the existing syngas stream, which would result in lower GHG and SO_2 emissions from Polk Unit 1.

The proposed project would capture and sequester up to 300,000 tons of CO_2 over the demonstration period compared to the 72,731 tons of GHG emissions produced from generation of the power needed for the project. Therefore, the proposed project would result in a net decrease in GHG emissions. Further, DOE believes that the small, short-term increase in the emissions of criteria pollutants would have negligible effects on air quality, especially compared to the potential benefits of advancing the commercial deployment of the proposed syngas cleanup technologies.

MISCELLANEOUS

EPA commented that the Draft EA does not mention air deposition of emitted pollutants, particularly mercury, and should cover this issue. The proposed project would include technologies to remove 99.9 percent of the sulfur, reduce trace contaminant (arsenic, selenium, and mercury) concentrations, and capture 90 percent of the CO_2 in a slipstream of syngas from the existing Polk Unit 1 IGCC facility. Therefore, during the demonstration, the proposed project would actually decrease emissions and associated deposition of these pollutants compared to existing levels. For this reason, DOE believes that air deposition analyses are not needed for the proposed project.

OCT 0 3 2011

MEMORANDUM FOR ANTHONY V. CUGINI
DIRECTOR, NATIONAL ENERGY TECHNOLOGY LABORATORY

FROM: RICHARD A. HARGIS, JR.
DIRECTOR, ENVIRONMENTAL COMPLIANCE DIVISION

SUBJECT: Finding of No Significant Impact and Final Environmental Assessment for the RTI International Scale-Up of High-Temperature Syngas Cleanup and Carbon Capture and Sequestration Technologies Project, Polk County, Florida (DOE/EA-1867)

The National Energy Technology Laboratory (NETL) prepared an environmental assessment (EA) under the U.S. Department of Energy's (DOE's) National Environmental Policy Act implementing procedures to analyze the potential environmental impacts of its proposed action and this proposed project. DOE would provide cost-shared funding to RTI International (RTI) to demonstrate the pre-commercial scale-up of RTI's high-temperature syngas cleanup and carbon capture and sequestration technologies. The proposed project would be located at Tampa Electric Company's existing Polk Power Station in Polk County, Florida.

DOE's proposed action would provide approximately \$168.8 million of DOE's total \$171.8 million funding for the proposed project from funds authorized in the *American Recovery and Reinvestment Act of 2009* (Public Law 111-5, 123 Stat. 115). RTI's proposed project would advance the commercial deployment of cost-effective, environmentally sound technology options that reduce the constraints associated with using domestic coal energy resources and may ultimately assist in reducing greenhouse gas intensity.

DOE issued a draft EA on July 29, 2011, and advertised its availability in the *Lakeland Ledger* on July 31, 2001, and August 1 and 2, 2011. DOE also placed copies of the draft EA in the Mulberry Public Library in Mulberry, Florida, and the Lakeland Public Library in Lakeland, Florida, for public review. DOE established a 15-day public comment period that began July 31, 2011, and ended August 15, 2011. DOE announced it would accept comments by mail, email, or facsimile. DOE also made the draft EA available on its NETL web site. No public comments were received.

DOE distributed the draft EA to federal, state, and local agencies with jurisdiction or special expertise, and conducted formal consultations by mail with the Florida State Historic Preservation Office (SHPO), the Seminole Tribe of Florida, and the Seminole Nation of Oklahoma. The Florida SHPO and Seminole Tribe concurred with DOE's determination that no historic properties would be affected. DOE received comments on the draft EA from the U.S. Environmental Protection Agency (EPA) Region 4 in a letter dated August 19, 2011. The correspondence stated the agency supports the project and believes the proposed facility and its operation do not appear to represent a significant impact to human health and the environment. DOE addressed additional EPA comments on the draft EA during development of the final EA.

Based on the analyses in the EA, DOE determined its proposed action and RTI's proposed project would result in no significant adverse impacts. The attached Finding of No Significant Impact (FONSI) documents this determination, which is supported by the final EA.

The proposed project would have only minor short-term impacts on air quality and traffic during construction; and would offer minor beneficial impacts on local socioeconomics. Also, during the 18-month operational period, the project would reduce greenhouse gas emissions by capturing and sequestering up to 300,000 tons per year of carbon dioxide, which would otherwise be released to the atmosphere. All other potential environmental impacts would be negligible or minor. Therefore, preparation of an environmental impact statement is not required and the Environmental Compliance Division recommends that NETL issue a FONSI for DOE's proposed action.

RECOMMENDATION: Sign and issue attached FONSI.

Attachments

DISTRIBUTION:
S. Klara
B. Tomer
R. Detwiler
K. Mahajan
D. Lyons
M. Lusk

FINDING OF NO SIGNIFICANT IMPACT
FOR
RTI INTERNATIONAL SCALE-UP OF HIGH-TEMPERATURE SYNGAS CLEANUP AND CARBON CAPTURE AND SEQUESTRATION TECHNOLOGIES, POLK COUNTY, FLORIDA

RESPONSIBLE AGENCY: U.S. Department of Energy (DOE)

ACTION: Finding of No Significant Impact (FONSI)

SUMMARY: DOE completed the *Final Environmental Assessment for RTI International Scale-Up of High-Temperature Syngas Cleanup and Carbon Capture and Sequestration Technologies* (DOE/EA-1867). Based on the analyses in the environmental assessment (EA), DOE determined that its proposed action—providing cost-shared funding to RTI International (RTI) to demonstrate the precommercial scale-up of its high-temperature syngas cleanup and carbon capture and sequestration technologies—would result in no significant adverse impacts. DOE further determined that RTI's proposed project would have potential beneficial impacts in advancing the commercial deployment of cost-effective, environmentally sound technology options that reduce constraints associated with using domestic energy resources and may ultimately assist in reducing greenhouse gas (GHG) levels. In addition, beneficial local socioeconomic impacts would occur from increased employment opportunities and expenditures in the project area.

BACKGROUND: Congress appropriated funding for DOE's Industrial Carbon Capture and Sequestration (ICCS) Program as part of the *American Recovery and Reinvestment Act of 2009* (Recovery Act) (Public Law 111-5, 123 Statute 115) to stimulate the economy and reduce unemployment in addition to furthering DOE's ICCS Program. DOE selected RTI's proposed project to receive noncompetitive financial assistance from funds authorized in the Recovery Act as an expansion of a smaller project previously funded by DOE.

The federal action of providing funding for ICCS projects requires compliance with the *National Environmental Policy Act of 1969* (NEPA) (42 United States Code [U.S.C.] 4231 *et seq*.), the Council on Environmental Quality regulations (Chapter 40, Parts 1500 through 1508, Code of Federal Regulations [CFR]), and DOE's NEPA implementing procedures (10 CFR Part 1021). DOE prepared an EA to evaluate the potential environmental consequences of providing financial assistance for this proposed project under the ICCS Program.

PURPOSE AND NEED: The overall purpose and need for DOE action, pursuant to the ICCS Program and the Recovery Act, is to demonstrate high-temperature syngas cleanup technologies integrated with carbon capture and sequestration at a precommercial scale sooner than might otherwise be possible. Information provided by the demonstration would mitigate the technical risks associated with scale-up of these technologies to advance commercial deployment. The project supports DOE's ICCS Program goal of advancing environmentally sound, cost-effective options that reduce the constraints associated with the use of domestic energy resources and assist in improving the efficiency of capturing and sequestering carbon dioxide (CO_2).

DESCRIPTION OF THE PROPOSED PROJECT: DOE's proposed action is to provide noncompetitive financial assistance to RTI for the precommercial scale-up of high-temperature syngas cleanup and CO_2 capture and sequestration technologies. DOE would provide approximately $171.8 million in cost-shared funding to facilitate the design, construction, and operation of the project. The project would be located at Tampa Electric Company's existing Polk Power Station in Polk County, Florida.

The proposed project would treat a slipstream, equivalent to up to 66 megawatts of electricity generation, of the coal-derived syngas from the Polk Unit 1 integrated gasification combined-cycle (IGCC) power plant to remove 99.9 percent of the sulfur, reduce trace contaminant (arsenic, selenium, and mercury) concentrations, and convert removed sulfur compounds to elemental sulfur. The proposed project would also capture up to 300,000 tons per year, or 90 percent, of the CO_2 in the cleaned syngas and sequester the CO_2 by injection into a deep geologic formation at the site. The proposed project would operate for approximately 8,000 hours over an 18-month operational period.

ALTERNATIVES CONSIDERED: In addition to the proposed action, DOE considered the no-action alternative as required under NEPA. Under the no-action alternative, DOE would not provide funds for the proposed project. For the purposes of the EA, DOE assumed that the project would not proceed without DOE funding. This assumption established a baseline against which the potential environmental impacts of the proposed project were compared.

ENVIRONMENTAL CONSEQUENCES: DOE evaluated the potential environmental consequences of the proposed project and the no-action alternative. DOE considered 13 environmental resource areas in the EA. However, not all areas were evaluated at the same level of detail. For six of the resource areas, DOE determined there would be no impacts, or the potential impacts would be small, temporary, or both, and therefore did not carry these areas forward for additional analysis. DOE focused its more detailed analyses on those resources that have the potential for significant impacts or controversy, or interest the public. These resource areas included air quality, geology and soils, water resources, socioeconomics, transportation, management, and human health and safety.

The proposed project would be located in an area designated as attainment for all National Ambient Air Quality Standards (NAAQS) criteria air pollutants. Construction of the proposed project would result in fugitive dust air emissions during site preparation activities and the release of nitrogen oxides, carbon monoxide, and other fuel combustion emissions from equipment and vehicles. The potential air quality impacts of the construction-related emissions would be minor due to the temporary and localized nature of the emissions. During operations, the proposed project would include three sources of intermittent emissions and one continuous emissions source, a propane-fired heater. Due to the intermittent and minor level of emissions from these sources, potential air quality impacts would be minor and would not contribute to exceedances of the NAAQS or changes in attainment status. During the 18-month operational period, the project would also reduce GHG emissions by capturing and sequestering up to 300,000 tons per year of CO_2, which would otherwise be released to the atmosphere.

The targeted injection zone would be a deep saline carbonate system located between 4,200 and 8,000 feet below the surface. The injection zone is overlain by a laterally continuous, more than

1,300-feet-thick, low-permeability confining unit. A release of CO_2 vertically through the geologic materials up to the surface or shallower geologic units is considered unlikely because of well design, a monitoring program, and the presence of the thick confining unit. At this time, it is anticipated that the CO_2 injection well would be permitted under the Underground Injection Control Program as a Class V experimental well. Therefore, DOE expects the proposed project to have minimal impacts on geologic and soil resources, including underground sources of drinking water.

During construction of the proposed project, soil erosion and stormwater runoff from the facility and construction laydown areas would be the primary potential surface water concern. Appropriate stormwater management and erosion control measures would be used to avoid or minimize potential impacts, and any potential impacts would be minor and temporary. During operation, the proposed project would use minor amounts of additional water and discharge minimal amounts of wastewater. However, water would be provided from the existing Polk Power Station supply system, and wastewater would be discharged to the existing on-site treatment system. Therefore, potential impacts to surface water resources would be minimal.

Transportation facilities in the vicinity of the Polk Power Station include several state and county roadways currently functioning at acceptable levels of service (LOS). During construction, the proposed project would have short-term, minor transportation impacts due to the movement of construction workers and the deliveries of equipment and materials to and from the site. Potential impacts could involve minor traffic congestion and delays near access road entrances to the Polk Power Station. These potential impacts would be temporary and would not be expected to cause the roads to function at an unacceptable LOS. During operation, the potential transportation impacts would be minimal due to the small number of operational employees.

The proposed project would store and use various chemicals and materials, and generate moderate quantities of waste products, some of which may be hazardous. Such wastes would be managed, controlled, characterized by testing, and transported offsite for appropriate disposal in compliance with all regulations. Workers responsible for project operations would be properly trained in waste handling and emergency response procedures. Based on these measures and the estimated waste quantities, DOE expects the project would have minimal impacts from the generation, handling, and disposal of wastes.

The proposed project would have minor beneficial impacts to the local area economy through the creation of jobs and expenditures during construction and operation. DOE estimates the proposed project to create a monthly average of 107 jobs during the 13-month construction period and 12 jobs during the 18-month operational period.

Cumulative impact considerations included air emissions from the existing power plant and potential future generating units at the Polk Power Station. Tampa Electric Company also plans to use the CO_2 injection well for disposal of wastewater from its existing operations after completion of the demonstration project. Due to the intermittent, minor level of emissions from the proposed project, the cumulative impacts on air quality would be negligible. Based on preliminary geochemical modeling, the combined CO_2 and wastewater plumes would not migrate a considerable distance from the injection site. Modeling predicted the CO_2 plume would react with and dissolve in the brine wastewater within the injection zone in a relatively short period of time (less than 5 years). Therefore, any cumulative impacts associated with future use of the injection well are expected to be minimal.

Under the no-action alternative, DOE assumed the project would either be delayed, as RTI sought other funding sources, or abandoned altogether. The potential environmental consequences, if the project was delayed, could be different if the project was modified. If abandoned, the potential environmental consequences would not occur. Furthermore, the potential beneficial impacts would change or not occur.

PUBLIC AVAILABILITY: DOE issued the draft EA on July 29, 2011, and advertised its availability in the *Lakeland Ledger* on July 31, and August 1 and 2, 2011. In addition, DOE sent copies of the draft EA to the Mulberry Public Library in Mulberry, Florida, and the Lakeland Public Library in Lakeland, Florida, for public review. DOE established a 15-day public comment period that began July 31, 2011, and ended August 15, 2011. DOE announced it would accept comments by mail, email, or facsimile. DOE also made the draft EA available on its National Energy Technology Laboratory (NETL) web site. No public comments were received.

DOE distributed the draft EA to federal, state, and local agencies with jurisdiction or special expertise. DOE conducted formal consultations by mail with the Florida State Historic Preservation Office (SHPO), the Seminole Tribe of Florida, and the Seminole Nation of Oklahoma. The Florida SHPO and Seminole Tribe concurred with DOE's determination that no historic properties would be affected. DOE received comments on the draft EA from the U.S. Environmental Protection Agency (EPA) Region 4 in a letter dated August 19, 2011. The correspondence stated the agency supports the project and believes the proposed facility and its operation do not appear to represent a significant impact to human health and the environment. The EPA correspondence also provided several comments on the draft EA for consideration, which were addressed in the final EA.

DOE distributed copies of the final EA and this FONSI to stakeholders and resource agencies that provided comments or consultation. DOE also makes these final documents available at its NEPA web site at http://energy.gov/nepa/doe-nepa-documents and the NETL's web site at http://www.netl.doe.gov/publications/others/nepa/ea.html.

DETERMINATION: On the basis of the evaluations of the final EA, DOE determined that its proposed action to provide $171.8 million in cost-shared funding, and RTI's proposed project to demonstrate the scale-up of high-temperature syngas cleanup and carbon capture and sequestration technologies, would have no significant impact on the human environment. All potential environmental impacts identified and analyzed in the EA would not be significant. Therefore, preparation of an environmental impact statement is not required, and DOE is issuing this FONSI.

Issued in Pittsburgh, Pennsylvania, this 13th day of October 2011.

10.13.11

Anthony V. Cugini
Director
National Environmental Technology Laboratory

Appendix D

Project Execution Plan (PEP)

WARM SYNGAS CLEAN UP and CCS DEMONSTRATION PROJECT

Research Triangle International, Inc

Project Execution Plan

Revision History

Revision	Date	Description
0	May 6, 2011	Initial Issue

Approval

Approval				
Name	**Title**	**Print**	**Signature**	**Date**
Ben Gardner	**Project Manager**	**Ben Gardner**		**5/6/2011**

Table of Contents

The Warm Gas Cleanup and CCS Demonstration Project involve several stakeholders; DOE, RTI, TEC, BASF, Sud Chemie, Shaw Group and the Owner's Engineer, CH2M HILL. A stakeholder is defined as persons or entities, who will be impacted by the execution and completion of the project. Due to the complexities of stakeholder involvement, the integrated Project Execution Plan is divided into two parts: Part A, applicable to all stakeholders and Part B, specific to the EPC Contractor's (Shaw Group) execution. Both parts are complimentary to each other.

Part A governs the overall project execution and integrates the involvement of all stakeholders, especially those parties executing portions of the work. It is at a strategic level, not a tactical level. It governs all project team members and includes an integrated project management approach, overall project scope, baseline cost estimate, baseline schedule, overall project organization, integrated project controls, document and communications management, risk management, HSEQ (health, safety, environment and quality) management, operating management and closure management.

Part B is specific to the EPC contractor, Shaw Group, who is executing the majority of the work. The EPC contractors plan governs the planning and execution of the work in Shaw's scope. Part B is completely complimentary with Part A, but allows for more detailed management of the EPC portion of the work by Shaw and oversight by RTI. Part B is divided into two sub-parts; sub-part 1 provides the "who, what, and when" direction to the Shaw team members and sub-part 2 will contain the day to day procedures and work processes for each individual Shaw department/discipline to follow in producing their respective work products. Since the project is in the early phases of the project, Part B will focus mainly on FEED.

Part A

1.0 Project Execution Plan

This Project Execution Plan (PEP) includes information relating to project organization, execution strategy, communication management, project controls (i.e. change control, scope, schedule, and cost), environmental, health, and safety (EHS) management, quality management, interface management, engineering management, procurement management, construction management, commissioning management, operating management, risk management, and closure management.

In addition, information pertinent to the project but either too large to include in the text or sufficiently self-contained to be a stand-alone document will also be presented as appendices. These appendices are:

A. Cost Estimate
B. Schedule
C. WBS Map
D. Division of Responsibility
E. Project Change Notice Form
F. Project Rules of Credit
G. Document Control Flow Diagram

The Project Management Plan is governed by the change control process described in Section 8. Any changes to this document must be made in accordance with these procedures.

Adherence to the Project Management Plan will be critical to achieve RTI's goals. Failure to execute the plan will delay project schedule, result in budget overruns, and compromise project safety and quality. Therefore, it is incumbent upon each project stakeholder to ensure that their participating project team members are conversant with and execute their work in accordance with this Project Management Plan.

2.0 Project Charter

RTI's charter for the Warm Syngas Clean up and CCS Project is to design, build, and operate RTI's warm gas clean-up technology (this includes warm gas desulfurization and multi-contaminant removal), BASF's aMDEA CO_2 capture technology, and a well to sequester CO_2. The overall objective of this project is to mitigate the technical risk associated with scale-up of warm syngas cleaning and CO_2 capture and sequestration technologies, enabling subsequent commercial deployment.

The activities to be accomplished in this project are funded under DOE Contract DE-AC26-99FT40675 and work under the DOE Cooperative Agreement DE-FC26-05NT42459.

The specific objectives for this project are outlined below:

1. Commission the syngas cleaning and to continue operation for 8,000 hours to achieve the target of sequestering up to 225,000 tons of CO_2/year. The syngas cleaning system will contain the following capabilities:

    a. Water Gas Shift (WGS) unit to optimize the ratio of carbon monoxide, carbon dioxide, and hydrogen for chemical production in a carbon capture sequestration setting.

    b. Scale-up and operate the high temperature desulfurization process (HTDP) system to process a syngas flow equivalent to about 30 to 50 MW of power and producing a desulfurized syngas with a total sulfur concentration (H2S + COS) <10ppmv.

    c. A low temperature cooling unit for the cleaned syngas to enable CO_2 capture with activated MDEA.

    d. Drying and compression unit for the CO_2 sequestration product to enable injection into a deep saline aquifer.

2. Establish reliability, availability, and maintenance (RAM) targets for a full-scale commercial system, based on observed performance during operation of pre-commercial scale units scaled up during this project.

3. Establish operating experience enabling start-up/shut-down, system turn-down, and operator training for a commercial system.
4. Mitigate design risk for commercial plant with adequate design data obtained from pre-commercial plant operation.

In order to accomplish this charter, the following milestones have been identified:

- RTI hire Project Manager
- RTI bring on Owner's Engineer
- Execute agreements with Tampa Electric Company
- Execute agreements with FEED and EPC contractor
- Execute agreement with BASF for aMDEA license
- Execute agreement with Sud Chemie for desulfurization and multi-contaminant sorbents and catalysts
- Complete FEED and develop +/-20% cost estimate by October, 2011
- Complete Environmental Assessment by November, 2011
- Complete Well Construction by April, 2013
- Achieve Mechanical Completion by June, 2013
- Achieve Commissioning Complete/Startup Authorization by September, 2013

In addition to project execution goals, it is necessary that the project meet the expectations of its major stakeholders, defined as those persons or entities, who will be impacted by the execution and completion of the project. Major stakeholders identified for the Warm Syngas Clean up and CCS Project, and primary expectations are shown in the Table 2.1:

Stakeholder	Expectation

RTI	• Prove the economic and technical viability of Warm Gas Cleanup System • Successfully and safely design, build, and operate carbon capture (capture up to 90% CO_2) unit and sequester CO_2 in deep saline aquifer • Collect Process Data required to further scale-up project to support commercial deployment of the technology • Collect operational data required to support commercial deployment of the technology • Successfully execute the Warm Syngas Clean up and CCS Project (i.e. under budget, on schedule, meet quality standards, exceed safety targets, and minimize operational upsets to TEC)
DOE	• Create jobs to support ARRA programmatic goals • Prove the economic and technical viability of Warm Gas Cleanup • Prove the economic and technical viability of the carbon capture sequestration scope • Understand geological impacts of CO_2 sequestration
TEC	• Evaluate the performance and gain experience with the operation of WGC and CCS applied to Polk Unit 1. • Demonstrate the viability of geologic carbon sequestration in the lower Lawson formation beneath the Polk site • Retain the equipment and capability to operate the WGC/CCS system to meet future needs (CO_2 sequestration, chemical production or other uses)

	• Obtain a technology license for any future application of WGC within the TEC system • No negative impacts to operations or TEC customers during construction and operation of the WGC/CCS system • Operate the demonstration process within the permit limitations and avoid any exceedances, etc • Operate the demonstration process in a safe manner, including a goal of zero injuries
Shaw	• Considering the "first of a kind nature" of the project, seek out creative solutions to problems • Engage in open, honest and respectful communication • Work seamlessly with all major stakeholders promoting a culture of shared success • Demonstrate capabilities to be a valued Partner in the Warm Syngas Clean-up Technology • Successfully complete the Extended Pre-FEED, FEED, EPC and Operational phases of the project with: o Zero EHS Incidents o On-time delivery o Within agreed budgets
BASF	• Collect operation and process data for aMDEA system that is integrated with warm gas cleanup system • Gain a reference in an IGCC plant in North America
Sud Chemie	• Develop a new market line of multi-contaminant sorbents

	• Successfully manufacture warm gas desulfurization sorbent
CH2M HILL (Owner's Engineer)	• Monitor progress and schedule • Maintain and update Project Execution Plan • Manage and control change • Manage risk and maintain risk register • Manage and control project documents • Manage project quality and safety

3.0 Project Management Approach

The objective of the Warm Syngas Clean up and CCS Project Execution Plan is to implement clear directions and priorities to successfully achieve the requirements and goals outlined in Section 2. The goals and priorities outlined in this plan apply to all RTI employees, A/E firms, fabricators, suppliers, construction firms, and commissioning and operation team. The priorities of the project are listed in order of importance to this project:

1. Safety
2. Quality
3. Cost
4. Schedule

The RTI project approach begins with a clear definition of project scope (See Subsequent Section). From the scope statement, a baseline cost estimate, schedule, and cash flow will ultimately be developed in order to accurately track the Warm Syngas Clean Up and CCS Project. Activities within the schedule will be associated with its own work breakdown structure (WBS) code. In order to control both cost and schedule, each WBS element will be subject to Change Control to ensure that changes are evaluated and implemented in a controlled fashion.

The project will implement a staged gate process by which the documentation associated with major milestones will be formally evaluated and approved by RTI and ultimately DOE. Approval will allow the project team to advance to the next gate and begin a new series of project activities as defined by the project schedule. The milestones are defined in Section 6.

The Project Execution Plan is comprised of Subsidiary plans established to address items critical to the success of the project. They will be directed by the appropriate party for Project Controls, Contract Management, Communications Management, Document Management, Engineering, Procurement, Construction, Quality, Commissioning, Operations, and Risk. The details for each are outlined in the remaining sections of the Project Execution Plan.

4.0 Project Scope

The overall objective of this project is to mitigate the technical risk associated with scale-up of RTI's warm syngas cleaning and CO_2 capture and sequestration technologies, enabling subsequent commercial deployment.

To scale-up the warm syngas cleaning technologies, a slipstream from a commercial coal gasification-based power utility will be used to mimic commercial operation. To scale-up carbon capture and sequestration, up to 225,000 tons per year of CO_2 will be separated from the cleaned syngas and subsequently injected into a deep saline aquifer for long-term geological storage. The syngas cleaning system that produces the CO_2 sequestration product also produces a syngas product suitable for chemical applications. The proposed site for this project is Tampa Electric Company's gasification facility at Polk Power Station located near Tampa, Florida, which operates based on a mixture of petroleum coke and coal. This site also has suitable deep saline aquifers for CO_2 sequestration.

Therefore, the project scope will include the project oversight, design, procurement, construction, commissioning, operation, and permitting of the Warm Syngas Cleanup and Carbon Capture Sequestration systems. The intent of this scope is to accomplish the cleaning of syngas and integrate CO_2 capture from the entire cleaned syngas stream from the high temperature desulfurization process and sequester up to 225,000 tons per year of CO_2.

The project has been divided into three Budget Periods that include four tasks. These tasks are organized to

- Project Management and planning
- Prepare the Front End Engineering Design (FEED) package, well construction, and environmental and NEPA permitting
- Complete detailed engineering design, procurement, construction of the syngas cleaning and sequestration systems, and pre-commissioning activities.
- Operate the syngas cleaning and carbon sequestration systems

Each task consists of a number of subtasks in which supports a specialized work assignment supporting the overall task and project goals. The preliminary design study will be used to fully define the project by developing contractual agreements with subcontractors outlining their roles and responsibilities. The syngas cleaning and CO_2 sequestration system will be composed of a water gas shift system, RTI's warm syngas cleaning technologies, an activated MDEA system, a CO_2 drying and compression system, and a well system for CO_2 sequestration. Design, procurement, and construction (EPC) of this system will proceed through the conventional FEED and engineering, procurement and construction activities. Key design information developed during the preliminary design will be used to support obtaining all necessary environmental and NEPA permitting. The goal will be to operate the syngas cleaning and CO_2 sequestration system for 8,000 hours and effectively sequester up to 225,000 tons/year of CO_2 while demonstrating up to 90% CO_2 capture and producing a syngas suitable for chemical production.

Budget Period 1 – Project Management and Planning

The work in Budget Period one will be to support FEED, well construction, and permitting. The work during this period will be performed with American Recovery and Reinvestment Act (ARRA) industrial Carbon Capture and Sequestration (iCCS) funds.

Task 1: Project Management and Planning

As the prime contractor, RTI will have the overall responsibility of ensuring all project tasks in each Budget Period of the project are performed and delivered with the highest scientific quality and integrity, on schedule, and within budget to DOE. RTI will also be responsible for project management, coordinating the interactions with the DOE/NETL, and coordinating the activities of the project partners. To effectively manage the risk associated with this project, RTI has assembled a strong team that includes (i) the Tampa Electric Company (TEC) – responsible for providing the site and the syngas slipstream and the management and oversight of CO_2 sequestration, measurement, monitoring and accounting portion of the project, (ii) Shaw Group Incorporated (Shaw) – responsible for completing the FEED and EPC of the overall syngas cleaning system and providing assistance in commissioning and operating of the syngas cleaning system, (iii) BASF Corporation – responsible for providing the solvent and the technology package for their aMDEA-based CO_2 capture technology, and (iv) Sud-Chemie Incorporated (SCI) – responsible for providing the sorbents and catalysts for the HTDP and WGS units. Each of these organizations is a recognized industry leader in their respective fields and their capabilities encompass complimentary experience and expertise critical to successful execution of this project. To further enhance its project management capability for a project of this scale and scope, RTI is also considering engaging an experienced engineering firm which will act as the "owner's engineer" to oversee the overall project management on RTI's behalf. If selected, the owner's engineer will provide a team of 5-6 experienced personnel including an overall project manager, engineering manager, quality and safety manager, constructability manager, and cost and schedule control manager. The owner's engineer would act as RTI's eyes and ears on the ground ensuring the project is executed according to the plan in an efficient manner and in full alignment with DOE's goals and objectives in the field of high temperature syngas cleanup and carbon management.

The following two subtasks must be completed before moving onto any other aspect of the project:

Subtask 1.1 – Project Manager Identification

The recipient must identify a project manager (PM) for the project. This individual must have significant project management experience directly applicable to the management needs of this project, especially with respect to its size and complexity. This individual must also have corporate support including: access to the necessary project management tools, personnel assistance as needed, and PM replacement capability. The DOE FPM approval is required to staff this position, and replacements.

Subtask 1.2 – Project Management Plan (PMP):

The Recipient shall manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements. The Recipient will manage, coordinate and report on the technical scope, budget and schedule basis consistent with a task-oriented work breakdown structure in order to effectively accomplish the work. The Recipient shall ensure that project plans, results, and decisions are appropriately documented and project reporting and briefing requirements are satisfied.

The Recipient will update the Project Management Plan as necessary to accurately reflect current status of the project. Examples of when it may be appropriate to update the Project Management Plan include: (a) project management policy and procedural changes; (b) changes to the technical, cost, and/or schedule baseline for the project; (c) significant changes in scope, methods, or approaches; or, (d) as otherwise required to ensure that the plan is the appropriate governing document for the work required to accomplish the project objectives.

Management of project risks shall occur in accordance with the risk management methodology delineated in the Project Management Plan in order to identify, assess, monitor and mitigate technical uncertainties as well as schedule, budgetary and environmental risks associated with all aspects of the project. The results and status of the risk management process shall be presented during project reviews and in Progress Reports with emphasis placed on the medium- and high-risk items.

Subtask 1.3 – To enable execution of this project, the project management task will be further divided into following subtasks:

Subtask 1.3.1 – Teaming Agreements with Project Partners:

In parallel to submission of PMP described in Subtask 1.2, RTI will initiate formal subcontract negotiations with the individual partners and develop statement of work documents for each project partner. RTI will also discuss with its project partners particularly with Shaw and make a decision on the need for hiring the owner's engineer. If mutually acceptable, RTI will select an engineering firm as owner's engineer. Selection of the owner's engineer is one method of satisfying requirements set forth in Subtasks 1.1 and 1.2. During this subtask, RTI will also assist TEC to file the local, state and federal permitting and environmental assessment applications. By the end of this Budget Period, the following will be completed: (i) approved PMP (ii) subcontract negotiations with its partners, (iii) an agreement on clearly defined roles and responsibilities of each project partner, (iv) Identification of Project Manager and associated support team (includes a decision on hiring and selection of an owner's engineer), (v) establishment of a preliminary process flowsheet, and (vi) initial filing of the local, state and federal permitting and environmental assessment applications.

Subtask 1.3.2 – Management of the FEED Effort:

RTI, through its Project Manager and associated team, will oversee the development of FEED package as described in Task 2. By the end of FEED task a ± 20% cost estimate will be developed for the EPC task so that the Project Manager and DOE will have the tools to complete the project within budget.

Subtask 1.3.3 – Management of the EPC Effort:

During this subtask, Shaw Energy & Chemicals, Inc., RTI's Engineering Partner for the project, will perform the detailed engineering as described in Task 3 and based on information specified in the FEED package. During this subtask, RTI, through its Project Manager and associated team, will interact with its project partners and will ensure that the deliverables assigned to individual partners are delivered on schedule and within budget.

Subtask 1.3.4 – Management of Commissioning, Operation, and Decommissioning Efforts:

RTI, through its Project Manager and associated team, will ensure that the project's scaled-up plant is commissioned and operated with minimal impact to TEC's ongoing operations. Under this management subtask, the Project Manager will assure that Task 4 activities occur according to the roles and responsibilities agreed in the teaming agreements (Subtask 1.3.1).

Task 2: Front End Engineering Design (FEED)

The objective of this task will be to prepare a FEED package and a definitive cost estimate for the project. The specific units to be included in the syngas cleaning system include (1) a water gas shift unit, (2) a high temperature desulfurization process (HTDP) unit, (3) a low temperature cooling unit for the syngas, (4) an activated MDEA unit for CO_2 capture, and (5) a drying and compression unit for the CO_2 sequestration product.

Subtask 2.1: Preparation of FEED Package

RTI, Shaw, BASF, and TEC will be intimately involved in the development of the FEED package by providing and reviewing the design for consistency with known design issues from the pilot plant testing at Eastman and integration with TEC's equipment and facilities. The design review will include potential iterations of unit sizes to optimize support of up to 90% CO_2 capture and sequestering up to 225,000 ton/year of CO_2 in a deep saline aquifer.

The FEED package will consist of the following items:

- Process Description with Basis of Design
- PFD/HMB
- Sized Equipment List
- Process Data Sheets for Towers, Drums, Vessels, Reactors, Heat Exchangers, Pumps, Compressors, Filters, Coalescers, Fired Heaters
- Mechanical Data Sheets for Towers, Drums, Vessels, Reactors, Heat Exchangers, Fired Heaters, Filters, Compressors
- Utility & Effluent Summary
- Catalyst and Chemical Specification, and Consumption Summary
- Operating Guidelines
- P&IDs
- Relief Valves Process Data Summary
- Tie-in List
- Specialty Piping Item Data Sheet
- Basis of Design for Flare and Blow down system
- Plot Plan
- Index of Piping Material Classes
- Smart Plant 3-D model
- Piping MTOs
- Material Selection Diagram
- Conceptual design of site rough grading, as well as cut and fill soil balance
- Conceptual design of storm drainage system, site paving, surfacing, and roads
- Conceptual design of pipe racks and process structure
- Conceptual design of equipment, structures, buildings, and pipe-rack foundations

- Civil/Structural MTO
- Medium Voltage and Low Voltage overall one line diagrams
- Area classification drawings
- Lighting layout sketches
- Grounding Layout sketches
- Conceptual Substation and Remote Instrument Enclosure layout sketches
- Load Flow, Short Circuit and Motor starting calculations
- Cable Sizing Calculations
- Electrical Load List
- Electrical MTO
- I&C MTO
- Instrument List
- Instrument and Analyzer Datasheets
- Control Valve Datasheets
- Cause and Effect Diagram
- Interlock Diagram and Narratives
- Vendor Quotes for Major Equipment
- +/-20% Cost Estimate
- CPM Schedule

Using the information in the FEED package, the engineering partner will prepare a ± 20% budget estimate for engineering, procurement, and construction. In addition to this estimate, the project team will develop a budget estimate for commissioning/start up activities and up to 8,000 hours of operation.

Subtask 2.2: Environmental Permitting

For the proposed project, environmental assessments for both the Department of Energy's National Energy Technology Laboratory (NETL) and local and state environmental permitting agencies are required. The following two subtasks include the preparation of the specific environmental permitting applications. No field work will be initiated until a written approval from DOE/NETL is received that the proposed project meets the National Environmental Policy Act (NEPA) requirements. No construction work will be commenced at TEC's site until all permitting has been approved.

Subtask 2.2.1: Support for Preparation of Environmental Assessment (EA) Document by DOE

Support DOE's effort to prepare an EA document and the review and approval process to meet the NEPA requirements.

Subtask 2.2.2: Local and State Permitting

Documentation and applications necessary for local and state environmental permits will be prepared. In addition to preparation of the permit applications, several face-to-face meetings with the Florida Department of Environmental Protection (FDEP) Siting Coordination Office and Air Regulation staff will be arranged.

Based on the preliminary evaluation of the planned design, construction, and operation in this project, no change in existing and/or allowable emission rates compared to current rates at the Polk Power Station are anticipated. As a result, the permitting effort is expected to require only a minor air construction permit and an amendment to the existing Polk site certification. Furthermore, no other permits or permit modifications are currently considered necessary for water use, wastewater discharge or storm water management. This task assumes that the agency review process and permit modification and post-certification amendment are non-controversial and no parties file objections.

Subtask 2.3: Deep Saline Aquifer Well for Long Term Geological CO_2 Storage

The University of South Florida (USF), under contract to TEC, developed a preliminary model of the site using reservoir data available in the literature. This model was used to simulate the radial extent and pressure buildup from CO_2 injection at Polk Power Station. These model predictions were used to select potential well sites on TEC's site that would ensure that the CO_2 plume generated in this project would stay within Polk Power Station property boundary. Prior to construction of the well, additional information gathered during the construction of wastewater injection wells will be used to update the model and reassess the proposed site for the CO_2 injection well.

The CO_2 injection well will be constructed in accordance with industrial standards and procedures and in accordance with Underground Injection Control (UIC). Part of the installation of the CO_2 injection well will include hydrologic injectivity testing. This testing will be used to infer field-scale permeability, flow geometry, and boundaries of storage formation. This new data will be used to improve the geologic static model and provide more accurate reservoir simulations predicting the size and shape of the CO_2 plume over time.

Due to the time required to drill this well, construction will start as soon as the appropriate UIC well permits are in place.

Subtask 2.4: Planning for Demonstration of DSRP and TCRP Technologies

In addition to the warm syngas desulfurization, RTI has also developed two complementary technologies, namely Direct Sulfur Recovery Process (DSRP), and Trace Contaminant Removal Process (TCRP). The DSRP converts the regeneration off-gas from the HTDP to elemental sulfur using a slipstream of syngas over a catalyst in a fixed-bed reactor system. If elemental sulfur is a desired byproduct, DSRP provides an elegant and cost-effective integration for tail gas treatment to produce a marketable sulfur byproduct. The DSRP (tested in a fixed-bed mode at a gas flow rate of about 500 SCFH) was demonstrated its ability to produce elemental sulfur production with actual feed gases (regeneration tail gas from HTDP and syngas as a reducing agent from the Eastman gasifier) for >100 hours. In addition to demonstrating 98% SO_2 conversion, additional key results from this testing include successful handling of liquid sulfur product at small scale and processing elemental sulfur in tail gas eliminating sulfur plugging in downstream equipment and enabling long term continuous operation. For successful commercialization of this process technology, 100 hours of testing is not adequate and additional testing is required, specifically to demonstrate long-term stability of the catalyst. The fixed-bed reactor design, however, can be scaled up from the results of the testing in this unit.

To obtain additional data on catalyst deactivation, RTI proposes to refurbish the existing skid-mounted unit (used at Eastman) and integrate at TEC with a slipstream of actual regeneration off-gas and a slipstream of actual syngas from TEC gasifier and operate the unit for at least 1,000 hours to obtain data on catalyst stability and deactivation. This will include parametric testing at typical operating conditions, extended operation to evaluate long term performance of the catalyst under actual operating conditions, evaluation of the quality and potential end uses of sulfur product. Planning for this activity will be completed in the BP1 in consultation with TEC and Shaw.

As with the DSRP, the most promising option for TCRP will be to reuse the existing pilot scale unit, which was successfully used at Eastman. This would be beneficial, because the fuel mixture for TEC is petroleum coke (petcoke) and coal. The different chemical composition of petcoke compared to coal means that the contaminant concentrations particularly of As, Se, and Hg in the syngas at TEC will be very different from a gasifier using coal (such as Eastman) as the primary fuel component. The net result is that the syngas available at TEC might not be the most representative syngas for testing TCRP to support DOE programmatic goals for syngas cleaning for both power and chemical/fuel production. A smaller unit would be more mobile and enable testing at different gasifier locations. We propose long-term testing of TCRP at both Eastman and TEC in this project to obtain results with both coal (at Eastman) and petcoke + coal blends (at TEC) to provide DOE/NETL needed information on the ability of solid sorbents to remove the trace elements. We propose that this testing will not only include analysis of sorbent samples for their trace metal concentration to determine their capacity, but also the characterization of inlet and outlet syngas for their trace metal concentrations. The methodology for this chemical analysis was successfully developed by URS Corporation under the Contract 40675. Combination of gas and solid analyses will provide mass balance closure and performance of the sorbent for their efficacy for trace metal removal under parametric test conditions. This will allow process integration and optimization of the TCRP into both IGCC and chemical/fuel production applications for coal as well as coal + petcoke blend.

RTI proposes to conduct this testing in BP2 at Eastman (current plans are to carry out the TCRP testing in summer 2012) and then move the skid to TEC in 2013 to conduct the testing in 2014 along with HTDP testing. These testing plans will be finalized as part of BP1 activities.

Deliverables for BP1:

The deliverables for BP1 include:

A comprehensive FEED package with ± 20% cost estimate

- Verification of costs provided by Shaw for the FEED by two additional engineering companies
- Approved Environmental Assessment
- Air and UIC well permit applications submitted
- Well characterization for CO_2 injection initiated
- Sorbent manufacturing arranged with Sud Chemie
- Plans for DSRP and TCRP demonstration finalized and costs included in the BP2 estimate
- Execution strategy for EPC developed and agreed upon by various stakeholders.

Stage Gate Criteria:

The following list outlines the criteria necessary to move into the BP2:

1. Task 3.1 (Detailed Engineering) – if the ± 20% estimate produced during FEED is within the baseline budget, the project will move into Detailed Engineering (i.e. Task 3.1).

2. Task 3.2 (Procurement) – if the ± 20% estimate produced during FEED is within the baseline budget, the project will move into Procurement (i.e. Task 3.2). This is required in order to support Detailed Design and keep the project on schedule. The exception to this decision point will be long lead procurement items identified during FEED. If during FEED, delivery schedules for certain items are determined to exceed baseline schedule requirements, RTI will issue purchase orders (to initiate engineering design) for these items with DOE's permission.

3. Task 3.3 (Construction) – if the EA and air permit are in place, Construction (i.e. Task 3.3) will be allowed to start. Additionally, a detailed construction plan will be developed and submitted to DOE/NETL for review and approval prior to starting any construction.

4. Task 3.4 (Deep Saline Aquifer Well for Long Term Geological CO_2 Storage) – if the UIC permit is in place, well construction will be started.

Budget Period 2 – Engineering, Procurement, and Construction Phase

Task 3: Engineering, Procurement, and Construction (EPC)

The FEED package will be the basis for detailed engineering initiation. The design package developed during this phase will contain all the necessary information to procure all the engineered equipment, which will secure pricing, delivery schedule, and receive engineering drawings required for plant 3-D model development. Once the 3-D model is approved, IFC drawings for civil, structural steel, piping ISOs, and electrical will be developed and issued to construction.

Task 3.1: Detailed Design

The detailed design will be used to finalize the following

- Project description
- Soil investigation
- Plot plan – Issued for Construction (IFC)
- Process flow diagrams (PFDs) – IFC
- Piping and instrumentation diagrams (P&IDs) –IFC
- Detailed equipment list with final sizes and specifications
- General arrangement diagrams –IFC
- 3-D Plant Model – IFC
- Civil Drawings – IFC

- Structural Steel Drawings – IFC
- Electrical Drawings – IFC
- Instrument Index
- DCS Architecture – IFC
- Piping ISOs - IFC
- Equipment quotations – firm quotes ready for requisition
- Final specification for power and lighting requirements
- Hazardous area classification
- Hazardous energy control review
- CPM schedule with milestones

These items will also be used to complete a detailed cost estimate for the syngas cleanup system. Another action that will be completed during the detailed design is conducting a final design hazard review for the syngas cleaning system and CO_2 injection into the deep saline aquifer. Any issues identified during this review will be addressed and implemented prior to construction of the system.

Task 3.2: Procurement

Procurement will start as soon as engineering from Task 3.1 starts developing the technical specifications for each piece of equipment. Therefore, Task 3.2 and Task 3.1 essentially start at the same time.

Based on delivery schedules obtained with vendor quotes for major equipment for the demo plant by Pegasus TSI, the compressors required for retrofitting into the TEC's system were extremely long lead items (~12 months). As these compressors and other long lead items could significantly slow down the construction schedule, procurement of these long lead items needs to be initiated as soon as possible during or after the detailed design work.

Additionally, RTI will work with Sud Chemie to secure the sorbents and catalyst for this project.

Task 3.3: Construction

Construction will start as soon as all permits are in place and IFC drawings for early construction activities (such as underground, civil foundations, pipe rack, and piping tie-ins) are issued. During this phase, all mechanical equipment will be set, structural steel erected, civil foundations poured, pipe installed and hydrotested, electrical and instrumentation wiring landed, instrumentation installed, MCCs installed, insulation and painting completed.

Budget Period 3 – Operational Phase

Task 4: Commissioning and Operation

After final construction activities of the syngas cleaning system are completed, commissioning of this system will begin. The main commissioning activities will be used to demonstrate that the system has been constructed according to plans and that it is operationally functional. In addition to these activities, a pre-commissioning design hazard review will be conducted and operators trained. As part of commissioning, all necessary modeling for CO_2 injection into the deep saline aquifer will be completed to demonstrate suitability of the well for CO_2 injection.

Completion of the commissioning activities will lead into the actual operation of the syngas cleaning system with sequestration of the CO_2. Individual units will probably be brought online following a sequence that will establish satisfactory operation of each unit. When all the units are operational, the objective will be to continue operation for 8,000 hours of operation and achieve the target of sequestering 225,000 tons of CO_2/year. To extract the maximum benefit from this operation, a test plan will be developed to demonstrate the performance of the system to effectively capture up to 90% of the CO_2, sequester up to 225,000 tons of CO_2/year, and produce a syngas product that is suitable for chemical production applications. A key component of this plan will include collection of key data about the performance of the different process units and associated with the well and CO_2 injection into the saline aquifer.

Subtask 4.1: Commission

In preparation for commissioning and shakedown, a pre-commissioning Process HAZOP will be completed, and operators will be trained. Specific activities to be performed as part of commissioning and shakedown are pressure testing, leak checks, proper functioning of all the instrumentation and controls, and functioning of units in the syngas cleaning system.

Subtask 4.2: Test Plan

A test plan for the syngas cleaning system and CO_2 sequestration will be developed to meet the overall project goals of up to 90% CO_2 capture and sequestering up to 225,000 tons of CO_2/year. In addition this test plan will include parametric testing of the distinct units within the syngas cleaning system. The test plan will include: overall PFD highlighting integration of test components/processes, feed type(s), tests durations, input conditions (each unit), measurements to be taken (what will be measured, measurement device type and sensitivity limits, location of measurement, frequency, etc.), and test goals and success criteria. Test goals and success criteria will focus on attaining DOE programmatic goals for syngas cleaning for chemical production applications to enable commercial deployment of this technology for coal gasification.

Subtask 4.3: Operation

The primary focus during operation will be achieving the target objectives and implementing the test plan. However, the most valuable feature of this operation will be the data collected and its analysis. Specific details about the data collection and analysis are provided in the following subtasks.

Subtask 4.3.1: Syngas Cleaning Data Collection and Analysis

The data collected from the different units will include temperatures, pressure, feed and product and potentially intermediate compositions. These data will be used to determine the efficiency of each unit, effective operation ranges for key operating parameters, and critical data to design and operate commercial-scale units. Beyond the actual data, attempts will be made to capture the lessons learned by the operators during startup, shutdown and operation of the syngas cleaning system (including DSRP and TCRP units) and CO_2 sequestration in a deep saline aquifer.

Subtask 4.3.2: Measurement, Monitoring and Accounting

At the wellhead, injection rate and pressure will be monitored. Downhole pressure will also be monitored. Vertical seismic profiles (VSPs) and/or other means will be used to periodically track the CO_2 plume. Monitoring for leakage out of the storage formation will be conducted using a combination of seismic imaging and analysis of fluid samples from nearby shallow groundwater monitoring wells. Geochemical analysis of these samples will be used to detect any CO_2 or brine leakage from the primary storage reservoir. Post-injection monitoring will also monitor and model the pressure fall off and CO_2 plume stabilization.

The objectives of this monitoring program include:

- Obtaining baseline data on reservoir pressure, temperature, and water quality
- Quantifying the amount of CO_2 injected into the saline reservoir
- Monitoring the pressure buildup in the saline reservoir
- Assessing the condition of the injection well
- Tracking dispersion/migration of the injected CO_2 plume in the storage reservoir
- Detecting potential leakage of CO_2 out of the storage formation to overlying strata
- Detecting brine displacement associated with CO_2 injection
- Demonstrating the feasibility of safely storing CO_2 in carbonate systems found throughout the region

5.0 Baseline Estimate

A baseline cost estimate (See Appendix A) was developed that includes a preliminary cost estimate for engineering, procurement, construction, commissioning, and operations of the Warm Gas Cleanup/Carbon Capture Sequestration Project.

Upon initiation of this project, a master WBS will be developed to track and control cost and schedule performance. The current estimate is based on the following engineering documents:

- Preliminary PFD/HMB
- Preliminary Sized Equipment List
- Preliminary Plot Plan

Each piece of equipment was sized and estimated from either vendor quotes or cost database. After developing the equipment cost, factors for pipe, civil, steel, I&C, electrical, insulation, and painting were applied. Finally, costs for Engineering, Construction Management, First Fills, Commissioning, Spares, Site Support, Site Security, Home Office, Contingency, and Start-up/Operations were derived.

Due to the staged approach of the project (i.e. Conceptual Engineering, FEED, Detailed Engineering), the estimate will be constantly updated in order to ensure the project stays within budget. During FEED, RTI will take the PFDs/HMB, P&IDs, and plot plan and give to an outside engineering firm to develop a cost estimate as a due diligence measure to check the estimate produced by Shaw.

During EPC, RTI will keep a working estimate that is updated as purchase orders are secured and take-offs are finalized.

6.0 Baseline Schedule

A baseline schedule (See Appendix B) was prepared to track and control schedule performance for each work package or WBS element. As the project moves from one phase to the next, the schedule will become more detailed and granular in nature. As the project moves into EPC, relationships between activities will be established based upon detailed engineering, procurement, construction, and commissioning plans.

The baseline schedule includes the major milestones or staged gate decision points. These decision points will be used to determine whether the project is continued, terminated, or redirected. These decision points are indentified below:

ID	Description	Baseline Due Date	Forecast Due Date	Actual Completion
1	Initiate EA	3/2011		3/2011
2	Initiate FEED	5/2011	5/2011	
3	Initiate Well Construction	9/2011	8/2011	
4	Finalize FEED	10/2011	9/2011	
5	Finalize EA	10/2011	9/2011	
6	Initiate Detailed Engineering	12/2011	10/2011	
7	Submit Air Permit	5/2011	3/2011	

8	Initiate Construction	5/2011	3/2011	
9	Finalize Detailed Engineering	12/2012	10/2012	
10	Initiate Commissioning	1/2013	12/2012	
11	Complete Well Construction	5/2013	3/2013	
12	Mechanical Completion	5/2013	4/2013	
13	Finalize Commissioning	9/2013	7/2013	
14	Startup/Operations	9/2013	8/2013	
15	Operations Complete	6/2013	5/2013	
16	Project Complete	9/2015	9/2015	

7.0 Project Organization

RTI has developed a project team with experience in large, industrial energy project development and management in the oil, chemical, petrochemical, coal gasification, and power industries.

Two organization charts are provided in Figures 7.1-7.2 that depict the overall organization developed for project management, engineering, procurement, and, construction of this project.

FEED Organization Chart

Figure 7.1 shows the organization chart for the FEED effort. The major players for this phase are:

- DOE – is responsible for the project funding (minus cost share). Ultimately, the project is accountable to DOE.
- RTI – is the prime recipient to DOE. RTI is responsible for overall project planning, cost controls, schedule, and reporting to DOE.
- Shaw – is responsible for developing the FEED package
- CH2M Hill – will act as RTI's owner's engineer.

- BASF – is responsible for providing the process design package for the activated MDEA system.

- TEC – is responsible for providing input into the process design, UIC well permit, air permit, and well design.

EPC Organization Chart

Figure 7.2 shows the organization chart for the EPC effort. The major players for this phase are:

- DOE – is responsible for the project funding (minus cost share). Ultimately, the project is accountable to DOE.

- RTI – is the prime recipient to DOE. RTI is responsible for overall project planning, cost controls, schedule, and reporting to DOE.

- EPC Contractor – is responsible for detailed engineering, procurement, and construction.

- CH2M Hill – will act as RTI's owner's engineer.

- BASF – is responsible for supporting detailed design.

- TEC – is responsible for providing input into the detailed design, air permit, and well construction

Note: Responsibility for Commissioning and Operations is currently being developed. Once finalized, the Project Execution Plan will be updated.

Roles and Responsibility

Appendix D shows a detailed Division of Responsibility matrix.

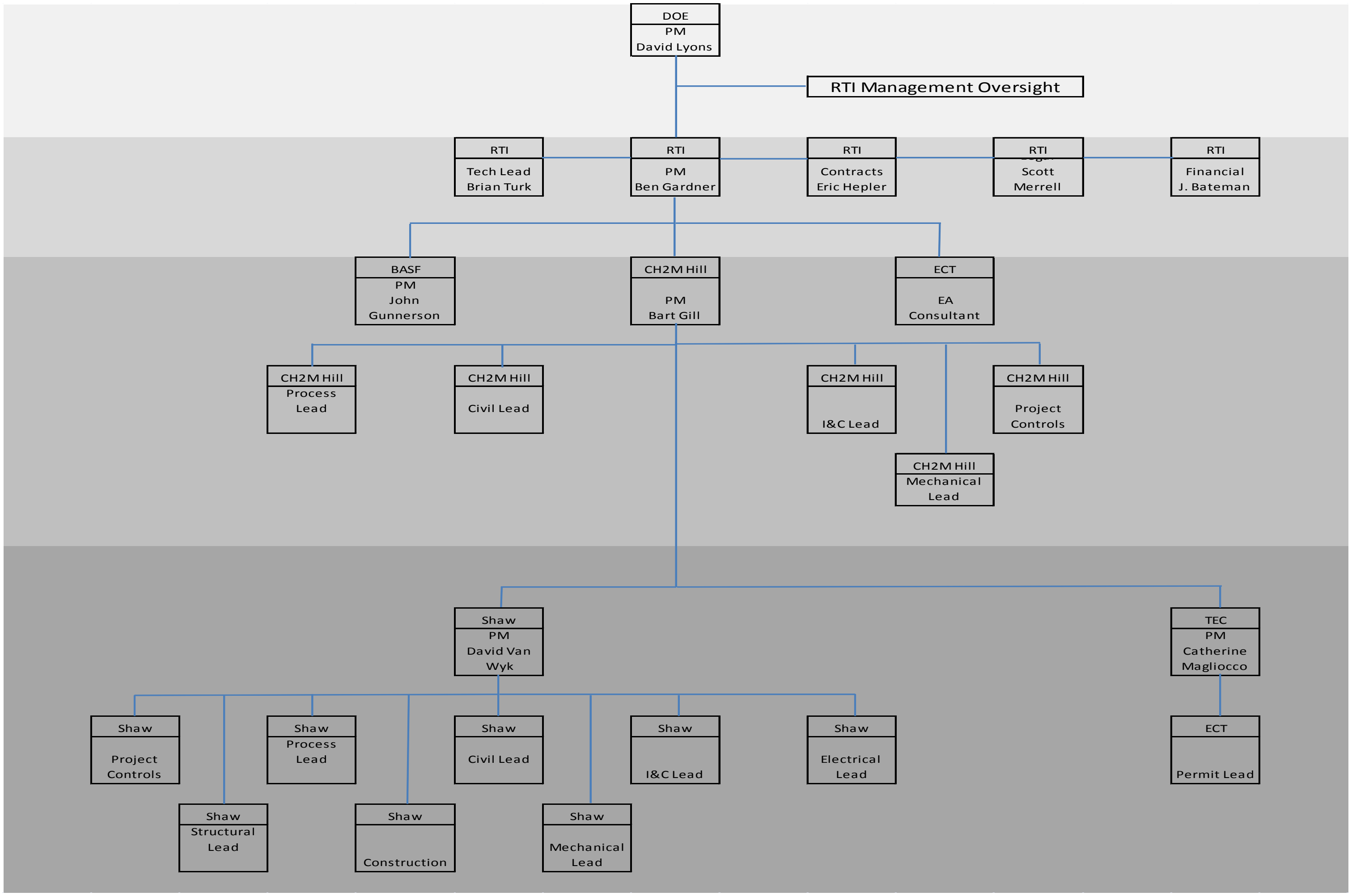

Figure 7.1: FEED Organization Chart

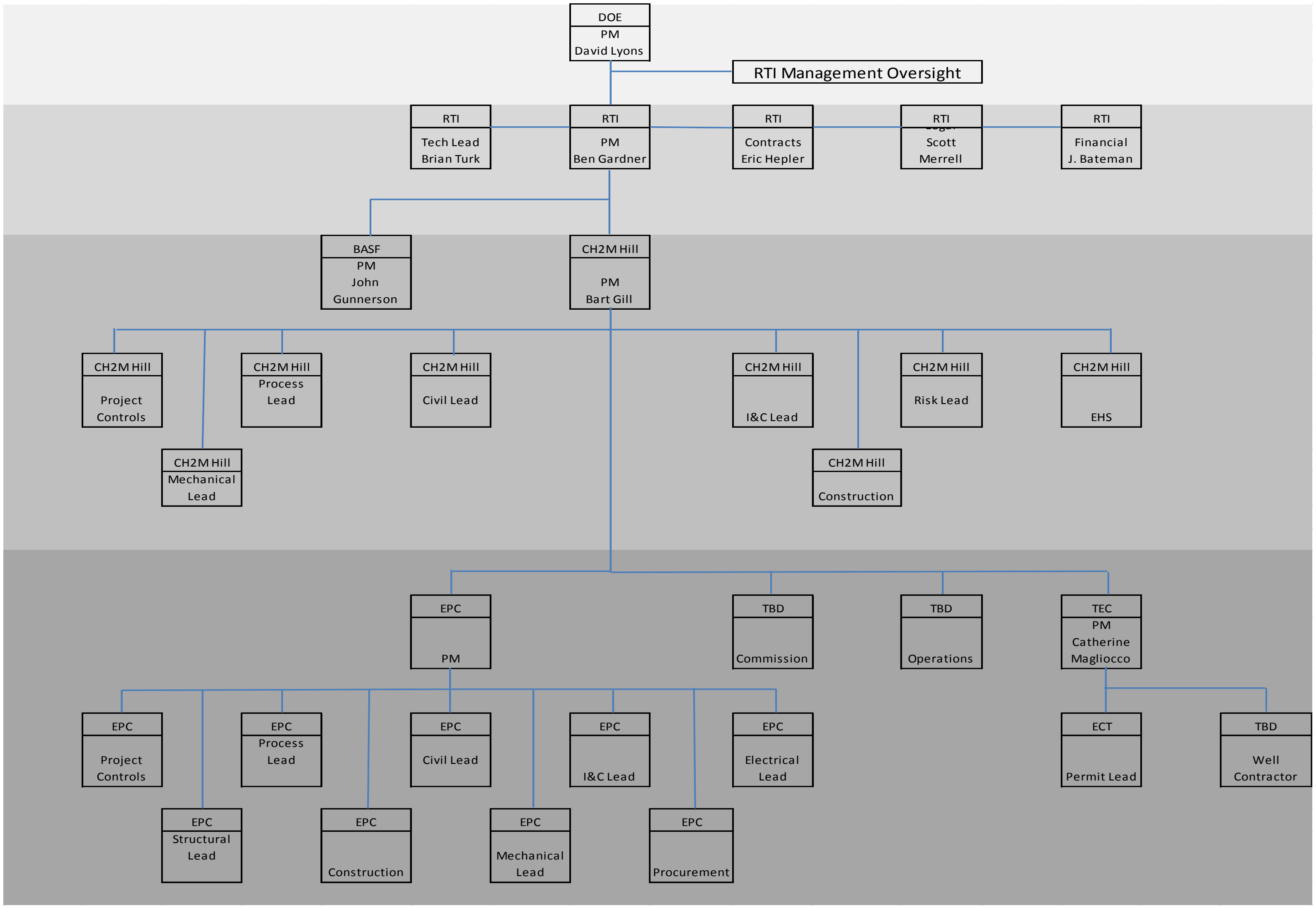
DOE
PM
David Lyons
RTI Management Oversight
RTI
Tech Lead
Brian Turk
RTI
PM
Ben Gardner
RTI
Contracts
Eric Hepler
RTI
Scott
Merrell
RTI
Financial
J. Bateman
BASF
PM
John
Gunnerson
CH2M Hill
PM
Bart Gill
CH2M Hill
Project
Controls
CH2M Hill
Mechanical
Lead
CH2M Hill
Process
Lead
CH2M Hill
Civil Lead
CH2M Hill
I&C Lead
CH2M Hill
Construction
CH2M Hill
Risk Lead
CH2M Hill
EHS
EPC
PM
TBD
Commission
TBD
Operations
TEC
PM
Catherine
Magliocco
EPC
Project
Controls
EPC
Structural
Lead
EPC
Process
Lead
EPC
Construction
EPC
Civil Lead
EPC
Mechanical
Lead
EPC
I&C Lead
EPC
Procurement
EPC
Electrical
Lead
ECT
Permit Lead
TBD
Well
Contractor

Figure 7.2: EPC Organization Chart

8.0 Project Controls

To achieve overall success, CH2M Hill will assist RTI with implementing the following types of project controls processes. The following discussion outlines high-level functionality and capability for each of these controls.

- Project Cost Control
- Earned Value Management
- Project Schedule Control
- Scope Management/Change Management
- Reporting

8.1 Project Cost Control

Cost control is probably the most well known of project controls and it must encompass several key attributes as discussed below:

- Able to establish and continuously change budgets through the use of estimating and forecasting for each anticipated activity of the project
- Allow a universal coding structure that is representative of RTI's practice, methodology, and reporting standards
- Provide complete and flexible reporting capabilities that meet differing requirements of different stakeholders.
- Should have the ability to manipulate data into any format desired so that the actual costs of the project can be compared to budgets and estimates
- Capable of tracking all funding sources
- Capable of determining the estimate at completion for the entire project on an ongoing basis
- Capable of tracking and managing all risks that could impact the actual costs of the project and the contingency sources that can potentially fund them
- Enable a single point for data entry for budget, estimate, and actual cost data from whatever software package is used and validate the accuracy of the data on a weekly basis

CH2M Hill will provide the project level systems, staff and training to establish and maintain a project level cost management system for RTI. Below are some of the major elements that are used for cost analysis/tracking and make up the Work Package Performance Report. These elements are explained in greater detail later in this section.

Current Budget at Completion (BAC)

Actual Cost to Date

Estimate to Complete (ETC)

Estimate at Completion (EAC)

Variance at Completion (VAC)

Other items reported in the cost report include Planned Value, Earned Value, Schedule Variance, Schedule Performance Index (SPI), Cost Performance Index (CPI), and Physical and Expenditure Percent Complete.

Proper cost tracking helps the PM forecast accurately and avoid over runs. Costs are rolled up from activities and tracked at the lowest WBS level as shown in Figure 8-1.

ctivity ID	Activity Name	Current Approved	Actual Costs	Estimate To Complete	Estimate At Completion	Variance At Completion	Planned	Earned	Schedule Variance	SPI	CPI	Physical % Complete	Expenditure % Complete
P1-102 Secondary Activated Sludge Facility 2 at Pl...		$242,542,332	$4,913,652	$286,521,096	$291,434,748	($48,892,416)	$7,233,238	$6,773,629	($459,609)	0.94	1.38	2.79%	2.03%
Work Package Performance Analysis		$242,542,332	$4,913,652	$286,521,096	$291,434,748	($48,892,416)	$7,233,238	$6,773,629	($459,609)	0.94	1.38	2.79%	2.03%
Phase 1 - PROJECT DEVELOPMENT		$109,000	$136,968	$0	$136,968	($27,968)	$109,000	$109,000	$0	1.00	0.80	100%	125.66%
3000	Project Development	$0	$83	$0	$83	($83)	$0	$0	$0	0.00	0.00	100%	0%
3010	Project Management - Development	$47,859	$71,744	$0	$71,744	($23,885)	$47,859	$47,859	$0	1.00	0.67	100%	149.91%
3020	Project Technical Support- Development	$60,457	$64,457	$0	$64,457	($4,000)	$60,457	$60,457	$0	1.00	0.94	100%	106.62%
3031	Feasibility study	$684	$684	$0	$684	$0	$684	$684	$0	1.00	1.00	100%	100%
Phase 2 - PRELIMINARY DESIGN		$6,796,802	$4,761,426	$659,209	$5,420,635	$1,376,167	$6,796,802	$6,664,629	($132,173)	0.98	1.40	98.06%	70.05%
3100	Preliminary Design	$232	$1,087	$0	$1,087	($855)	$232	$232	$0	1.00	0.21	100%	468.53%
3110	Project Management - Preliminary Design	$650,428	$469,424	$0	$469,424	$181,004	$650,428	$630,915	($19,513)	0.97	1.34	97%	72.17%
3120	Project Technical Support - Preliminary Design	$422,000	$360,109	$0	$360,109	$61,891	$422,000	$409,340	($12,660)	0.97	1.14	97%	85.33%
3141	Engineering Study #1	$512,192	$0	$0	$0	$512,192	$512,192	$512,192	$0	1.00	0.00	100%	0%
3143	New equipment studies / testing	$85,365	$0	$0	$0	$85,365	$85,365	$85,365	$0	1.00	0.00	100%	0%
3146	Preliminary Design Report	$5,000,000	$3,927,604	$659,209	$4,586,813	$413,187	$5,000,000	$4,900,000	($100,000)	0.98	1.25	98%	78.55%
3158	Environmental Documentation	$85,365	$430	$0	$430	$84,935	$85,365	$85,365	$0	1.00	198.52	100%	0.5%
3170	Consultant Selection	$41,220	$2,772	$0	$2,772	$38,448	$41,220	$41,220	$0	1.00	14.87	100%	6.72%
Phase 3 - DESIGN		$16,330,106	$9,294	$14,074,033	$14,083,327	$2,246,779	$327,436	$0	($327,436)	0.00	0.00	0%	0.06%
3200	Design	$431	$431	$0	$431	$0	$8	$0	($8)	0.00	0.00	0%	100%
3210	Project Management - Design	$894,275	$729	$1,524,120	$1,524,849	($630,574)	$20,447	$0	($20,447)	0.00	0.00	0%	0.08%
3220	Project Technical Support - Design	$900,000	$8,134	$937,994	$946,128	($46,128)	$4,116	$0	($4,116)	0.00	0.00	0%	0.9%
3250	Consultant Services - Design	$1,950,000	$0	$1,131,941	$1,131,941	$818,059	$44,586	$0	($44,586)	0.00	0.00	0%	0%
3251	Design Submittal 1	$3,100,000	$0	$3,590,099	$3,590,099	($490,099)	$258,280	$0	($258,280)	0.00	0.00	0%	0%
3252	Design Submittal 2	$3,900,000	$0	$2,541,410	$2,541,410	$1,358,590	$0	$0	$0	0.00	0.00	0%	0%
3253	Design Submittal 3	$2,490,000	$0	$1,998,947	$1,998,947	$491,053	$0	$0	$0	0.00	0.00	0%	0%
3254	Bid Support Services	$1,300,000	$0	$500,194	$500,194	$799,806	$0	$0	$0	0.00	0.00	0%	0%
3258	Environmental Documentation	$260,000	$0	$264,307	$264,307	($4,307)	$0	$0	$0	0.00	0.00	0%	0%
3259	District Design Reviews	$1,008,000	$0	$1,051,254	$1,051,254	($43,254)	$0	$0	$0	0.00	0.00	0%	0%
3273	Construction Bid and Award	$122,400	$0	$127,091	$127,091	($4,691)	$0	$0	$0	0.00	0.00	0%	0%
3280	Permit Acquisition	$405,000	$0	$406,676	$406,676	($1,676)	$0	$0	$0	0.00	0.00	0%	0%
Phase 4 - CONSTRUCTION / INSTALLATION		$183,206,629	$5,964	$227,865,785	$227,871,749	($44,665,120)	$0	$0	$0	0.00	0.00	0%	0.00%
3310	Project Management - Construction	$2,817,511	$0	$2,846,287	$2,846,287	($28,776)	$0	$0	$0	0.00	0.00	0%	0%
3320	Project Technical Support - Construction	$7,367,101	$3,676	$7,519,654	$7,523,330	($156,229)	$0	$0	$0	0.00	0.00	0%	0.05%
3321	PCI Support	$126,000	$0	$128,095	$128,095	($2,095)	$0	$0	$0	0.00	0.00	0%	0%
3350	Consultant Services - Construction	$5,147,916	$2,288	$5,286,499	$5,288,787	($140,871)	$0	$0	$0	0.00	0.00	0%	0.04%
3360	Contractor Work - Construction	$164,518,012	$0	$208,831,506	$208,831,506	($44,313,494)	$0	$0	$0	0.00	0.00	0%	0%
3362	Inspection	$1,514,117	$0	$1,525,161	$1,525,161	($11,044)	$0	$0	$0	0.00	0.00	0%	0%
3363	Testing	$1,715,972	$0	$1,728,583	$1,728,583	($12,611)	$0	$0	$0	0.00	0.00	0%	0%
Phase 5 - COMMISSION		$1,698,814	$0	$1,725,704	$1,725,704	($26,890)	$0	$0	$0	0.00	0.00	0%	0%
3410	Project Management - Commission	$93,407	$0	$94,947	$94,947	($1,540)	$0	$0	$0	0.00	0.00	0%	0%
3420	Project Technical Support - Commission	$576,000	$0	$585,903	$585,903	($9,903)	$0	$0	$0	0.00	0.00	0%	0%
3421	PCI Support	$180,000	$0	$183,011	$183,011	($3,011)	$0	$0	$0	0.00	0.00	0%	0%
3450	Consultant Services - Commission	$127,411	$0	$129,104	$129,104	($1,693)	$0	$0	$0	0.00	0.00	0%	0%
3460	Contractor Work - Commission	[illegible]	$0	[illegible]	[illegible]	[illegible]	$0	$0	$0	0.00	0.00	0%	0%

FIGURE 8-1. PROJECT COST REPORT

8.2 Earned Value Management

Earned Value (EV) is the value of completed work expressed in terms of the approved budget assigned to that work for a schedule activity or work breakdown structure component.

A critical component of accurate Earned Value Management is to determine the method by which Physical Progress will be measured.

- Consider project packages, complexity, duration, labor tracking requirements, construction tracking requirements, client requirements, schedule requirements, supplier progress tracking requirements, and subcontractor progress tracking requirements. Depending on the work breakdown structure, these factors can easily dictate which method would be most effective to utilize.

- Decisions on which method(s) of progress tracking to use can vary within a project based on different project situations. While there are several options, this project will include the following:
  - Resource Loaded Critical Path Method (CPM) Schedule
  - Rules of Credit/Schedule of Values
  - Quantity tracking
  - Level of Effort

The Earned Value for this project will be tracked in a Resource Loaded Critical Path Method (CPM) schedule with Physical Progress being measured against Rules of Credit (See Appendix F).

After identifying the different methods to be used, CH2M Hill will collaborate with RTI to determine progress measurement cycle. As Owner's Engineer, CH2M Hill will consolidate schedule updates into a master schedule as a means of evaluating project progress across several stakeholders.

Lastly, it is important to determine the specifications to be included for Earned Value reporting. These include the frequency and format of reports. With the Department of Energy providing funding and oversight for this project, the bulk of these specifications have been dictated to RTI and CH2M Hill.

8.3 Project Schedule Control

Schedule control serves as the primary tool for evaluating the overall status of the project. The schedule is a time-scaled graphic of the program, which displays the "big picture," comprising of owner activities, business planning, feasibility studies, design, preconstruction procurement activities, all construction activities from notice-to-proceed (NTP) through the punch list, and closeout. The project schedule is developed at the activity level of the project WBS structure. The key attributes of an integrated project schedule are as follows:

- Allows the tracking of all project milestones;
- Provides uniform mechanisms for measuring project performance (Earned Value Management)
- Identifies all dependencies between activities;
- Determines whether adequate time exists to accomplish all the activities of the project, regardless of who performs them;
- Capable of determining the critical path using critical path method (CPM) process;
- Exports into and imports from other schedule formats (for example from Primavera P6 to MS Project and vice versa);
- Electronically publishes into a document collaboration system or a public outreach web site to regularly update the general progress of the program (increases transparency);
- Integrates with the cost controls system, which assists in projects identifying project variances

A recommended schedule system will ensure resources are available at the points in time that are scheduled, and will monitor any funding constraints. The project schedule is shown in Appendix B.

The schedule also provides users with a sequence of activities that follow the progress of the project from initial project development through preliminary and final design, construction, commissioning, and closeout. A baseline of the initial schedule is captured and used to compare against evolving changes as identified by the PM. Variances from the initial baseline are reported in terms of days ahead or behind the approved baseline.

8.4 Scope Management/Change Management

It is the goal of the project leadership to develop a Balanced Change Culture amongst the various team members. This is accomplished by establishing a commitment to the following elements:

- Understanding of project “baseline” including contract, scope, and schedule from which changes may be recognized.
- Knowledge of and communication of change management philosophy, processes, and relevant forms to Project Team, client, suppliers, subconsultants, and subcontractors.

- Inclusion of clearly-defined change management methodology in subcontractor, subconsultant, and supplier requirements.
- Encouragement of beneficial change including Pro-Active Value Engineering and discouragement of detrimental change.
- An emphasis on the early identification and handling of potential changes.
- Commitment to include change management as a part of regular project meetings during the life of the project.
- Commitment from Project Team and client team members that authorization is mandatory before implementation of a change.
- Issue of project deliverable documents with well-defined scope, date, requirements, boundaries, and other requirements from which potential changes may be clearly identified.

Project Changes are the most common source of disruption, disagreements, and dissatisfaction among participants on projects. In order to create change management success, we will:

- Ensure complete understanding amongst team members of the baseline schedule, cost and scope criteria – recognize change.
- Agree as a group to distinguish scope changes from design developments.
- Commit to maintaining a baseline and promptly report and process all variances – evaluate and implement change,
- Use the results of project review meetings to incorporate lessons learned throughout the project phase implementation – continuously improve.

A Project Change Notice (PCN) is the standard format for recording, administrating and approving a change at the project level . It includes a brief description of the change and its associated impact on project cost (engineering and construction) and schedule. Any scope changes that impact project cost or schedule will require a PCN to be initiated and approved by RTI prior to implementation. The PCN form proposed for the project is shown in Appendix E:

PCNs will be tracked through the Project Change Notice Log (PCN Log) which is a log used to track and provide, at a glance, up-to-date information on the status of each PCN. The PCN log will be maintained by CH2M HILL and will be able to be accessed in real time through the project SharePoint site.

8.5 Reporting

8.5.1 EPC Contractor Reporting

To ensure early detection of schedule slippage and/or unfavorable cost trends, we have implemented the following schedule of weekly and monthly reports to be produced by the EPC contractor.

Reports Required by Phase

FEED

Weekly (Due by Noon Monday)

- Planned vs. Actual Hours and Cost
- Weekly Hours Charged and associated Cost
- Earned Value Analysis - By Discipline
- Weekly Engineering Metrics Report
- One Week Back / 3 Week Lookahead
- Updated P6 Schedule - Electronic Format (.xer file) through the last Friday
- Value Engineering Log
- Change Management Log with Number, Description, reason for change, Status, Hour, Cost and schedule impact,
  - Impacts organized and Reported by Phase
- Needs List/Action Items List

Monthly

- Project Cost Report
  - Original and Revised Budgets and Commitments, Actual Cost and Forecast
  - Earned Value Analysis
  - Cost Performance (Planned vs. Actual vs. Earned)
- Schedule
  - Critical Path Analysis
  - Float Analysis
  - Planned vs. Actual Progress Analysis
  - Milestone Table
- Monthly Metrics Analysis
- Staffing Report (planned vs. actual and forecast)
- Change Management Analysis
- Value Engineering Analysis
- Risk Register and Assessment
- Needs List/Action Item List

Detailed Design

Weekly (Due by Noon Monday)

- Planned vs. Actual Hours and Cost
- Weekly Hours Charged and associated Cost
- Earned Value Analysis - By Discipline
- Weekly Engineering Metrics Report

One Week Back / 3 Week Lookahead
Updated P6 Schedule - Electronic Format (.xer file) through the last Friday
Value Engineering Log
Change Management Log with Number, Description, reason for change, Status, Hour, Cost and schedule impact,
- Impacts organized and Reported by Phase

Needs List/Action Items List
Procurement Status
- PO Status
- Expediting Status
- Long Lead Item Status
- Commitments for the Week, Planned Commitments for following Week

Monthly

Project Cost Report
- Original and Revised Budgets and Commitments, Actual Cost and Forecast
- Earned Value Analysis
- Cost Performance (Planned vs. Actual vs. Earned)

Schedule
- Critical Path Analysis
- Float Analysis
- Planned vs. Actual Progress Analysis
- Milestone Table

Monthly Metrics Analysis
Change Management Analysis
Value Engineering Analysis
Risk Register and Assessment
Needs List/Action Item List
Work Package Matrix Status
Procurement Status
- PO Status
- Expediting Status
- Long Lead Item Status
- Commitments for the Week, Planned Commitments for following Week

Construction

Weekly (Due by Noon Monday)
Safety
- Hours Worked By Trade
- Incident / Near Miss Report

Quantities Installed by Subcontract / Trade
Productivity Report by Subcontract / Trade
Change Management Log
Open Submittal Log
Open RFI Log
Needs List / Action Item List
One Week Back / 3 Week Look-ahead

Monthly

- Safety
  - Safety Statistics including Number of Employees by Contract, Monthly and Project To Date Hours, Injury/Illness Type, etc.
  - Incident Summary Report
  - Planned Trade/Craft Histogram, Forecast
  - Planned Construction Management vs. Actual, forecast
- Project Cost Report
  - Original and Revised Budgets and Commitments, Actual Cost and Forecast
  - Earned Value Analysis
  - Cost Performance (Planned vs. Actual vs. Earned)
  - Cash Flow Curve
- Schedule
  - Critical Path Analysis
  - Float Analysis
  - Planned vs. Actual Progress Analysis
  - Forecast Analysis
  - Milestone Table
- Change Management Analysis
- Value Engineering Analysis
- Risk Register and Assessment
- Needs List/Action Item List
- Procurement Status
  - PO Status
  - Expediting Status
  - Long Lead Item Status
  - Commitments for the Week, Planned Commitments for following Week
- Construction Status
  - Contract Status
  - Commitments for the Week, Planned Commitments for following Week
  - Change Order Status

Quantity Curve
Productivity Report
Quality
Non Conformance Report Analysis and Status
Quality Incident Analysis

If an unfavorable trend is disclosed, a corrective action/recovery plan will be developed and implemented to mitigate the impacts.

8.5.2 RTI reporting to DOE

RTI with the assistance of their Owner's Engineer, CH2M HILL, will prepare quarterly progress reports to DOE. This report will include a cover page, table of contents, and the following sections:

- **Executive Summary** including a narrative of the project status to address design, procurement and construction phases. Key elements to be addressed are progress on the project, potential delays, budget status, and planned corrective actions for changes to schedule and cost.
- **Current Project Status** including highlights on completion of design, procurement, and construction as a function of percent complete. General status of EPC contractor's progress.
- **Project Schedule** update highlighting critical path and major milestone tasks to be accomplished within the next month's work schedule.
- **Project Cost Update** including original and revised budgets and commitments, actual cost and forecast, earned value analysis.
- **Project Manpower and Safety Record** tracking headcount for the contractors and subcontractors, labor hours on the project and definition of safety incidents.
- **Change Order Status** including an update of PCNs and Change Orders for design and construction.
- **Risk register and assessment**
- **Construction Site Photographs**

9.0 Environmental, Health, and Safety Management

The project leadership has adopted a zero incident target for this project – zero recordable and lost time safety incidents and zero environmental incidents. Safety is the responsibility of all team members. Achieving this target will involve considerable management attention to safety. The purpose of the Environmental, Health and Safety Plan is to ensure that the safety and health of plant personnel, contractor personnel and visitors is of primary importance through the establishment of safe procedures. The plan will include all the health, safety, and environmental programs and procedures required for project execution. The EHS Plan will be based on Shaw's standards and will incorporate standards of TEC if more stringent. The plan will incorporate a behavioral based safety program with elements of continuous improvement. An equally important element of the EHS management is Process Safety; that is to guide and ensure the safe development of the process during the design phase. This is accomplished by adopting safe design practices and adherence to process safety standards. The EHS plan will be incorporated into the PEP.

10.0 Quality Management

10.1 Scope

The purpose of the Quality Management Plan is to ensure that structures, systems, and components delivered are safe, reliable, operable, and well documented. Quality is an overarching function affecting Engineering, Procurement, Fabrication, Construction, and Commissioning. RTI's goals include the evaluation of performance as it relates to quality and the identification and correction of problems throughout the project-lifecycle.

This Quality Management Plan describes the Quality Management System (QMS) to be implemented for the Warm Gas Cleanup/CCS Project to achieve the quality objective stated above. It documents interfaces with other functional areas and project approach.

Engineering, fabricators, and construction will develop, document, and implement a Quality System Plan (QSP) specific to the project. The QSP will be reviewed and approved by RTI as part of the selection process and prior to commencing work. The QSP will define how each organization will address quality and reference all implementing procedures. Collectively, the project's QMS consists of this Quality Management Plan and the QSP developed by each major supplier.

10.2 Interfaces

<u>Engineering</u>

Engineering will review and approve the QSP for each supplier and proved limited monitoring of engineering activities. Interfacing will take place during the Quality Council sessions and through the review of quality reports prepared by each supplier. Monitoring of engineering quality is largely the responsibility of the Engineering team (See Engineering Plan for further details).

Procurement

Procurement and fabrication protocol are defined within the Procurement Plan. Fabrication quality control is complex and immensely important to the project; this responsibility is completely under the direction of Procurement. Quality will interface with Procurement through the review and approval of the QSP for suppliers providing procurement service, Quality Council sessions, and the review of quarterly quality reports.

Construction

Construction Management responsibilities will be assigned to EPC contractor. The Construction team will be responsible to develop a Quality Assurance Program and ensure all contractors adhere to the requirements of the program (See Construction Plan for further details).

Commissioning

Commissioning will prepare a litany of checklists, procedures, and reports in support of the plant commissioning activities. The Commissioning Team will ensure (in addition to construction) that all equipment and materials have been installed in accordance with the appropriate QSPs.

10.3 Approach

The Quality Management team will ensure that the project personnel performing or managing activities affecting quality are conversant with this plan by way of training (required reading). Key personnel will consequently be aware of the quality objectives defined within this plan. Records of training will be tracked by the Project Quality Management Team.

Each major supplier will be required to develop a QSP. The QSP will be reviewed by the Quality Management Team. Once approved, the supplier will be required to submit quality status reports on a regular basis. This will allow RTI to be certain that equipment fabrication is in accordance with the agreed upon QSP.

Finally, RTI intends to have a quarterly Quality Council meeting to solve problems in engineering, procurement, and construction with the intent to improve and set best practices in the quality area. The council will be represented by quality assurance manager, RTI key personnel, and major suppliers. The council will review quarterly reports and openly discuss issues affecting quality. Conference notes will be issued with recommended corrective actions, recommended preventative actions, and recommended defect repair as required.

11.0 Communications Management

The project has adopted a communications protocol that will ensure that all relevant project communications are logged and archived for record keeping purposes. The protocol is based on a document numbering system that facilitates retrieval. All communications will be stored electronically on CH2M HILL's SharePoint server site. The following outlines the communications protocol.

COMMUNICATIONS MANAGEMENT

1.0 General
- 1.1 Correspondence should be in writing
  - 1.1.1 Informal discussions are encouraged to be documented by e-mail
- 1.2 Correspondence should be transmitted electronically
- 1.3 Each originator should maintain its own sequential control log
  - 1.3.1 Log should include date transmitted , document name and number, and brief description
- 1.4 CH2M HILL will maintain record copies of all correspondence on its SharePoint
  - 1.4.1 All correspondence must be copied to 419203@sites.ch2m.com

2.0 Naming Convention for E-mails and Letters		Type
2.1 For E-Mails:	Type-Originator-Receiver-XXXX	E
2.2 For Letters:	Type-Originator-Receiver-XXXX	L

2.3 Originator - Receiver Key

DOE	Department of Energy
RTI	RTI International
S	Shaw Group
C	CH2M HILL
TEC	Tampa Electric Company
B	BASF
SC	Sud Chemie

2.4 Examples

2.5.1	Outgoing letter from Shaw to RTI:	L-S-RTI-XXXX
2.5.2	Outgoing e-mail from Shaw to RTI:	E-S-RTI-XXXX
2.5.3	Outgoing transmittal Shaw to Distribution:	T-S-DIST-XXXX

3.0 Naming Convention for Transmittals:

3.1 Engineering transmittal for External Issue –
SHAW-T-E-RTISYNGAS-xxxxxx

3.2 Shaw Internal transmittal for Incoming Vendor Documentation Review –
SHAW-T-V-RTISYNGAS-xxxxxx

3.3 Shaw Outgoing transmittal for submittal back to Vendor –
SHAW-T-SD-RTISYNGAS-xxxxxx

3.0 Naming convention for Meeting Minutes

3.1 MOM-ORIGINATOR-DISCIPLINE IDENTIFIER-XXXX

3.1.1 Discipline Identifiers

CSA	Civil / Structural
E	Electrical
FS	Fluid Systems
I	Instruments
ME	Mechanical
PE	Project Engineering
PM	Project Management
PG	Piping
PR	Process
PS	Plant Services
CON	Construction
PRO	Procurement
HSE	Health, Safety, Environmental
Q	Quality

3.2 Example

FEED Kick-off meeting MOM-C-PM-0001

12.0 Document Management

CH2M HILL will be the single point of contact for all project documents issued for information, review and approval. CH2M HILL will receive transmittals from Shaw and distribute the documents with appropriate instructions to team members in accordance with the approved document control matrix. CH2M Hill will also consolidate comments from team members and transmit them back to Shaw. All record documents will be stored electronically on a secure CH2M HILL server. A flowchart depicting the flow of information is shown in Appendix G.

13.0 Engineering Management

Basic and detailed engineering for the Warm Syngas Cleanup and CCS Demonstration Project will be executed by the Shaw Group, in accordance with Part B, sub-part 1, section 7 of the Project Execution Plan. This section details the design basis by engineering discipline. The design effort is being prosecuted by Shaw engineering discipline leads who report to the Engineering Manager, who is responsible for coordinating the overall design effort. The Engineering Manager in turn reports to the Shaw Project Manager, who is responsible for coordinating the design effort with the procurement and construction groups.

As Owner's Engineer, CH2M HILL has engineering leads assigned in each engineering discipline to review and approve selected design documents as identified on the Document Control Index on behalf of RTI. CH2M HILL discipline engineers will also spot check documents issued for review. The primary intent of these reviews is to help catch potential design errors before they may impact procurement or construction and to possibly suggest a more efficient and less costly design approach.

14.0 Procurement Management

Procurement for the project will be executed by the Shaw Group, in accordance with Part B, sub-part 1, section 8 of the Project Execution Plan. This section governs the purchasing, inspection, expediting, logistics of equipment and bulk materials procurement.

15.0 Construction Management

Construction Management will be executed by the Shaw Group, in accordance with Part B, sub-part 1, section 10 of the Project Execution Plan. The early interfacing among the engineering team, TEC operations, and the construction team is of the upmost importance to developing a constructible design that is integrated with the Polk power plant. Constructability reviews will facilitate and formalize this process. Site construction will be governed by the Project Construction Plan. This plan to be developed by Shaw Group will cover construction mobilization, construction permits, craft labor management, construction equipment, tools and consumables management, subcontractor management, site HSE and security management, construction quality control and quality assurance, and construction site closeout.

Permitting and construction of the deep well for carbon sequestration will be executed by TEC utilizing plant standards and procedures.

CH2M HILL, as Owner's Engineer, will supplement the on-site construction team with a construction engineer, a project controls/scheduling specialist, and a document controls specialist. These positions will continue to support the RTI Project Manager during the construction phase.

16.0 Commissioning Management

Commissioning Management will be executed by the Shaw Group, in accordance with Part B, sub-part 1, section 11 of the Project Execution Plan. A system package identification and turn-over sequencing will be developed to provide the drivers for the prioritization and completion of the preceding engineering, procurement, construction and construction testing activities. The commissioning and start-up plan will cover assembly and management of the commissioning team, system turnover packages, system turnover schedule, system turnover process, testing and reinstatement, initial fills, start-up, operations and shut-down procedures.

17.0 Operations Management

Operator training in the start-up and operating procedures is critical to the successful operation and demonstration of the plant. A training program will be developed in close coordination with TEC to provide the necessary training. The plant will be demonstrated through 8000 hours of operation. The operating plan will identify which operating parameters will be measured and at what frequency. It will also establish an operating reporting format for monthly reporting of operating performance to DOE.

18.0 Closure Management

A Closure Management Procedure will be developed to govern the closure of the demonstration project. It will cover issues such as dismantling or transfer of ownership of the physical plant, continued operations of the plant, continued access to operating data by RTI and DOE, and final closure report.

19.0 Risk Management

19.1 Purpose

This Project Risk Management Plan establishes the process for implementing proactive risk management as part of the overall project management. The purpose of the plan is to identify potential problems before they occur, so that risk-handling activities may be planned and invoked as needed across the life the project to mitigate adverse impacts to project objectives. Project Risk management is a continuous, forward-looking process that addresses issues that could endanger achievement of critical objectives and includes early and aggressive risk identification through the collaboration and involvement of relevant stakeholders.

This document describes the process to:

- Identify risk events and risk owners.
- Evaluate risks with respect to likelihood and consequences.
- Assess the options for risks and develop mitigation plans.
- Track risk mitigation efforts.

- Conduct periodic reassessment of project risks.

The Project Risk Management Plan should be updated as necessary and the identified risks will be tracked until they are retired.

19.2 SCOPE

The Risk Management Plan applies to major projects or significant programs where numerous execution risks exist and a robust management plan involving multiple persons and parties is advised.

The Risk Management Plan includes risk identification, qualitative analysis, risk mitigation, and risk monitoring for the Warm Gas Cleanup and CCS project. The Risk Management Plan will initiate from the onset of the project, continue through EPC, Commissioning, and Operations, and close out once all the risk items are closed out.

RTI will utilize CH2M Hill to develop the Risk Management Process and facilitate the initial risk management workshop. Once the risk register is created, RTI will manage the risk register by working with Shaw and TEC to develop risk impact scoring for each item, develop mitigation plans for each risk item, and monitoring the progress of existing risk items and identification of new risk items.

19.3 Definitions

1.1. Company – RTI

1.2. Consultant – Project Management Consultant (PMC) – CH2M HILL

1.3. Contractor – EPC Contractor – Shaw Group

1.4. Risk is a measure of the inability to achieve overall project objectives within defined cost, schedule, and technical constraints, and has two components: 1) the probability (or likelihood) of failing to achieve a particular outcome, and 2) the consequences of failing to achieve that outcome.

1.5. Risk Events are those events within the project that, if unsuccessful, could result in the failure to meet the project's objectives. Risk events should be defined to a level so that the risk and causes are understood and can be accurately assessed in terms of probability and consequences to establish the level of risk.

1.6. Technical Risk is the uncertainty of achieving the project's requirements for function, performance, and operability within the planned cost and schedule. Technical risks are associated with the ability of the system (i.e. product) design to meet the level of performance required to satisfy the operational requirements. Failure to adequately address technical risk generally results in an inability to meet cost and schedule constraints while meeting technical requirements.

1.7. Cost Risk is the uncertainty in achieving the cost budget if none of the technical or schedule risks should materialize. Cost risks are associated with the ability of the project to achieve its overall cost objectives. Two risk areas bearing on cost are: 1) the risk that the cost estimates and objectives are inaccurate and/or unreasonable, and (2 the risk that project execution will not meet the cost objectives as a result of a failure to mitigate cost, schedule, and performance risks.

1.8. Schedule Risk is the uncertainty of achieving the project schedule if none of the technical or cost risks should materialize. Schedule risks are those associated with the adequacy of the time estimated and allocated for the planning and execution of the project. Two risk areas bearing on schedule risk are: 1) the risk that the schedule estimates and objectives are unrealistic and/or unreasonable, and 2) the risk that project execution will fall short of the schedule objectives as a result of failure to mitigate cost, schedule, and performance risks.

1.9. Project Risk is a risk that affects multiple project phases or spans the whole project structure and is subject to scrutiny at the highest levels of project management. Project risk is associated with the overall status of the project. Failure to meet cost, schedule, and technical objectives can produce project risk. In addition, external budget, priority, and customer considerations can produce project risk.

Risk Assessment is the translation of risk data into information for evaluating risk and determining the probability and consequence. A risk assessment (or rating) is the value or level that is given to a risk event based on the analysis of the probability and consequence of the event. The two primary methods of risk assessment are:

Qualitative – Evaluation of the amount of risk by comparative methods.
Quantitative – Evaluation of the amount of risk in a project by numerical means.

1.10. Risk Analysis is the process of calculating or determining the probability of occurrence, magnitude of impact, and the relationships between risks and their cumulative impact upon the project outcome.

1.11. Risk Prioritization consists of rank those risks that, if they occur, will have the greatest effect on the project.

1.12. Risk Metrics are measures used to indicate progress toward the avoidance, mitigation and/or monitoring of risk events.

1.13. CPM – Critical Path Method

1.14. PERT – Program Evaluation and Review Technique

1.15. WBS – Work Breakdown Structure

1.16. RBS – Risk Breakdown Structure

1.17. Mitigation Measures – Measures to reduce the effect of a risk by either a) reducing the probability of a risk, b) reducing the risk impact, or c) eliminating the risk inputs all together.

1.18. P10 - The value that separates the smallest 10% of all values from the largest 90% (10th percentile).

1.19. P50 - The value that separates the smallest 50% of all values from the largest 50% (50th percentile).

1.20. P90 - The value that separates the smallest 90% of all values from the largest 10% (90th percentile).

19.5 PROCEDURE

The risk management process is comprised of five phases: strategize, identification, assessment, respond, and monitoring. (Refer to Figure 1 below)

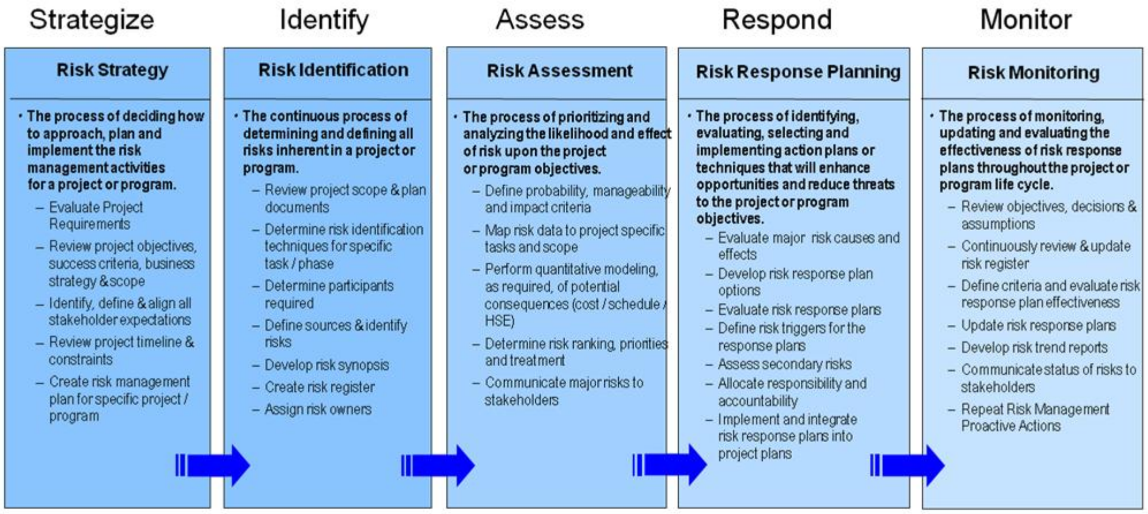

Figure 1: Risk Management Process

The following sections describe the suggested risk management process. Project may tailor this process to best meet the needs of the project and/or satisfy the customer. The risk management process includes the following elements:

- Strategize – This is the process of deciding how to approach, plan and implement the risk management activities for a project or program. This step takes into account the project requirements (such as objectives, success criteria, business strategy & scope), defining and aligning all stakeholder expectations, review project timelines and constraints, and create risk management plan for the project.

- Risk Identification – Examine all project elements in detail. Identify, describe, and document cost, schedule, technical, financial, and other risks. Begin the identification process as early as possible and continue throughout the project lifecycle.

  This element should be reviewed and re-analyzed at minimum after major stage gates of the project. Larger projects should consider formal reviews more frequently (quarterly or twice per year) and informal internal project reviews monthly.

- Risk Assessment – Evaluate the identified risks for probability of occurrence and potential impact. Estimate project exposure and establish risk-handling priorities. Qualitative assessments may be used as an initial filter, but all medium and high risks must be assessed quantitatively. Express quantitative assessments (i.e. Rough Order of Magnitude – ROM) in terms of dollars, time, and performance impact, as applicable.

This element should be reviewed and re-analyzed correspondingly with the Risk identification activity. At minimum after major stage gates of the project. Larger projects should consider formal reviews more frequently (quarterly or twice per year) and informal internal project reviews monthly.

- Risk Response – This is the process of identifying, evaluating, selecting, and implementing action plans or techniques that will reduce threats to the project. During this phase, risk mitigation plans will be developed for each risk identified and ownership assigned for each mitigation plan.

- Risk Monitoring – Track progress against action plans and established metrics to ensure timely completion of actions. Include risk name, description, identification date, owner, action plans, milestones, status, and contingency actions.

  This element should be performed/updated on a regular repeatable timeframe. Depending on project size and length, monthly or quarterly updates are common schedules for performing these updates.

19.6 RISK IDENTIFICATION

Risk identification is the process of examining the project areas and each critical technical process to identify and document the associated risk. The identification of potential issues, hazards, threats, vulnerabilities, and opportunities that could negatively affect work efforts or plans is the basis for the risk management strategy. The project utilizes several methods for identifying risks:

- Examination of the work breakdown structure (WBS)
- Reviewing risk management efforts for similar projects
- Examination of Lessons Learned
- Examination of design specifications and requirements

It is vital that the teams understand that the risk identification process is to identify not only negative risks to the project – but also should spend significant effort in identifying positive risks (opportunities) for the project.

Risk Identification efforts will be formally conducted at the following project lifecycle points:

- Project FEL-2 commencement

- Project Full Sanctioning / FEL-3 Engineering & Procurement commencement
- During early Detailed Construction Planning. Engineering should be well progressed and Procurement should be initiated on all materials with the exception of bulks.
- During Detailed Commissioning / Startup Planning.

Cost risks may include those associated with funding levels, funding estimates, and distributed budgets. Schedule risks may include risks associated with planned activities, key events, and milestones. Performance risks may include risks associated with the following:

- Requirements
- Analysis and design
- Functional performance and operation

Individual team members involved in the detailed day-to-day technical, cost, and scheduling aspects of the project are most aware of the potential problems (i.e. risks) that need to be managed. Part of the risk assessment process will be survey the team members for potential risk events and circumstances. The process accumulates and documents information on events or circumstances that will be evaluated to determine any potential adverse impact on the project from a technical, cost, or schedule standpoint. The following indicators should be used:

- Lack of stability, clarity or understanding of requirements
- Failure to use best practices
- Insufficient resources
- Negative trends or forecasts

Identification gathering techniques which will be utilized include the following (with commentary on where and how each is applicable):

- Brainstorming Workshops – will be applied at 4 stages of the project. Better results are often had applying this at the beginning of individual phases of the project and with the project team members. Brainstorming participants will involve personnel with a wide vertical range of control of the project rather than simply the leadership. Brainstorming sessions will be lead by a neutral/independent facilitator.

- Checklist Analysis – this will be accomplished by fashioning CH2M HILL's standard checklist into an electronic questionnaire. The questionnaire will be developed after the Brainstorming workshop at each phase and will focus both on additional identification as well as quantification

- Assumptions Analysis – these reviews are most applicable to early and late stages of projects. Early stages are validation that reasonable assumptions have been made to move forward with. Mid to Late stage assumption analysis is more geared to identifying if conditions exist on the project which raise question to assumptions.

- Lessons Learned review. Lessons Learned from prior similar projects will be examined with relevant items placed before the leadership team for inclusion to the risk register. This will be performed after the Brainstorming Workshop and Checklist Analysis efforts so as not to create duplicates.

19.7 RISK ASSESSEMENT

Risk assessment is the process of analyzing known risks and prioritizing them based on their impact to project goals and objectives. During the assessment stage, the project analyzes each risk to isolate its cause and to determine its effect. The project rates the risk in terms of its probability of occurrence and its severity of impact to cost, schedule, and technical performance, as applicable.

The probability of a risk issue is the chance that the risk will materialize as a "real project problem". This probability can be expressed in quantitative (e.g. ROM) or in qualitative terms (i.e. high, medium, or low). The risk impact is a measure of how the project is affected if the risk issue materializes.

Qualitative assessment will be performed on this project at every formal stage as well as at regular interval updates. Qualitative assessment can be made by either the Risk Management team/staff, the Project Management staff, or a subset of project leadership personnel.

Quantitative assessment should be performed on projects with significant risk sensitivity, rigid performance requirements on schedule or cost and in particular where there are regulatory consequences, very large or mega projects, and on projects with complex risk components that have high levels of interaction and potential correlation.

Where quantitative analysis is performed it is advised that the risks modeled be selected from those identified through the qualitative process for those having high-high or any combination of medium – high rankings.

The criteria for qualitative assessment follows:

- A high occurrence of the undesirable event will result in:
  - Inability of the design to meet primary functional requirements
  - Unacceptable cost performance (i.e. major cost overrun)
  - Failure to meet schedule (i.e. critical delivery date(s) missed)
- A medium occurrence of the undesirable event will result in:
  - Non-critical design requirements not met
  - Minor cost overruns
  - Intermediate milestones not met
- A low occurrence of the undesirable event will result in:
  - Some non-critical design requirements not met
  - Minor cost overruns that are offset by underruns
  - Intermediate milestones not met

Overall risk assessment is the product of combining the probability of occurrence with the severity of impact as follows:

	Degree of Probability	**Qualitative Approach Estimate**	**Quantitative Approach Estimate**
Probable	High Probability	Very High	85% - 100%
Probable	High Probability	High	65% - 85%

Probable	Medium Probability	Medium	50% - 65%
Improbable	Medium Probability	Medium	35% - 50%
Improbable	Low Probability	Low	15% - 35%
Improbable	Low Probability	Very Low	0% - 15%

Once the risks are assessed, they are categorized into defined risk categories, providing a means of determining the most effective area to which resources for mitigation may be applied to achieve the greatest positive impact to the project.

Quantitative assessment shall be applied where required.

19.8 Risk Response

Risk Response is the process of identifying, evaluating, selecting and implementing action plans to mitigate identified risk items. This process includes the evaluation of major risk causes and effects. From that evaluation, risk response plans are developed to mitigate the risk. Once the plans are created, the Project Manager will assign responsibility to one of the project team members to complete. Finally, the risk response plans will be assigned a completion date.

19.9 REPORTING AND MONITORING

The PMC Risk Manager shall be responsible for the following activities as part of the Risk Monitoring efforts. These actions will be focused on determining new project risks, changes to existing known risks, effectiveness of mitigation/handling methods, and effects of current project status upon forecasted outcome.

- Review of project status reports
- Participation in project review meetings on an as-needed and regular basis.
- Regular and on-going engagement with EPC CONTRACTOR's key leads.

- Review of Requests For Information and Change Orders
- Sampling review of major deliverables from CONTRACTOR's
- Update of the Quantitative Risk Models to included:
    - Schedule and Cost Progress
    - Risk Updates and Retirements
    - Incorporation of EPC CONTRACTOR risk model input changes (schedule, estimate, etc.)
    - Updated forecast of mitigation / handling measure effects.

19.10 RISK CLOSEOUT AND LESSONS LEARNED

At the end of the project – all risks associated with project execution should be closed out and retired. In particular, each risk should be noted as to whether the risk was actually experienced or not. Where experienced, a qualitative assessment of the effect of mitigation should be recorded.

The qualitative assessment of the impact of the mitigation should be fed to the Project Lessons Learned and suggestions developed there for improving the mitigation efforts in the future.

Part B – Shaw Project Execution Plan

Project Management Plan, Part 1 – Shaw Energy & Chemicals
This part of the Integrated Project Plan, compiled by Shaw, consists of component plans that provide the "who, what and when" direction to the Shaw team members. It is at a strategic level, not the "how to" tactical level. The "how to" details (procedures, work instructions, etc.) will comprise Part 2.

As the project moves through the project life-cycle from FEED to the detail engineering, procurement, construction, commissioning, operations and testing phases, this plan will be updated as required. It will be a dynamic and living document expanding the content only as developments occur that necessitate adjustment or clarification regarding the "who, what and when" direction.

Project Management Plan, Part 2 – Shaw Energy & Chemicals
This part of the Integrated Project Plan compiled by Shaw will contain the day-to-day procedures and work processes for each individual Shaw department/discipline to follow in producing their respective work products. They will likely be a combination RTI, TEC, Shaw and permitting agency standards. They may be implemented by specific reference or by attachment. Deviation from Shaw standards on an 'added –value basis' is acceptable if submitted, approved an incorporated in this part of the Project Management Plan in advance.

PROJECT MANAGEMENT PLAN – PART 1

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General

As of May, 2011, the path forward is that a FEED will begin approximately May, 2011. The objective is to establish a technical basis and deliverables for providing a Class III Estimate (± 20%) and CPM Schedule by approximately September, 2011. Following the submittal the Department of Energy will assess the project for providing full funding for the detail engineering, procurement, construction, commissioning and testing operations. The purpose of this project management plan is to address only the activities to carry the work through the FEED cycle, but enable the structure for an efficient and rapid transition to the full EPC phase. When the EPC phase is approved, this plan will be expanded commensurate with the scope and detail required. All the basic elements are contained in the present document.

It is emphasized that the primary purpose of the FEED and its supporting documentation is to provide to Research Triangle Institute a Class III Estimate (± 20%) and CPM Schedule.

1 Contract Management

Throughout the life cycle of this project, the project manager/director is responsible for all aspects of the management of the contract with RTI. This includes all interfacing with RTI and all of Shaw's groups and affiliates. As the project evolves the project manager/director may delegate responsibilities, but is still accountable.

Given the nature of the contract and requirements of the Department of Energy and the American Recovery and Reinvestment Act (Recovery Act) of 2009, it is important that all team members are familiar with the requirements effecting responsibilities.

2 EHS Management

Shaw's Senior Director of Environment, Health and Safety in the Houston Office is accountable for ensuring the compliance with Shaw's standards, incorporating standards of RTI and TEC, where they exceed or compliment Shaw's requirements. Due to the nature of installing this demonstration plant in the Polk Power Station, it is necessary that sound EHS standards are deployed immediately to communicate and train personnel who will need to visit the site early in the FEED execution.

At a minimum, during the FEED for this project the EHS activities will include:

A. Begin every meeting with a safety topic

B. Ensuring that Shaw personnel visiting either operating facilities of Tampa Electric, Eastman or potential manufacturing locations of suppliers are properly indoctrinated and trained. This is to include task safety analyses.

C. Authoring the preliminary EHS Plan for the EPC and Operations Phase of the project to ensure the costs are included in the Class III estimate product of the FEED

3 Quality Management

A. Quality Assurance

Shaw's Director of Quality Management is responsible for the assurance that sound and value-added work processes for all components of work on this demonstration project are deployed. This individual will report to the Shaw Project Manager/Director for the demonstration project. This begins immediately. Where it makes sense and in good judgment to modify standards consideration the demonstration nature of this project, his timeliness oversight, recommendation to Shaw's project Manager/Director is crucial. As the life-cycle progresses, it is expected the Director will delegate responsibilities to manager within the staff.

B. Quality Control

Quality Control for the project is the responsibility of the Manager of Quality Control. This individual will report to the Shaw Project Manager/Director for the demonstration project. During the FEED it will be necessary for the manager to compile the equivalent of a vendor/supplier quality plan. This is necessary to ensure that all budgetary quotations solicited during the FEED are in compliance with contract requirements. As the FEED concludes with the potential of commitments for long lead engineering and/or equipment, the appropriate quality requirements will be updated to a commensurate, for purchase quality.

4 Communications Management

Shaw will comply with the Communication Management process outlined in Section 11 of RTI's overall Project Execution Plan.

5 Document Management

Shaw will comply with the Document Management process outlined in Section 12 of RTI's overall Project Execution Plan.

6 Scope Management

Refer to Appendix D Division of Responsibilities Matrix This document provides the basis for all of the parties' scopes of work.

7 Engineering Management

General Engineering Requirements

Execution Strategy/Deliverables to RTI

This is a Class III Estimate (±20%) and CPM Schedule driven FEED. RTI's direction is for Shaw to provide the minimum level (type, quantity and level of completeness) practical in order to support Shaw's Class III Estimate (±20%) and CPM schedule. Therefore Shaw will proceed on the requirements required by the Estimating Group to compile a Class III Estimate (±20%) supplemented by recommendations from engineering considering special/unique situations given the first of a kind nature of the project.

Design Criteria

Engineering will issue at the beginning of the FEED and continue to update throughout the FEED phase the appropriate documentation to ensure the Class III Estimate (±20%) incorporates the proper design parameters from the process perspective (to ensure successful demonstration testing) and to comply with the applicable codes, standards, etc. that comprise sound, process plant engineering. The methodology used for documenting the criteria and basis is to be cost effective and suit for purpose. It is the engineering team's responsibility to choose the commensurate best path forward regarding separation of documents or compilation into a single document.

Equipment & Material Procurement

Engineering will initiate and participate in the procurement process as outlined in the following sections.

Requisitions

The Class III Estimate (± 20%) requires that budget pricing be obtained for approximately 80% of the total equipment value. Requisition packages for these equipment items will be prepared by the Shaw subject matter expert and released for competitive inquiry through the Procurement Department. They will include scope of supply, technical data sheets and specifications.

After an inquiry is issued and until the order is awarded, all contacts relating to commercial aspects with vendors will be conducted through the Procurement Department. All contacts relating to technical issues will be made by the responsible engineer and procurement must be copied. These will apply to telephone calls, meetings, and all correspondence and communication with vendors. During the FEED phase, equipment and material technical bid evaluations will only be done for the lowest bid in order to qualify it technically.

Internal Design Reviews

Each discipline will conduct internal reviews of all documents prior to release for inter-discipline squad check. Any changes to scope requested by RTI or Shaw must be approved via the change control process before implementation.

The review of released documents is managed and coordinated by Shaw's technical information group.

The Engineering Manager or designee will provide final internal approval of all FEED documents issued.

Professional Sealing of Documents

Sealing of final drawings, specifications, plans, reports and final documents provided to the owner or the owner's representative shall be sealed per Florida Statutes. FEED documents which are preliminary and are expected to be further developed by the detailed design engineering firm shall NOT be sealed but shall be designated as "Preliminary Not for Construction intended for Planning or Permitting Purposes only".

Project Document Master Sets

Master Sets of scope setting documents such as P&ID's, Plot Plans, Equipment Lists and Equipment Arrangements will be maintained by the responsible discipline lead at the squad check table or equivalent.

Design Change Management

Changes will be managed using a rigorous work process in compliance with Shaw's standards. As soon as a potential change is identified the Engineering Manager will be notified immediately prior to commencing work. The

Engineering manager will meet with the Project Manager/Director and establish a path forward.

Drawing and Document Lists
All disciplines will prepare a comprehensive list of drawings and deliverables at the beginning of the FEED and provide to the Engineering manager for review and distribution. The discipline will keep this list up to date through-out the project as new documents are identified or removed from the project.

Progress Reviews
The progress of the design will be tracked on a monthly basis by WBS element using Shawtrac. Shawtrac uses a rule of credit milestone drive earned value system to track progress. In some cases the tracking may be done with an external list such as the drawing index or line list and the data transferred to Shawtrac. Tracking will be done at the deliverable level where possible based upon predetermined milestones. The milestones shall be associated to a percent of budget expended and rolled up into an overall percent complete. Each discipline shall update the status tracking system by the end of the week on during the last week of each month.

Requisition Log
The requisition log will be maintained by the Procurement Manager.

Specification Deviation Requests
Requests for changes to or deviations from the RTI specifications are to be done via formal written request.

Original Site Drawings
Requests for original TEC drawings, either checking out of originals or getting copies, should be made through the Engineering Manager. The technical information lead will keep a log of all checked out originals.

Process Engineering

Process Engineering shall develop a process basis of design per the process design discipline technical procedure. The previous Design Basis Memorandum from the PDP (Areas 100 to 300) shall be revised and either modified to incorporate the carbon capture portion (Areas 400 to 600) or appended to accommodate it. The Process design basis will define the methodology, procedures and tools that will be used to develop the process design deliverables. A project design data document will be developed to define basic key project data.

PFDs will be further developed during FEED to Shaw Energy & Chemicals and Tampa Electric Company's formats and standards.

P&IDs will be developed to Shaw Energy & Chemicals and Tampa Electric's formats and standards. Existing P&IDs in OSBL will be modified and updated where required.

Tie-in interface diagrams will also be developed as part of the FEED.

Process will perform preliminary hydraulic calculations for pump circuits, reboilers and tower overheads to determine the required minimum line size for all single phase, 2- phase and compressible fluid lines. .

Relief loads will be tabulated and summarized for various relieving cases. The relief header will be sized and routed to existing relief systems. The cases will be compared to what TEC is able to receive.

Process engineering will prepare and issue a Line Designation Table (LDT or Line List) which shall indicate the normal operating and design conditions, piping line class, line size and insulation type.

Process will prepare a Tie-In/ Battery Limit Summary and a preliminary piping specialty items list.

Process Data Sheets will be developed for all tagged equipment consistent with the requirements set forth in the Estimate Plan contained in Part 2 of the Project Management Plan in support of the Class III Estimate (±20%).

Process instrument data will be presented in tabular format.

Process/Process Environmental will provide technical support to RTI for environmental permitting in accordance with Tampa Electric Company's Permitting Information Spreadsheet, "PPS Warm Syngas Clean-up/Carbon Capture & Sequestration Permitting Information Needs List". Assumptions/Clarifications with regard to the process Environmental Scope of Work and Design Basis are as indicated in Attachment 9, Process Environmental/Utility/Offsites Requirements Chart, Rev 1, updated 2/24/11.

Process will update fire protection model provided by RTI. Basic P&IDs for new fire protection and deluge systems will be developed.

Process will participate in a Preliminary Hazard Analysis and prepare a report of findings for implementation.

Process will participate in the HAZOP.

Process will prepare a preliminary as detection and monitoring location plan.

Piping Design/Layout

Plot Plan

Preliminary conceptual Plot Plan development will begin with 2D studies and be further developed into a conceptual 3D equipment model. Plot development will take into account Shaw, RTI, code and regulatory spacing requirements.

Piping material MTOs will be extracted from the plot plan and line list for piping components 3" and larger. Small bore piping will be factored using in-house metrics by Estimating Group. General Pipe Supports MTO will be factored based on Piping quantities.

Mechanical Engineering

Sized Equipment List

The sized equipment list will be maintained by Process Engineering with input from the leads for the vessels, heat exchanger and rotating equipment groups. The list will contain the equipment tag numbers, physical size, weights, material of construction, estimated motor horse power and P&ID reference.

Equipment Data Sheets with Mechanical Drawings

The mechanical group will develop equipment data sheets and/or equipment outline drawings for those items that will be inquired in support of the budget equipment pricing provided to the Class III Estimate.

Materials Engineering Technology

The Materials Engineering Technology Group will provide the following services:

- Review of Line classes
- Produce a Material Selection Diagrams (CAD Format-Color Version) as needed.
- Review Vendor quotes for Equipment as needed

Electrical Engineering

General

The Electrical Scope of Work includes: electrical systems basis of design philosophy and narrative, motor/load list, analysis of the existing electrical systems and tie-in points, overall one-line diagrams for switchgear and MCC's, hazardous area classification drawings, specifications & data sheets for major electrical equipment and electrical system calculations.

Preparation of the electrical systems design philosophy and narrative will be done in accordance with Shaw Energy and Chemicals and Tampa Electric Company's formats and standards.

Electrical System Design

The electrical system will be designed and developed based on established, engineering practices. Emphasis will be placed on reliability of service, safety of personnel and equipment, ease of maintenance and operation and maximum interchangeability of equipment.

Major electrical system components and their mutual relationships to each other will be as shown on the one-line diagrams. The power system will be designed to support the functional requirements of loads for all modes of plant operation. Protective and control devices will be provided to ensure operational reliability and availability of the electrical systems. The electrical system will be simple to operate and maintain and will have adequate backup facilities.

Voltage, insulation levels, interrupting and continuous current capacities, circuit protection, and short circuit withstand capability of electrical equipment will be selected and coordinated in accordance with applicable standards and codes.

Bulk material quantities will be determined by using some basic design sketches and some Material Take-Offs (MTO) will be performed using standard factors.

Power Control Center (PCC) layout and specification

Data sheets for the Power Control Center will be issued during the FEED phase along with one line diagrams, and the specifications for the electrical distribution equipment and the building.

Control Systems (CSE)

The Control Systems Scope of Work includes:

General Instrumentation Philosophy

General Instrumentation Philosophy will be developed in accordance with Process Industry Practices (PIP), Shaw and Tampa Electric's standards.

Complex Control Narrative

The Control Narrative will be developed describing complex control for major controls shown on the P&IDs.

Interlock Narratives (SIS/ESD)

The Interlock Narratives will be developed in accordance with Shaw standard interlock narrative guideline templates.

Instrument Data Sheets
Instrument Data Sheets will be prepared by CSE, listing control valves, on-off automated valves, orifice plates, analyzers, etc. Individual instrument data sheets will not be developed.

Instrument List
The Instrument List will be developed will include Instrument Tag Number, P&ID Reference Number, Service, Location, Instrument Type, and I/O Type.

Control System design and specification
The Control System Design and Specification will be developed and will include preliminary specifications for DCS and SIS systems, including system architecture and I/O count, suitable for obtaining budgetary quote.

Plant DCS to Warm Syngas Clean-up System control datalink
Will be developed with selected vendor assistance and thoroughly reviewed by RTI and TECO for acceptability. The results will be communicated as part of Control System design and specification.

P&ID Input/Review
Control Systems input to P&I Diagrams and review.

Civil/Structural (CSA)

The Civil effort will be executed in accordance with Shaw and Tampa Electric's Civil/Structural Technical and General Procedures. Input from these procedures will be tailored as required to meet RTI and project objectives and requirements.

Design Criteria
At the beginning of the project, Design Criteria will be produced for use by the CSA team members. This document is based on the Basic Engineering Design Document, RTI Specifications and Practices and Procedures.

Structural and civil drawings
Preliminary or conceptual structural and civil sketches will only be developed as needed for support of the other disciplines or estimating.

Specifications
Shaw will provide CSA specifications as indicated in the attached External Deliverables List (See Attachment 7).

Material take-off

Material take-off for major structural steel and concrete will be developed from the conceptual sketches. Miscellaneous steel and concrete quantities will be developed manually.

Soil Investigation

If additional to Tampa Electric's available soils data, additional investigation is required, Shaw will develop a detailed specification and subcontracting package Shaw will develop the materials quantities for the estimate based on the recommendations of the soils investigation.

8 Procurement Management

Of highest importance is to establish a process that is in compliance with Attachment A to the agreement with RTI, American Recovery and Reinvestment Act (Recovery Act) of 2009, Provisions Applicable to this Agreement. Sections 3 and 4 Pages 6 through10) address specific requirements effecting procurement.

Procurement will support the estimating group and perform the following procurement activities during the development of the Class III Estimate during the FEED:

Identify capable suppliers and finalize a manufacturer/bidder's list for the equipment.

Issue inquiries for quotation as appropriate to support the estimate.

Condition bidder's quotations consistent with the requirements of the estimate.

Develop procurement man hours to purchase the equipment and bulk materials identified in the estimate. Man hours for execution will include the following:

- Purchasing
- Inspection
- Expediting
- Logistics

Solicit quotations for shipping, freight and insurance requirements as required

All procurement activities shall be documented in accordance with Shaw's standards and procedures used to solicit quotations.

The Buyer will have the overall responsibility for the bid evaluation process, including maintaining the confidentiality of commercial information and documenting all required reviews and approvals.

9 Construction Management

The early interfacing among the engineering team, the TEC operations team and the construction team is of utmost importance. Early assessment of the impact of the employment of the Davis-Bacon Act is critical.

Following a visit to the Polk Power Station, the Constructability Representative will be an active participant in leading the constructability reviews during the FEED. The representative will regularly meet with the project team members.

The contributions will include:

Constructability plan FEED Phase

- Site survey focusing on access and location of staging provisions
- Assist with finalization of the Plot Plan
- Early assessment of value-added by maximizing pre-assembly and modularization
- Input into the EPC schedule and milestones
- Report on Constructability and Logistic Studies
- Preliminary construction and sub-contracting execution strategy
- Preliminary heavy lift studies
- Assessment of the possible contribution of other Shaw entities having construction capabilities
- Develop Construction Org Chart and staffing plan

10 Commissioning Management

At a minimum during the FEED, the Shaw team will mobilize commissioning specialist(s) following receipt of RTI's milestone dates in order to establish the initial targeted dates for beginning the commissioning of the equipment and systems. A product will include the preliminary turnover package listing and sequencing. These will provide the drivers for the prioritization and completion of the preceding engineering, procurement and construction and construction testing activities. Of keen importance are the necessities to work closely with the TEC operations team and the early identification of start-up and both routine and emergency shutdown requirements. Since this demonstration plant is being installed within an operating facility, the need to minimize interference with the day-to-day activities is significant. There also needs to be close coordination with TEC's planned outages and the need to be flexible with the unplanned/emergency outages. For the purposes of the FEED, the objective will be the commissioning team assembled by Shaw for the EPC phase will include representatives from both RTI and TEC.

11 Operating Management

Similar to the Commissioning section, much of this section will be developed during the FEED. Of keen importance are the necessities to work closely with the TEC operations team and the early identification of start-up and both routine and emergency shutdown requirements. For the purposes of the FEED, the objective will be the operating team assembled by Shaw for the EPC phase will include representatives from both RTI and TEC. The scope of work developed during the FEED phase must also include Shaw conducting both operating and maintenance training for the TEC team.

A preliminary start-up/shutdown procedure to support permit activities and equipment required solely for start-up/shutdown is of utmost importance.

12 Time Management

The Project Master Schedule will be produced by CH2MHill. Initially it will provide the dates for the major milestones to align RTI's objectives with the DOE's requirements. Upon validation of this alignment, Shaw will be provided with these milestone dates in order to establish a Preliminary Level 2 FEED schedule for Shaw's activities. Upon completion of the Preliminary Level 2, RTI will validate that the timings will support their commitments with the DOE. Following this validation, Shaw will finalize the Level 2 schedule and refine it to a deeper level of detail for establishing the Level 3 schedule.

When Shaw's Level 3 schedule is finalized and with periodic updates, CH2MHill will incorporate the information in the Project Master Schedule

Time Records

Every team member must ensure that their staffs are recording their time in the Shaw time system every day. It is not acceptable to delay time charges to the end of a working week.

Schedule

A project schedule using Primavera Scheduling software will be developed to plan, control, and manage the sequence of activities to achieve the scope of work within the period required by the project. Attached is the Preliminary Level II FEED Schedule, as Attachment 2. The present schedule will be resource loaded and maintained throughout the FEED.

An agreed-to work breakdown structure (WBS) will be developed and applied to planning, scheduling, progress measurement, and cost forecasting.

A Project Planning / Scheduling Representative will interface with the Project Team to identify status of activities that have started, completed, or ongoing. This information will be used to status the schedule and all dates compared against the Baseline Schedule.

The Critical and Near Critical Paths will be identified and tracked throughout the project. Potential problems or delays will be identified in advance and resolution/recovery sought to mitigate.

Timely float analysis by the Project Planning / Scheduling Representative is crucial.

Progress Measurement

The progress of the FEED package will be updated on a monthly basis by WBS element using Shawtrac. Shawtrac uses standard rules of credit milestones to track progress. In some cases the tracking may be done in an external list such as the drawing index or line list and the data transferred to Shawtrac. Tracking will be done at the deliverable level where possible based upon predetermined milestones. The milestones shall be associated to a percent of budget expended and rolled up into an overall percent complete. Each discipline shall update the status tracking as required to meet internal management and external client requirements.

13 Cost Management

Estimating Methods

Due to the development nature of this project and the limited budget, it is critical this project is implementing a program to forecast final quantities of equipment, bulk quantities, services etc. on a continuous on-going basis. This is required to be able to identify and eliminate non-value-added costs to the project. These forecasts are also to identify trends in value-added items that if left unchanged indicate a budget overrun. This early identification will provide the management team with the ability to identify these to RTI. The result may be a further exercise to identify potential reductions in other areas to compensate, should RTI decide not to institute modifications.

This project is required to comply with the provisions of the Davis-Bacon Act.

The FEED Quality Class III Estimate ($\pm$ 20%) will be developed based on discrete scope blocks utilizing a Work Breakdown Structure (WBS) that meets the requirements of RTI and the DOE. An Estimating Plan will be provided at the beginning of the work (see Project Management Plan, Part 2, also referenced in Section 7 above). This plan will evolve into the Basis of Estimate document provided as a deliverable with the FEED.

Of possibly unique, yet undefined at the time of the writing (mid-February 2011) of this plan, are tracking and reporting requirements governed by the Depart of Energy and the American Recovery and Reinvestment Act. The ability to control and monitor cost and progress on the project will rely heavily on the work breakdown structure (WBS) employed during the estimate. Specific requirements for Shaw will be a flow-down from the DOE, RTI and CH2MHill. These requirements must be confirmed at the soonest to ensure that Shaw's estimate for FEED services is in alignment.

The estimate will be completed using a combination of methodologies. They will range from obtaining quotations for equipment, to use of similar equipment from Shaw's database to factoring.

14 Financial Management

During the FEED phase, the financial management of the project will be the responsibility of the project manager/director. Both the Project Controls Manager/staff and the Accounting and Finance Group will be assigned specific responsibilities, but the accountability remains with the project manager/director.

As the project transitions through the life-cycle, additional responsibilities will be assigned to the supporting project team.

Since this project is financially supported by the U.S. Department of Energy (DOE), the DOE has contracted with RTI as a "recipient" under the provisions of the American Recovery and Reinvestment Act (Recovery Act) of 2009. Shaw has been designated as a "sub-recipient". It is anticipated that since Shaw's Environmental & Infrastructure Group has already established acceptable precedents with the governmental agencies, these precedents are also acceptable for this demonstration project.

15 Risk Management

Shaw will work with RTI to develop a risk register and develop mitigation plans to address identified risk.

16 Resource Management

The project will be assembled in a space area remote the team members' home departments. A modified task force approach will be employed comprised of the core team and other personnel during their period of high activity on the project. RTI will also locate their representative (Mr. Thomas Nelson) within the task force.

As mentioned in Section 13, the Primavera schedule will be resource loaded at the start of the work and maintained through the project.

Personnel are to be added to the project team as the work level, resource loading, manpower forecasts and schedule dictates. T he Shaw Resource Tracking System (RTS) will be employed. However there is to be no change, additions or deletions, to the specific personnel assignments on the project without the express advance approval by the project's Engineering Manager or Project Manager.

Refer to the Project Organization Chart (Attachment 3) for the Shaw team structure.

The project roster is housed in the project directory and updated as required.

One (1) representative from CH2MHill will reside within the modified task force in Shaw's office.

17 Closure Management

During FEED, Shaw will work with RTI to develop a detailed plan for project closeout. Items to be addressed are:

A. Records
B. Lessons Learned
C. Demolition and Salvage Plan
D. Abandon in Place Plan

APPENDIX

APPENDIX A – Cost Estimate

RTI Cost Estimate — **Project Class Summary**

Raleigh, NC

Project Title: — **Basis:** 1,500 KSCFH — **Prep. By:** Ben Gardner

Scenario Name: — **Proj. Location:** North America Polk Pow er Station

Estimate Date: 5/9/2011 — **Est. Class:** Estimate Accuracy -10% +30% — **Job No:** FLTA1001 — **Currency:** DOLLARS USD

Account	Key Qty	Key Units	Unit MH	MH	Wage Rate	Indirect	Labor	Unit Matl	Matl	Other	Sub-Contract	Total
Earthwork/Drainage											$ 300,000	$ 300,000
Paving		SF	0.00	6,900	$ 39.71		$ 274,000		$ 212,000	$ -	$ -	$ 486,000
Equipment	63	EA	0.01	6,200	$ 39.44	$ 162,998	$ 244,528	$ 499,441	$ 31,464,783	$ -	$ 5,800,000	$ 37,672,309
AG Pipe		LF		106,041	$ 41.79	$ 2,954,307	$ 4,431,460		$ 5,526,877	$ -	$ -	$ 12,912,644
IT									$ -	$ -	$ 200,000	$ 200,000
Architecture		SF								$ -	$ 780,000	$ 780,000
Civil		CY		65,631	$ 34.30	$ 1,500,988	$ 2,251,154		$ 1,059,367	$ -	$ -	$ 4,811,509
Steel		TN		26,838	$ 36.12	$ 646,251	$ 969,377		$ 1,723,336	$ -	$ -	$ 3,338,964
I&C	668	EA	0.07	9,887	$ 36.07	$ 237,772	$ 356,608	$ 9,851.31	$ 6,580,672	$ -	$ -	$ 7,175,052
Electrical		LF		57,239	$ 35.36	$ 1,349,117	$ 2,023,962		$ 2,830,559	$ -	$ -	$ 6,203,638
Insulation		SF		5,662	$ 28.43	$ 107,342	$ 160,957		$ 394,067	$ -	$ -	$ 662,366
Spares									$ 319,000	$ -	$ -	$ 319,000
Freight									$ 739,300	$ -	$ -	$ 739,300
Paint		SF		7,502	$ 26.17	$ 130,843	$ 196,340		$ 55,378	$ -	$ -	$ 382,562
Sub-Totals:				**291,899**		**$ 7,089,618**	**$ 10,908,385**		**$ 50,905,339**	**$ -**	**$ 7,080,000**	**$ 75,983,342**
Engineering				132,191	$ 123.00		$ 16,259,538					$ 16,259,538
TEC/Permit							$ 8,624,462					$ 8,624,462
Eastman							$ 120,558					$ 120,558
Owner's Engineer				15,388	$ 122.93		$ 1,891,737			$ 241,405		$ 2,133,143
Construction Management				25,950	$ 115.00		$ 2,984,250			$ 344,000		$ 3,328,250
Home Office (RTI)				61,650	$ 219.69		$ 13,543,756			$ 1,183,654		$ 14,727,410
MSE										$ 6,210,904		$ 6,210,904
License FEE										$ 342,500		$ 342,500
Insurance										$ 1,234,833		$ 1,234,833
Escalation										$ 2,279,500		$ 2,279,500
First Fills									$ 3,840,000			$ 3,840,000
Commissioning				11,260	$ 90.00		$ 1,013,400		$ 500,000		$ 183,000	$ 1,696,400
Project Costs SubTotal:												**$ 136,780,840**
EPC Risk	0%											**$ -**
Project Costs w EPC Risk												**$ 136,780,840**
Contingency	15%											$ 18,315,168
Project (TIC)												**$ 155,096,007**
Operations							$ 4,569,600		$ 10,432,875	$ 272,505		$ 15,274,980
Decommissioning											$ -	$ -
Total Project Cost												**$ 170,370,987**

APPENDIX B – Project Schedule

APPENDIX C – WBS Map

Appendix D – Division of Responsibility

DIVISION OF RESPONSIBILITY Revision - A		Legend: R = Responsible - Owns problem or projects A = to whom "R" is Accountable. Must sign or approve the work before it is OK. C = has to be Consulted. Has information and/or capability necessary to do the work. I = has to be Informed, but not necessary to be consulted						
DESCRIPTION		**RTI**	**Shaw**	**CH2M Hill**	**TEC**	**BASF**	**DOE**	**COMMENTS**
MANAGEMENT								
Program Management								
	Develop Project Execution Plan	A	C	R	C			
	Planning, Scheduling and Progress Monitoring	A	C	R	C			
	Document Control	A	C	R	R			TEC responsible Well Documentation
	Cost Estimating	A/C	R	C				
	Change Management	A	C	R	C			
	Contract Administration	R		C				
	Project Risk Management	A	C	R	C			
	Project Quality Management	A	C	R	C			
	Safety Management Planning	A	C	R	C			
ENVIRONMENTAL								
	Air Permit	C	C	C	R			
	Water	C	C	C	R			
	Land	C	C	C	R			
	EA	R	C		C			
	Construction Permits	C	R		C			
Warm Gas Cleanup/Carbon Capture								
Administrative								
Project Services								
	Project Management	A	R	R				
	Project FEED Schedule	A	R	R	C			Shaw is responsible for Feeding information to CH2M Hill
	Project EPC Schedule	A	R	R	C			Shaw is responsible for Feeding information to CH2M Hill
	Drawing Schedules	I	R	C				
	Equipment Delivery Schedules	I	R	C				
	Overall Project Status Reports	A	R	R				Shaw is responsible for Feeding information to CH2M Hill

	Major Equipment O&M Manuals							
	Factory tests reports for equipment	**I**	**R**	**C**				
	Performance test procedure and final report for equipment	**I**	**R**	**C**				
	Transportation risk insurance for equipment							Will handle in EPC
	Operating and maintenance personnel training program for equipment	**C**	**R**	**C**	**C**			
	Quality assurance/quality control	**I**	**R**	**C**	**C**			
	Tie-in Scheduling Plan	**I**	**R**	**C**	**C**			
Process								
	Basis of Design	**C**	**R**	**C**	**C**			
	Mass Balance Calculations and Report	**C**	**R**	**C**	**C**			
	Process Description Narratives	**C**	**R**	**C**	**C**			
	PFD / P&ID Details (line number, I&C input, etc.)	**C**	**R**	**C**	**C**			
	PFD / P&ID Drafting	**C**	**R**	**C**	**C**			
	P&ID Review/HAZOP	**C**	**R**	**C**	**C**			
	HAZOP writeup showing resolutions	**C**	**R**	**C**	**C**			
	Battery limit interface - line service, size, and specifications	**C**	**R**	**C**	**C**			
	Equipment Conditions of Service	**I**	**R**	**C**				
	Tie-In Battery Summary	**C**	**R**	**C**	**C**			
	Effluent Summary	**C**	**R**	**C**	**C**			
	Utility Summary	**C**	**R**	**C**	**C**			
	Generate Line List	**I**	**R**	**C**				
	Process Datasheets`	**I**	**R**	**C**				
	PSV calculations for all applicable relief cases	**I**	**R**	**C**	**C**			
	Cause and effect diagram	**I**	**R**	**C**				
	Start up and Operating manuals including process descriptions	**A**	**R**	**C**	**C**			
	Asbuilt - Update Construction P&ID redlines for reproducible drawings	**I**	**R**	**C**				
	aMDEA PDP	**C**	**C**	**C**		**R**		
Mechanical								
	Equipment Data Sheets	**I**	**R**	**C**				
	Equipment Specifications	**I**	**R**	**C**				
	Vessel Outline Drawings	**I**	**R**	**C**				
	Review Line Classes	**I**	**R**	**C**				
	Produce Material Selection Diagram	**I**	**R**	**C**				
	Ladder, stair and platform details	**I**	**R**	**C**				
	Equipment List with Vendors	**I**	**R**	**C**				
	Equipment Requisition packages	**I**	**R**	**C**				
	Equipment Bid Evaluation	**I**	**R**	**C**				
	Equipment Purchase packages	**I**	**R**	**C**				

Piping								
	Area Plan Drawing	**C**	**R**	**C**	**C**			
	Skid Definition	**I**	**R**	**C**				
	3D Piping Model	**I**	**R**	**C**				
	Isometric Drawings from 3D Model	**I**	**R**	**C**				
	Piping Stress Calculations	**I**	**R**	**C**				
	Piping Specifications	**I**	**R**	**C**				
	Piping Line List	**I**	**R**	**C**				
	Piping Specialty Item List (split)	**I**	**R**	**C**				
	Tie-in List	**I**	**R**	**C**	**C**			
	Bill of Materials / design quantities	**I**	**R**	**C**				
Electrical								
	Area Classification Drawings	**I**	**R**	**C**	**C**			
	One lines	**I**	**R**	**C**	**C**			
	Electrical Load List	**I**	**R**	**C**	**C**			
	Electrical Detail Drawings	**I**	**R**	**C**				
	Wiring Diagrams	**I**	**R**	**C**				
	Control Schematics	**I**	**R**	**C**				
	Motor Plan	**I**	**R**	**C**				
	Motor list with voltage levels	**I**	**R**	**C**				
	Junction Box Schematics	**I**	**R**	**C**				
	Layout Drawings	**I**	**R**	**C**				
	Lighting Plan	**I**	**R**	**C**	**C**			
	Lighting Schematics	**I**	**R**	**C**				
	Conduit/Cable Plan	**I**	**R**	**C**				
	Conduit Schedule	**I**	**R**	**C**				
	Cable Schedule	**I**	**R**	**C**				
	Panel Board Layouts	**I**	**R**	**C**				
	Power cable & duct bank design from 25kW transformers to K2 PDC buildings	**I**	**R**	**C**				
	Power, control, lighting & instrumentation circuits from the two PDC buildings	**I**	**R**	**C**				
	PDC Buildings design and specifications	**I**	**R**	**C**				
	PDC Bldgs Standy Generator & Transfer Switch design & specification	**I**	**R**	**C**				
	Interconnection Diagrams for 480V and below	**I**	**R**	**C**				
	Requirements for Emergency and UPS power	**I**	**R**	**C**				
	Grounding plan	**I**	**R**	**C**	**C**			
	Asbuilt - Update Construction Singleline redlines for reproducible drawings	**I**	**R**	**C**				
	Electrical Equipment Requisition packages	**I**	**R**	**C**				

	Electrical Equipment Bid Evaluation	I	R	C				
	Electrical Equipment Purchase packages	I	R	C				
Instrumentation								
General								
	P&ID development	I	R	C	C			
	P&ID Review and HAZOP	I	R	C	C			
	LOPAs / SIL Analysis	I	R	C	C			
	Process narratives and process logic	I	R	C				
	Complex Loop narratives and process logic	I	R	C				
	Instrument Index	I	R	C				
	Automation design basis	I	R	C				
	Automation Management	I	R	C				
Specifications								
	Process control philosophy	I	R	C	C			
	DCS specification	I	R	C	C			
	SIS specification	I	R	C	C			
	Configuration specification	I	R	C				
	Fire and Gas system specification	I	R	C				
	Machine monitoring specification	I	R	C				
	Burner Management systems specification	I	R	C				
	Analyzer specification	C	R	C				
	Analyzer Data Sheet	C	R	C				
	Telephone system specification	I	R	C	C			
	Radio system specification	I	R	C	C			
	Laboratory equipment specifications	R	C	C				
	Instrument specifications	I	R	C				
	Instrument datasheets	I	R	C				
Control System Hardware Design								
	Control system architecture design and drawings	I	R	C				
	DCS, SIS, Control panel and cabinet design and drawings	I	R	C				
	Control system communication network design and drawings	I	R	C				
Control System Design and Configuration								
	Alarm management plan	I	R	C				
	Historian design basis	I	R	C				
	Report design basis (eg. Shift reports)	I	R	C				
	Alarm List / Fieldbus Alerts	I	R	C				
	Graphics development and configuration	I	R	C				

	Process control configuration	**I**	**R**	**C**				
	Network configuration	**I**	**R**	**C**				
	Historian configuration	**I**	**R**	**C**				
	Shift and production report configuration	**I**	**R**	**C**				
	Alarm configuration	**I**	**R**	**C**				
	SIS configuration	**I**	**R**	**C**				
	Advanced Process Control	**I**	**R**	**C**				
Integration								
	Interface and coordination for vendor provided control systems	**I**	**R**	**C**				
	Interface and coordination for vendor provided instruments	**I**	**R**	**C**				
	Interface design and configuration for power monitoring systems	**I**	**R**	**C**				
	Interface and coordinate with TEC site operations	**I**	**R**	**C**				
Physical Design								
	Intools overall database management	**I**	**R**	**C**				
	Instrumentation design	**I**	**R**	**C**				
	Input to the Intools database	**I**	**R**	**C**				
	Installation details	**I**	**R**	**C**				
	Instrument installation details	**I**	**R**	**C**				
	Instrument winterization	**I**	**R**	**C**				
	Loop and wiring drawings	**I**	**R**	**C**				
	Loop drawings	**I**	**R**	**C**				
	Fieldbus segment design	**I**	**R**	**C**				
	Fieldbus segment wiring drawings	**I**	**R**	**C**				
	Motor control schematics	**I**	**R**	**C**				
	Network (bus technology) Design for motor control	**I**	**R**	**C**				
	Network (bus technology) Drawings for motor control	**I**	**R**	**C**				
	Instrument UPS distribution drawings	**I**	**R**	**C**				
	Control system ground Rod / Drawings	**I**	**R**	**C**				
	Termination lists and cable schedules	**I**	**R**	**C**				
	Communication cabling diagrams	**I**	**R**	**C**				
	Fiber optic network and patch panel drawings	**I**	**R**	**C**				
	Other communication network and interconnecting drawings	**I**	**R**	**C**				
	Layouts and Location drawings	**I**	**R**	**C**				
	DCS equipment layout in control room	**I**	**R**	**C**				
	DCS equipment layout in rack room	**I**	**R**	**C**				
	Junction box and remote I/O cabinet locations	**I**	**R**	**C**				
	Instrument and end device location drawings	**I**	**R**	**C**				
	Third party interconnect design to DCS	**I**	**R**	**C**				
	Third party interconnect drawings to DCS	**I**	**R**	**C**				
	System Testing (FAT, SAT)	**I**	**R**	**C**				

	Stage equipment and verify hardware functionality and communications	I	R	C				
	Verify all configuration to be in accordance with programming documentation	I	R	C				
Structural								
	Structural Steel Plan, Section and Detail Drawings	I	R	C	C			
	Ladders and Platforms Drawings	I	R	C	C			
	Steel Erection Drawings	I	R	C				
	Design Criteria, Quantities and Calculations	I	R	C				
Utilities								
	Feedwater	I	R	C	C			
	Potable Water	I	R	C	C			
	LP steam supply	I	R	C	C			
	MP steam supply	I	R	C	C			
	HP steam supply	I	R	C	C			
	Cooling Tower Water	I	R	C	C			
	Instrument Air	I	R	C	C			
	Propane	I	R	C	C			
	Waste Water Treatment	I	C	C	R			This item depends on whether we can use TEC"s WWT system
	Fire Protection/Foam	I	R	C	C			
	Switchyard	I	R	C				
	SF6 Circuit Breakers	I	R	C				
	Disconnect Switches	I	R	C				
	Capacitive Voltage Transformers	I	R	C				
	Surge Arresters	I	R	C				
	Interconnect Studies and Georgia Power Requirements	I	R	C				
	Support Steel, Aluminum Buss, Insulators	I	R	C				
	Lighting	I	R	C				
	Cable, Conduit, Trench, Relays	I	R	C				
	Ground Grid, Foundations, Fencing	I	R	C	C			
	Communication System, e.g. microwave	I	R	C				
	Metering/Control Building and HVAC	I	R	C				
	Direct Stroke Lighning Protection Equipment	I	R	C				
	Interface panel located at fence	I	R	C				
	Miscellaneous systems including battery, panels, etc.	I	R	C				
	Startup, Commissioning and Testing	I	R	C				
	Field Installed Conductors	I	R	C				
	Raceways	I	R	C				
	Miscellaneous Electrical Systems	I	R	C				
Buildings								

Control Building								
	Structural steel	**I**	**R**	**C**				
	Roofing	**I**	**R**	**C**				
	Metal Siding	**I**	**R**	**C**				
	HVAC	**I**	**R**	**C**				
	Lighting and Small Power	**I**	**R**	**C**				
	Building Insulation	**I**	**R**	**C**				
	Doors and Windows	**C**	**R**	**C**				
	Building finishes	**C**	**R**	**C**				
	Architectural items	**C**	**R**	**C**				
	Office equipment, furniture	**C**	**R**	**C**				
	Specialties (toilet accessories, lockers, etc)	**I**	**R**	**C**				
Civil - Site work, undergrounds								
	Foundation location plan	**I**	**R**	**C**				
	Foundation Plan, Section and Detail Drawings	**I**	**R**	**C**				
	Design Criteria, Quantities and Calculations	**I**	**R**	**C**				
	Storm Water Plan and Section, Detail Drawings	**I**	**R**	**C**				
	Access drawing	**I**	**R**	**C**				
	Landscaping and Fencing	**I**	**R**	**C**				
	Asbuilt - Update Construction Underground redlines for reproducible drawings	**I**	**R**	**C**				
Site Work								
	Site survey/access right of way & easement	**I**	**C**	**C**	**R**			
	Subsurface investigation	**C**	**R**	**C**				
	On-site Earthwork	**I**	**R**	**C**	**C**			
	Site drains (surface & buried drains)	**I**	**R**	**C**	**C**			
	Sanitary drains (septic)	**I**	**R**	**C**	**C**			
	Roads/paving/sufracing/all required surfaces	**I**	**R**	**C**	**C**			
	Crushed stone surfacing	**I**	**R**	**C**	**C**			
	Fencing/Gates	**I**	**R**	**C**	**C**			
	Final landscaping and irrigation for landscaping	**I**	**R**	**C**	**C**			
	Prepare soil under foundations	**I**	**R**	**C**	**C**			
	Heavy haul access preparation	**I**	**R**	**C**	**C**			
Civil Work								
	Pipe Rack Foundations	**I**	**R**	**C**				
	BOP Equipment and structures	**I**	**R**	**C**				
	Control building foundation	**I**	**R**	**C**				
	Miscellaneous Building Foundations	**I**	**R**	**C**				
	Infrastructure	**I**	**R**	**C**				
	Misc. Foundations	**I**	**R**	**C**				
	Misc. Tank Foundations	**I**	**R**	**C**				
	Trenches, Duct Banks & Manholes	**I**	**R**	**C**				

COMMISSIONING/START UP/OPERATIONS								
Start-up Support								
Consumables, fuels & operational chemicals		**I**	**R**	**C**	**C**			
	Initial fill of chemicals and lubricants of BOP equipment	**I**	**R**	**C**	**C**			
	Initial fill of chemicals and lubricants of major equipment	**I**	**R**	**C**	**C**			
	Chemicals, lubricants and consumables for Start-up and commissioning	**I**	**R**	**C**	**C**			
	Chemicals, lubricants and consumables for Performance testing	**I**	**R**	**C**	**C**			
	Fule, Water & power for Start-up and Commissioning	**I**	**R**	**C**	**C**			
	Chemicals, lubricants and consumables for Plant Operation	**I**	**R**	**C**	**C**			
Start-up Plans								
	Commissioning Plan	**I**	**R**	**C**	**C**			
	Commissioning Schedule	**I**	**R**	**C**	**C**			
	Leak Detection	**I**	**R**	**C**				
	Loop Check	**I**	**R**	**C**				
	Bump Motors	**I**	**R**	**C**				
	Operator Training	**I**	**R**	**C**				
	PSV Certification	**I**	**R**	**C**				
	System Turn-over Packages and Sequencing	**I**	**R**	**C**				
	Start-up/Shutdown Procedures	**I**	**R**	**C**	**C**			
Operations								
	Comply with Permits	**I**	**R**	**C**	**C**			
	Operations Test Plan	**R**	**C**	**C**	**C**			
	Operator Procedures	**I**	**R**	**C**	**C**			

APPENDIX E –Project Change Notice

Client: RTI International

PCN no.:

Project name:

Date:

Project number:

Contract no.:

System or Area:

Attention: *(name of Client Representative)*

Description of change:

Reason for change:

Reason code: *(delete this row if Reason code not required)*

Change requested by:

Date of request:

Scope definition:

The estimated impacts of this change are:

Design Cost

Design Schedule (calendar days)

Materials and Equipment (cost and delivery)

Construction costs

Construction schedule (calendar days)

Work will not proceed unless this PCN is approved. *(add or delete lines as needed)*

DESIGN SERVICES		
Discipline	Hours	Cost
Project Management		
Civil		
Structural		
Architectural		
Process		
Mechanical/HVAC		
Piping		
Electrical		
Life Safety		

Industrial Engineering		
Telecom		
Instrumentation and controls		
Equipment Installation		
Services During Construction		
Project Controls		
Procurement		
Estimating / Scheduling		
Subconsultants		
Expenses		
TOTAL DESIGN SERVICES	0	$0

CONSTRUCTION COST ESTIMATE		
Description of Item	Comments	Cost
	TOTAL CONSTRUCTION COST	$0

Please check appropriate box, sign below, and return one copy to CH2M HILL, Attention:

Submitted by: ______________________________

Project Manager Date

For Client: Approved

__ Disapproved By:

__ Authorized signature Date

[Note: Include this section if the list or description of the deliverables is required but are not provided elsewhere].

Discipline:	Deliverables:
Civil	
Structural	
Architectural	
Process	
Mechanical/HVAC	
Piping	
Electrical	
Life safety	
Industrial Engineering	
Telecom	
Instrumentation and controls	

Appendix F – Rules of Credit

	Permitting			
	Application Prep	Submit Permit Application	Permit Review	Permit Issued
Percentage Earned	80	15	3	2

	FEED								
	PFD IFD	P&ID IFD	Equipment Modeled and Layout Frozen	Single Line Diagrams Issued	I/O List Finalized	Hazardous Area Classification Defined	Long Lead Equipment Purchased	Estimate Issued for Approval	Resource Loaded Schedule Issued
Percentage Earned	20	20	10	8	5	2	20	10	5

	Detailed Design							
	Civil Drawings IFC	Structural Drawings IFC	Minor Equipment Orders Placed	Bulk Material Orders Placed	Electrical / I&C Drawings IFC	Mechanical (Utility) Drawings IFC	Mechanical (Process) Drawings IFC	Piping Drawings IFC
Percentage Earned	5	10	5	10	15	15	20	20

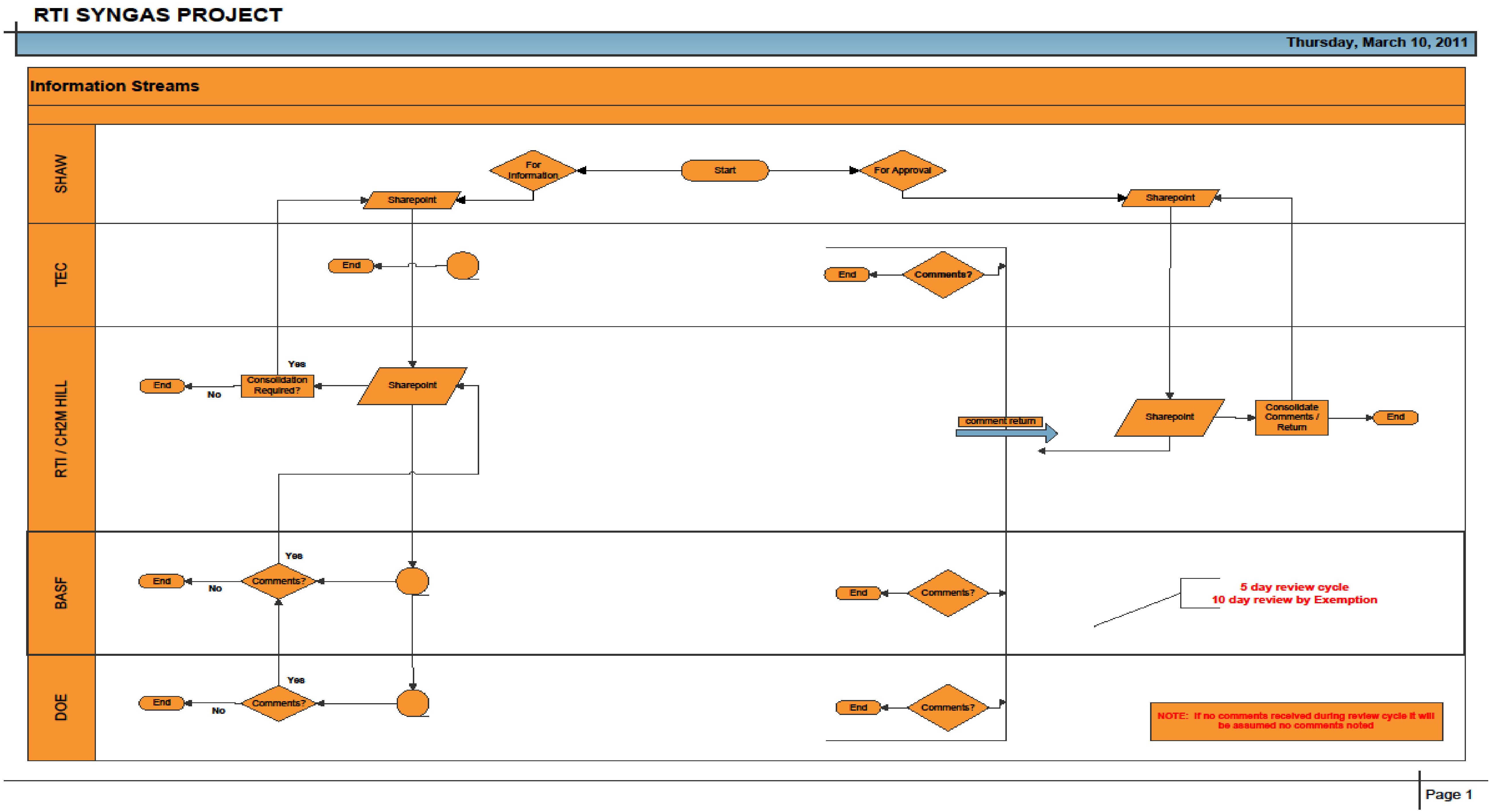
	Procurement			
	Issue for Bid	Issue Purchase Order	Submittals Approved	Equipment Delivered
Percentage Earned	75	10	10	5

	Construction										
	Site Preparation	Equipment Set	Structural Steel	Pipe Rack Steel	Misc. Steel	Electrical Substation Energized	MCC Energized	Piping (Utility) Systems Complete	Piping (Process) Systems Complete	System Loop Checks Complete	Mechanical Completion
Percentage Earned	5	5	10	15	2	8	10	15	15	10	5

	Start Up & Commissioning			Operations			
	Hydrotesting	Operational Acceptance Test	Functional Acceptance Test	Operator Training	Operating Procedures	Test Plans	Run Hours
Percentage Earned	70	20	10	5	10	10	75

Phase/Title	Weighted Percent
Owner	**10%**
Engineering (CH2M Hill)	**3%**
TEC	**5%**
Permitting	2%
Experimental Well	1%
Air Construction	1%
COC Mod for CCS	1%
UIC Operation of Well	1%
Well Construction	3%
Management (RTI)	**2%**
Pre-FEED	**1%**
FEED	**2%**
Detail Design	**4%**
Procurement	**24%**
EQ	17%
Bulk Mat'l Orders	7%
Construction/Pre-Commissioning	**57%**
Site/Civil	5%
Structural	5%
Mechanical	9%
Utility	3%
Process	6%
Piping	23%
Utility	8%
Process	15%
Electrical	7%
Instrumentation	8%
Commissioning	**1%**
Operations	**2%**

APPENDIX G – Document Control Flow Diagram



RTI SYNGAS PROJECT
Thursday, March 10, 2011
Information Streams
SHAW
TEC
RTI / CH2M HILL
BASF
DOE
Start
For Information
For Approval
Sharepoint
End
Comments?
Yes
No
Consolidation Required?
comment return
Consolidate Comments / Return
5 day review cycle
10 day review by Exemption
NOTE: If no comments received during review cycle it will be assumed no comments noted
Page 1

Appendix E

Risk Register

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
Technology												
T_001	Threat	Technology	Event	Ret.	Scale up of warm gas desulfurization unit.	PreFeed	Improperly designed scale up unit will not perform, thereby adversely impacting RTI's warm gas desulfurization program.	1. Leverage pilot plant experience from Eastman field test. 2. Take advantage of Shaw's successful design, construction, and commissioning of commercial transport reactor. 3. Leverage Shaw work preparing a Pre-FEED warm syngas cleaning system to provide a solid engineering pkg for the warm syngas cleaning system and identify any remaining technical issues and recommended mitigation strategy.	1. RTI collected performance data from Eastman pilot plant and passed on to Shaw. 2. Shaw has been selected to develop FEED package and has incorporated the learning's in the reactor design. This item is closed.	RTI/Shaw	March, 2011	March, 2011
T_002	Threat	Technology	Event	Ret.	Ensure that CO2 removal system can achieve up to 90% carbon removal	PreFeed	Wrong technology selection or improperly designed system will not achieve programmatic goal of 90% CO2 removal.	Select a commercially proven technology provider.	RTI has selected BASF, licensor of commercial activated MDEA processes, as a team partner with responsibility for the activated MDEA process design. Item closed	RTI/BASF	February, 2011	February, 2011
T_003	Threat	Technology	Event	Ret.	Ensure that GE turbine can handle proposed syngas changes	PreFeed	The changes to syngas composition has the potential to have a negative impact on the turbine burners at TECO. Burner modifications to the burners will add cost to the project. The additional risk to this item is that GE is notorious for not responding quickly, which add pressure to the schedule.	1. TECO approach GE with proposed changes to determine impact. 2. If the changes are deemed unacceptable, TECO will work with GE to find out what changes would be acceptable. RTI will incorporate these changes to the Basis of Design.	TECO has approached GE with this issue back in December, 2010. GE has communicated that work on this issue started the first week of January, 2011. Item closed.	TEC	February, 2011	February, 2011
T_004	Threat	Technology	Event	Ret.	Absorber and regenerator designed for a certain density and test installation was done on lower Density. Don't have correlation between Density and Velocity at operating conditions. Velocity and Density differential from test case affecting	Workshop	Increase in required pressure to move the sorbent from one reactor to the other due to the higher velocity of the operating case in this project. Could impact the amount of syngas that can be treated. Also could affect meeting the SO2 targets. It is not a show-stopper.	1. Based on Shaw's experience the appropriate design margins will be applied to ensure sufficient circulation rate. 2. RTI will have PSRI review design during detailed design.	Shaw has designed the system with sufficient design margin to ensure proper reactor performance. PSRI reviewed preliminary design before FEED and did not find any significant issues.	Shaw	August, 2011	July, 2011
T_005a	Threat	Technology	Event	Ret.	Plugging within the process - Scale up of Slide Valves.	Workshop	Failure of the refractory plugs the opening of the slide valve - this is really driven by the scale-up as the original test didn't use slide valves (too small). Applicable to the case of losing fluidity. Inability to control the circulation due to lose of the slide valve operability. Only applicable to this pre-commercial sized system. Not anticipated to be a problem at commercial size.	1. Issues with plugging will be mitigated by scaling up the reactor design. 2. RTI will select an engineering partner that has relevant experience with transport reactor and refractory design. 3. Shaw will develop a transport reactor design that will mitigate issues involving reactor plugging. 4. RTI will solicit PSRI's help to review the reactor design.	RTI has selected Shaw as engineering contractor, who is a world leader in transport reactor design for FCC applications. Additionally, PSRI has reviewed Shaw's preliminary design and given a favorable report. Shaw has included their standard slide valve into the design. Therefore, this item is considered closed.	Shaw	August, 2011	June, 2011
T_005b	Threat	Technology	Event	Ret.	Plugging within the process	Workshop	Plugging of Aeration nozzles / valves could impede circulation rate or force a shutdown.	AMEC's team has designed these reactor systems for various applications around the world. AMEC will implement their nozzle design that allows on-line rod out to unplug nozzles	AMEC's team has designed the system with their standard nozzle design. This has been incorporated in the final design.	AMEC	May, 2012	February, 2012
T_006a	Threat	Technology	Event	Ret.	Due to scale-up, can we achieve the mass transfer rates at this scale up size over a longer term operating period.	Workshop	Could be off 5%-10% which is a performance issue which would drive eventual commercial sizing. However, resident times of gas are in the range of the test case which is the underlying transfer mechanism.	1. AMEC will design the reactor to match the residence times achieved during the Eastman pilot plant design. 2. RTI will collect data during operational phase to determine how well the scale-up matches the pilot plant results. 3. RTI will take lessons learned from demonstration plant and include in future commercial projects.	RTI has provided AMEC a lessons learned document from the Eastman test runs to help assist with demonstration design. AMEC's team has incorporated those lessons learned into the design. Additionally, RTI has done CFD modeling that shows mixing within the Adsorber and Reactor are sufficient mixed. This action will not be resolved until the unit is up and running and performance data verified.	AMEC	March, 2014	April, 2015
T_006b	Threat	Technology	Event	Ret.	Due to scale-up, can we achieve the mass transfer rates at this scale up size over a longer term operating period.	Workshop	We will find an unknown impact on mass transfer due to another factor.	1. AMEC's team will design the reactor to match the residence times achieved during the Eastman pilot plant design. 2. RTI will collect data during operational phase to determine how well the scale-up matches the pilot plant results. 3. RTI will take lessons learned from demonstration plant and include in future designs.	RTI has provided AMEC's team a lessons learned document from the Eastman test runs to help assist with demonstration design. Additionally, RTI has done CFD modeling that shows mixing within the Adsorber and Reactor are sufficient mixed. This action will not be resolved until the unit is up and running and performance data verified.	AMEC	March, 2014	April, 2015
T_008	Threat	Technology	Event	Ret.	Absorber operates 300º below the Regenerator. Requires heating up the Regenerator to activate the catalyst - which at this size is a challenge. This has not been tested on the test case scale.	Workshop	a) Can't get it hot enough to run regenerator continuously on its own exothermic reaction. Major Problem B) Light off affects long term performance. - Operability C) Effort to provide a heat input source is more than expected (currently planned as burning diesel internally). Capitol Cost issue - could be significant to the project. D) internal burning creates introduces another reaction process in addition to the intended process during startup.	1. Shaw will develop a design that utilizes an external heat source in the event the exothermic reaction of oxidizing the Sulfur during the regeneration stage is not sufficient to maintain temperature in the regenerator.	RTI and Shaw have mitigated this problem by including an external heat source. This item will be reviewed during operation phase of the project. This item is closed out.	RTI/Shaw	March, 2011	March, 2011
T_009	Threat	Technology	Event	Act.	Un-spared equipment creates greater downtime than targeted in demonstration.	Workshop	Single Point failures overly stop operation not able to prove the scale-up and proving reliability. Add more spared equipment.	1. RTI has at least 18 months to achieve 8,000 hours of operations. 2. RTI will evaluate sparing philosophy once final equipment list is created. Additionally, RTI will create a RAM analysis to determine if the design can meet operational targets within the projected operation time period.	RTI is working with TEC operations to order operating spares to mitigate this risk. The vendor recommended spares were reviewed between engineers and operations. Spares were purchased.	RTI	January, 2015	
T_010	Threat	Technology	Event	Ret.	First of a kind CO2 compressor machine.	Workshop	May not be able to inject the target amount of CO2				March, 2011	March, 2011

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
T_011	Threat	Technology	Event	Ret.	Until Reliability and Maintainability (RAM) study is not completed - additional spared equipment will be required different than current plan.	Workshop	Additional spared equip. more than what has been included in the pre-FEED cost estimates become required.				March, 2011	March, 2011
T_012	Threat	Technology	Event	Ret.	Insufficient tempered cooling water from TEC.	Workshop	A dedicated cooling water system must be added to the project SOW of this project.	1. Shaw will develop a water balance to determine cooling water requirements. 2. Shaw, RTI, and TEC will review cooling water options at TEC to determine if TEC can provide the required cooling water.	Shaw is finalizing the PFD/HMBs which will yield the water balance. RTI, Shaw, and TEC have located several cooling water options that should mitigate this issue.	RTI/Shaw/TEC	April, 2011	April, 2011
T_013	Threat	Technology	Event	Ret.	TEC water treatment system is limited in capacity.	Workshop	A larger water treatment system is required than is currently in the project plan.	1. Shaw will develop a water balance to determine the amount of water to be treated. 2. If this amount exceeds TEC's water treatment capacity, the project will add water treatment to project scope.	Shaw has included a water treatment unit into the process design. Also, TEC has agreed to accept effluent from our process.	Shaw	August, 2011	July, 2011
T_014	Threat	Technology	Event	Ret.	Required startup flaring exceeds un-used emissions in TEC's permit. Startup flaring plan has not yet been prepared.	Workshop	Startup flaring may become problematic and impacting on the engineering plan or requires additional equipment / SOW.	1. RTI will provide a startup procedure to TEC. 2. TEC will determine if startup flaring is within permit constraints. 3. During operations, RTI will operate the plant to minimize flare during startup and shutdown if permit constraints are exceeded.	RTI has provided startup guidelines to TEC. TEC reported that current assumptions look reasonable. This item will be closed out and reviewed once operations and startup team are brought onto the project.	RTI/Shaw/TEC	April, 2011	April, 2011
T_015	Threat	Technology	Event	Ret.	Difficulty in smooth transition of flows into the syngas cleanup process could produce pressure / temperature variations which adversely affect TEC turbine operation	Workshop	Turbine trips offline. Worst case damage to turbine (anticipated unlikely).	Produce a startup procedure between TEC, AMEC and RTI. TEC will provide a minimal syngas heating value that the turbine can operate on. RTI and AMEC will develop a startup timeline that ensures the syngas heating value to the turbine always exceeds the minimal heating value constraint. Also, during detailed design, AMEC and TEC will evaluate control strategy to minimize pressure and heating value fluctuations.	AMEC, RTI, and TEC met in April, 2012 to review startup and shutdown scenarios. AMEC will incorporate findings into the control narratives and startup procedures. RTI, TEC, and AMEC will work on startup procedures. A meeting is planned in June, 2013 to review the control narratives at the interfaces to ensure the DCS is programmed in such a way as to minimize impact to TEC's operation	RTI/AMEC/TEC	May, 2014	October, 2015
T_016	Threat	Technology	Event	Ret.	Tie-In location upstream of the hydrolysis unit and immediately after the by-pass point, can cause problems in trip-out and unanticipated loss of feed-gas.	Workshop	Could have damage refractory if not properly cooled down. Damage to our booster and syngas compressor.	1. Shaw will include a knock out drum ahead of the compressors. This will condense liquids and drop out solids before they come into contact with the compressors. 2. The control system will be designed to implement a controlled shut down in event of syngas flow loss.	The current PFDs include the knock-out drum. This item is closed	Shaw	August, 2011	June, 2011
T_017	Threat	Technology	Event	Ret.	An oxidizing gas is introduced into the system after the initial reduction.	Workshop	Damage to the water gas shift catalyst by unintentional exposure to an oxidizing gas.	1. Oxygen analyzers will be installed upstream of the WGS. 2. In the event of O2 gets into the system, methods to purge will be included in the operational procedures.	This issue has been addressed in the design by adding O2 analyzers in the correct positions to monitor O2 content.	Shaw	August, 2011	July, 2011
T_018	Threat	Technology	Event	Ret.	Failure in the filter system during forward flow.	Workshop	Damage to our booster and syngas compressor due to particulates.	Shaw will select a reputable hot gas filter vendor that has experience designing these systems. This issue is further mitigated since MOC issues were addressed during the Eastman testing. Also, knock-out drums will be installed ahead of the compressors.	Shaw has included hot gas filters and knock-out drums upstream of the compressors.	Shaw	August, 2011	July, 2011
T_019	Threat	Technology	Event	Act.	Filters blinding over time.	Workshop	Capacity drop-off from compressor output. Happens slowly over time. Higher amounts of downtime to cleanout if online cleanout not provided.	1. Incorporate learning's from Eastman and TEC Operations into design. 2. Ensure temperatures stay above dew point during startup/shutdowns. 3. The filter systems will be designed with online cleaning and DP indications.	The RTI-3 sorbent should clean off the filters during back-pulsing. And the syngas from TEC is very low in tars, so condensation (that could exacerbate blinding) should not be an issue. Pall and Mott have reviewed the Eastman data and foresee no issues with filter blinding.	AMEC	May, 2014	
T_020	Threat	Technology	Event	Ret.	Another restriction point susceptible to plugging becomes apparent that hasn't been anticipated.	Workshop	Capacity drop-off from compressor output. Happens slowly over time. Higher amounts of downtime to cleanout if online cleanout not provided.	1. Incorporate learning's from Eastman and TEC Operations into design. 2. Shaw to work with TEC to get fouling factors from HX and include in the design. 3. Develop startup procedures that ensure the syngas stays above dew point during startup	According to TEC, tar concentration in the syngas is negligible. After reviewing with Shaw, RTI has determined this is not an issue. Therefore, this item is closed out.	Shaw	April, 2011	April, 2011
T_021	Threat	Technology	Event	Ret.	This process introduces a high concentration of hydrogen. This concentration level is new to the TEC plant.	Workshop	Hydrogen embrittlement - must choose appropriate materials. May require some upgrades to connection piping in existing TEC plant.	1. Shaw will develop a material selection diagram that is appropriate for H2 levels in the syngas. 2. TEC will have access to HMB at the interface. Shaw and TEC will develop a plan to ensure the appropriate upgrades are included at TEC"s facility.	Shaw has issued a MSD . TEC has the diagram and has reviewed. No issues were noted.		September, 2011	July, 2011
T_022	Threat	Technology	Event	Ret.	There is currently not in the project plan a method for relieving the CO2 stream.	Workshop	Not able to run the CCS portion of plant.	Shaw will develop a design that allows the plant to bypass the water gas shift and acid gas removal system.	Shaw is aware of this constraint and have included the by-pass line in the design. This item is closed.	Shaw	March, 2011	March, 2011
T_023	Threat	Technology	Event	Ret.	Our system goes off-line - upsets hydrogen mix in the feed gas to TEC turbine.	Workshop	Lower performance of TEC turbine during this short upset period.	Must understand the aspects of switching the gas feed. Faster actioning controls	This item is similar to TO15. Therefore, this item is removed from the list.	Shaw	March, 2011	March, 2011
T_024	Threat	Technology	Event	Ret.	Carbon stream exceeds permitted allowances for sequestering	Workshop	H2S concentration is higher than targeted.	Obtain adequate cushion on permitted levels.	RTI has provided TEC a conservative margin wrt the H2S in the CO2 stream for UIC permit. This item is closed out and will be reviewed during operations.	RTI	March, 2011	March, 2011
T_025	Threat	Technology	Event	Ret.	Fuel Gas off absorber is not met. Exceeding the window provided by GE. Overachieving is more of a concern.	Workshop	Differential from project objective results. Affects full-scale commercial installation.	TEC have GE review syngas composition and determine if there is any adverse impacts to the CT.	GE came back with a decision that the new syngas composition would not adversely impact the CT. This decision was based on 2 MM scfh assumption. Since the project has been descoped to 1.5 MM scfh, this issue is even less of a concern. This item is closed out.	RTI/Shaw/TEC	March, 2011	March, 2011
T_026	Threat	Technology	Event	Act.	Upset in the in the project gas cooling system doesn't remove the contaminants.	Workshop	Return tie-in is downstream of TEC's system to remove and would then move directly to turbine. Increases potential ammonia and contaminants to turbine resulting possibly in permit excursion event.	1. AMEC, RTI, and TEC develop procedures that shut the plant down when cooling system goes down or TEC notices that permit limits have been exceeded.	AMEC, RTI, and TEC have developed a preliminary startup/shutdown guidelines to address this issue. More details will be providing during detailed engineering.	RTI/AMEC/TEC	May, 2014	
T_027	Threat	Technology	Event	Ret.	Regenerator Stream is outside targeted range.	Workshop	Shutdown project process or flare.	1. AMEC, RTI, and TEC develop procedures that shut the plant down when regenerator stream is outside of targeted range.	AMEC, RTI, and TEC have developed a preliminary startup/shutdown guidelines to address this issue. More details will be providing during detailed engineering.	RTI/AMEC/TEC	May, 2014	October, 2015
T_028	Threat	Technology	Event	Ret.	Liquid sulfur flow characteristics is altered by small changes in temperature in the reactor.	Workshop	Ability to keep the DSRP unit in operation. Not able to reach the targeted 8000 hours of operation.		Since the DSRP is removed from the project scope, this item is retired.	RTI	April, 2011	April, 2011

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
T_029	Threat	Technology	Event	Ret.	Our system goes off-line - ability for TEC scrubbing system to accommodate change in flow rate of 18% swing in short amount of time.	Workshop	Biggest concern is MDEA system and removal of H2S. Believed worst case is that more H2S slips by until process re-tuned to handle full flow rate.	1. AMEC, RTI, and TEC need to develop procedures and control systems to accommodate fast transition to minimize the amount of H2S slip. 2. Due to the emergency nature, this gas stream can go to the flare, which allows the control systems to transition syngas stream back to TEC.	After discussing with TEC during the Aril, 2012 meeting, sudden trips by our process does not seem to be a concern. Therefore, this item is closed.	RTI/AMEC/TEC	August, 2012	April, 2012
T_030	Threat	Technology	Event	Ret.	Auxiliary equipment being as reliable or more than the equipment you are trying to test.	Workshop	The operations team spends more time working on aux equipment rather testing the core technology	All auxiliary equipment will be designed per appropriate codes and specifications.	All the datasheets have been issued for the project. Shaw did not use inferior specs for auxiliary equipment.	Shaw	September, 2011	July, 2011
T_031	Threat	Technology	Event	Ret.	Improper selection of valve and materials selection	Workshop	Immature valve wear and improper seating which would prevent complete shut off	1. Shaw will develop a Material selection diagram based on their experience with syngas processes. 2. Shaw will select valves based on their experience with FCC and acid gas removal processes.	Shaw has issued an MSD and selected the valve materials accordingly.	Shaw	August, 2011	July, 2011
T_032	Threat	Technology	Event	Ret.	Adequate accessibility and operability of valves and purging points.	Workshop	Could cause purging during startups and shutdowns to take longer and therefore causing schedule delays.	1. amec will have their operations group and TEC's operators to review 3-D model to ensure all valves are accessible.	AMEC is reviewing the 3-D model on a monthly basis with TEC and RTI to resolve accessibility issues. RTI started reviewing each of the control valves for accessibility. Commissioning team is currently walking systems down to	RTI/amec/TEC	January, 2014	October, 2015
T_033	Threat	Technology	Event	Ret.	Systems are historically not designed for adequate hazardous energy control.	Workshop	Cannot establish protection in a timely manner and will cause delays until this can be established.	1. Shaw will develop design with hazardous energy isolation as part of the criteria. 2. Shaw will conduct a HAZOP to ensure this issue is mitigated. 3. TEC operations will be included in the HAZOP and model	HAZOP was conducted and all of TEC's comments were picked up wrt to hazardous energy control and incorporated into the process design.	Shaw	September, 2011	August, 2011
T_034	Threat	Technology	Event	Ret.	Unable to adequately measure the liquid levels of sulfur in previously run pilot plant.	Workshop	Measuring liquid sulfur levels has been problematic due to small scale in pilot plant. Creates operability for maintaining liquid level in vessel	should be easier in bigger plants because we can utilize commercial methods	This item will be retired since the DSRP has been removed from project scope.	RTI	April, 2011	April, 2011
T_035	Threat	Technology	Event	Ret.	Lack of representatives from operations and construction for design reviews and HAZOP..	Workshop	Not getting proper inputs and reviews during design; could cause design changes later in the project from not having the proper reviews up front.	RTI, AMEC, and TEC will ensure proper representation from Operations and Constructions during design phases.	This item will be monitored through each review cycle to ensure that appropriate personnel are included. To date RTI, CH2M Hill, Shaw, and TEC have participated in PHA, PFD and P&ID reviews, and startup collaboration. Additionally, AMEC issues the 3-D model bi-weekly and reviews monthly with TEC operations. The HAZOP was completed in October 2012. During the	RTI/AMEC/TEC	August, 2012	October, 2012
T_036	Threat	Technology	Event	Ret.	Improper application of overall Material selection for equipment and piping	Workshop	critical to understand the corrosion or metallurgic impacts during process to understand the performance of the equipment. Where to put corrosion coupons and possibly needing to select different materials for commercial use	Shaw will develop a material selection diagram based on their experience with syngas applications, FCC experience, and acid gas removal processes.	Shaw has issued a MSD and issued to the project team.	Shaw	September, 2011	July, 2011
T_037	Threat	Technology	Event	Act.	Unable to identify the erosion points during the design phase.	Workshop	Not identifying the erosion points in solids handling systems could cause inappropriate down time.	1. AMEC and RTI will ensure that erosion points are identified based on the combined solids handling experience to mitigate the issue of erosion.	This item has been pushed out to Detailed engineering. AMEC has started working with vendors to design the solids transfer systems. This item will not be closed out until the end of the project. The operation team will monitor during operations. The sorbent feed system has incorporated erosion resistant elbows	RTI/AMEC	June, 2015	
T_038	Threat	Technology	Event	Ret.	Not having thorough change management design reviews and communications across disciplines.	Workshop	Not catching integration issues during reviews if they are not reviewed by all disciplines. This can cause late design changes or possibly having to make design changes in the field. Could cause schedule delays due to procurement delays.	1. AMEC will set up a change management process that facilitates communications to all project team members. This includes updating baseline documents (such as design basis memorandum, PFD/HMB, P&IDs, and basis of design). This is covered in Shaw's Integrated Project Plan. 2. RTI will conduct weekly progress meetings to ensure changes are captured, documented, and communicated to	To date this has not been an issue. RTI has ensured that all stakeholders are notified of changes. RTI will continue to monitor.	AMEC/RTI	January, 2014	January, 2013
T_039	Threat	Technology	Event	Ret.	Not having the appropriate people review engineering documents and the impacts related to them.	Workshop	Could cause improper reading of results such as looking only at the start of run and end of run test results .	AMEC and CH2M Hill will implement proper review procedures to ensure the appropriate reviews occur. Shaw will have a QA/QC reviews to ensure their processes are being followed	To date this has not been an issue. This item will be closed out.	AMEC/CH2M Hill	May, 2012	May, 2012
T_040	Threat	Technology	Event	Ret.	Changing control strategy during scale up	Workshop	During scale up the operating conditions will change and will not be able to work the same way it did during the pilot test. Capturing control strategy LL from pilot plant and implementing them into the scale up	RTI and Shaw design teams will meet and discuss control strategies to be taken forward from the pilot plant.	After reviewing this item with Shaw, it was determined that the similarities between the Eastman design and current demonstration design will translate. Therefore, this item is removed	RTI/Shaw	April, 2011	April, 2011
T_041	Threat	Technology		Ret.	Fuel to Air control on Regenerator when utilizing fuel oil	Project Meeting	Poor control could result in a reducing environment.	Shaw to develop control scheme to address issue.	Shaw developed a control scheme that was reviewed during HAZOP.	Shaw	July, 2011	July, 2011

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
T_042	Threat	Technology	Event	Ret.	Production of RTI-3 sorbent for 50 MW demonstration. Because of the new regulatory constraints implemented within the last 5 years, catalysts/sorbent manufacturers had to eliminate NOx emissions by reducing or eliminating ammonia systems during production of RTI-3.	Project Meeting	Production of the RTI-3 sorbent with the original recipe will not be possible without the addition of significant environmental control equipment and repermitting. Therefore, the original recipe used during Eastman pilot test will need to be adjusted. This may add potential cost, schedule, and quality risk to the project.	An alternative precipitating agent, which will perform the same function as the ammonium hydroxide (originally used) and will not require installation of additional environmental control equipment or repermitting, is sodium hydroxide. Based on this alternative, a plan was developed and is being implemented to optimize the production process using sodium hydroxide as the precipitation agent. Working backward from the required onsite delivery of the sorbent, this plan ensured that sorbent production would not have any impact on commissioning or operation of the 50 MW system. At this time, the delivery of the sorbent is being targeted for mid-August, which is ahead of the commissioning of the reactor system.	The optimization of the sodium hydroxide precipitation process is on schedule. A production trial batch is planned for January 2013 with the actual production to begin in the June 2013 time frame, which should enable completion of the fist production batch in January, 2014. RTI-3 material was delivered and placed in absorber/reactor. This item is closed out	RTI	October, 2013	1/17/2014
T_043												
T_044												
T_045												
Legal/ Commercial/Contractual												
L_001	Threat	Legal	Event	Ret.	Finalize contract with TECO to define scope, budget, and schedule during the FEED and Permit Phase of the project.	PreFeed	Without a signed contract, work to support CO2 permit, Air permit, and FEED support cannot begin. This could delay getting the permit process, which is a critical path item, started	RTI will meet with TECO while on site during Mid-January to finalize unresolved issues. Closed	Contract has been signed. This item is closed out.	RTI	February, 2011	February, 2011
L_002	Threat	Legal	Event	Ret.	Finalize FEED contract with Shaw to define scope, budget, schedule, and resource plan for FEED.	PreFeed	Without a signed contract, the FEED effort cannot begin, which will delay the project and put pressure on project schedule and budget.	1. Finalize the Basis of Design with input from RTI/TECO/Shaw and approval from DOE. 2. Agree on the final deliverable for FEED. 3. Shaw develop FEED plan (i.e. budget, schedule, scope, and resource plan).	1. RTI and Shaw have defined several cases to model that integrate warm gas desulfurization with CC technology. The results will be used to develop PFD/HMB, Equipment list, and factored cost estimate. The results of this study will be used to set the scope of the project. 2. RTI, Shaw and TECO have started reviewing the permit requirements to make sure the FEED effort will support the permitting process. 3. RTI and Shaw have started the FEED pre-planning with the goal of kicking off FEED no later than March 1, 2011.	RTI	May, 2011	May, 2011
L_003	Threat	Legal	Event	Ret.	Determine Contracting Philosophy for EPC.	PreFeed	The contracting philosophy needs to be determined very early in order for the stakeholders to understand the overall risk profile for the project, negotiations on T&Cs can be initiated, and proper scope for FEED determined.	1. Start discussions immediately within RTI to finalize contracting philosophy. 2. Get stakeholder approval. 3. Work with RTI legal to develop Terms & Conditions	Internally RTI project team is developing contract evaluation process that outlines the pros/cons of the different strategies. A proposal will be taken RTI Sr. Management for approval. Once approved RTI will seek approval from DOE.	RTI	March, 2011	March, 2011
L_004	Threat	Legal	Event	Ret.	Finalize Agreement with BASF	PreFeed	Without a signed license agreement with BASF design work on the CC system to support FEED cannot start.	RTI put pressure on BASF to produce a license agreement to review and authorize.	RTI has signed agreement with BASF. This item is closed.	RTI	March, 2011	March, 2011
L_005	Opportu nity	Legal	Event	Ret.	Ability to encompass off-shore engineering	Workshop	Allowing off-shore engineering labor can reduce the engineering costs.	RTI provide Shaw directions about using off-shore labor	RTI has instructed Shaw that off-shore labor can be used up to 10% of engineering cost. This item is closed.	RTI	March, 2011	March, 2011
L_006	Threat	Legal	Event	Ret.	Not getting or a delay in getting signed the four party NDA	Workshop	would create a lack of information flow between all 4 parties. Would create problems if a party has an issue then they would not be able to review necessary documents.	RTI will drive RTI, Shaw, CH2M Hill, and TEC to sign the NDA.	The NDA has been signed by RTI, TEC, Shaw, and CH2M Hill. This item is closed.	RTI	March, 2011	March, 2011
L_007	Threat	Legal	Event	Ret.	Finalize site access agreement with TEC	Workshop	Without site access agreement, DOE will not authorize BP2 which will result in project delay.	1. RTI and TEC will continue work to get agreement signed	RTI and TEC have a signed access agreement.	RTI	July, 2011	March, 2012
L_008	Threat	Legal	Event	Ret.	Finalize an agreement with Environmental assessment contractor. Need an agreement with DOE to proceed	Workshop	Without contract with environmental consultant, the EA documentation will be delayed	RTI will work with DOE to get approval to use ECT as EA consultant.	RTI has signed an agreement with ECT. Also, RTI, ECT, and DOE have signed a 3-way MOU. This item is closed.	RTI	March, 2011	March, 2011
L_009	Threat	Legal	Event	Act.	Failure to provide or submit the ARRA reporting	Workshop	Breach of contract could cause the project to be suspended or have the funding pulled.	RTI will set up process to ensure all reporting is submitted to DOE on time.	This will be ongoing throughout the life of the project. To date RTI has been on time with all ARRA reporting.	RTI	September, 2015	
L_010	Threat	Legal	Event	Ret.	Lack of signed contract with sub contractors. Several points that need to be resolved, in particularly the legal cost revolved around indemnities	Workshop	Subcontractors not getting paid or possibly being replaced	RTI legal and contracting team will develop an execution strategy to get the appropriate contracts in place.	This item is similar to L_015. Therefore it is going to be closed out.	RTI	October, 2011	October, 2011
L_011	Threat	Legal	Event	Ret.	Approval of RTIs continuation application	Workshop	Would not be able to continue with the project.	Once RTI finalizes the scope with Shaw, the continuation application will be submitted.	This item continues to slip. Current plans are to have an approved CA by the end of May, 2012. This item continues to slip. This is putting pressure on schedule. Additionally, vendor quotes are beginning to expire; therefore, this adds to cost risk. RTI received continuation application approval from DOE in	RTI	October, 2011	September, 2012
L_012	Threat	Legal	Event	Ret.	DOE stage gate approval Process	Workshop	Undefined schedule for or turn around time for review of documents could have a negative impact on project schedule.	1. RTI will submit draft concepts to DOE for approval. These concepts will give DOE the oversight and control they want without placing time consuming hold points on the project. 2. RTI will update the project management plan and SOPO and submit to DOE	Initial stage gates have been submitted to DOE. DOE has accepted in principle. RTI is updating the project management plan and SOPO. This item is closed.	RTI	May, 2011	May, 2011

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
L_013	Threat	Legal	Event	Ret.	Ultimate fate of CO2	Workshop	Travel of the CO2 off site to impact other land owners may prevent the TEC owners for allowing the CO2 Injection. Also, unforeseen impacts of the CO2 could result in lawsuits.	1. TEC will work with USF to model the impacts of injecting CO2 underground. 2. TEC will develop a detailed MVA plan to monitor CO2 after it is injected underground. 3. Both TEC and RTI need to develop an insurance strategy	The CO2 sequestration well has been descoped from the project. Therefore, this is no longer an issue for the project.	RTI/TEC	September, 2015	March, 2012
L_014	Threat	Legal	Event	Ret.	Negotiations with Government of the cost treatment of the subcontract with Shaw where there is 2 different methods of treating the cost.	Workshop	Until locked down there may be a potential for loss or unrecoverable cost.	methodology of 2 different contracts	Since Shaw is viewed at sub-contractor, this issue has been mitigated. This item is closed.	RTI	March, 2011	March, 2011
L_015	Threat	Legal	Event	Ret.	Lack of an agreement for project association which will allocate risk and responsibilities between contractors.	Workshop	The risk is one associated with allocation of liability, if not clarified between parties could cause discomfort between parties and ultimately have one or several decide not to continue with the project. If not decided in a timely fashion it could cause major schedule impacts.	1. RTI will determine contracting philosophy. 2. RTI work with contractors to develop risk allocation	The execution strategy has been determined for the project. RTI has decided to go with a fee at risk approach. Additionally, RTI has selected AMEC as EPC contractor. RTI is working with Marsh to develop risk allocation strategy for the project. Until the contracts with AMEC and TEC are singed this issue will remain critical. The EPC contract was	RTI	October, 2011	July, 2012
L_016	Threat	Legal	Event	Ret.	Signed EPC Contract		Without a signed EPC contract the project cannot move into the next phase of the project.	1, RTI is negotiating the EPC contract with AMEC. 2. RTI has been reviewing the EPC contract strategy with DOE to get buy-in before official submission.	AMEC and RTI are finalizing the terms for this project. The goal is to have a signed agreement in May, 2012. This contract was signed in July, 2012	RTI/AMEC	May,,2012	July, 2012
L_017	Threat	Legal	Event	Ret.	Finalize O&M Agreement with TEC	RTI	Without an agreement, TEC does not have a basis to provide operators for the project. This would require RTI to contract operators.	RTI and TEC finalize term sheet and draft agreement	All the terms of the agreement are agreed upon by both RTI and TEC. The contract should be signed by February, 2013. The contract was signed on 4/3/2013.	RTI/TEC	October, 2012	April, 2013
L_018	Threat	Legal	Event	Ret.	Receive authorization from DOE for BP3	RTI	Delay of BP3 could prevent transition to the operation phase of the project.	RTI will submit the BP3 continuation application early to start the DOE review process well in advance of when the funds are required.	RTI has submitted the BP3 CA to DOE. The package is currently under review. This item should be closed out by next reporting period. Authorization was received from DOE. This item is closed out.	RTI	October, 2013	1/8/2014
Environmental												
E_001	Threat	HSE	Event	Ret.	NEPA process has the potential to delay schedule	Workshop	Based on the current stage gate process for this project, Phase 2 of the project cannot start without a final EA. Since EA can take between 6 to 12 months, schedule risk are likely.	1. Start EA process immediately. 2. RTI needs to start discussions with DOE to allow detailed engineering (that includes initial payments to vendors) to start in the event the EA is not finalized at the end of FEED.	The EA was approved in October, 2011	RTI	October, 2011	
E_002	Threat	HSE	Event	Ret.	Project not staying within the confines of the Air Construction permit obtained by TEC for this project.	Workshop	Notice of violation (NOV) Financial fine changes to overall plant operating permits or conditions which could cause TEC to have a consent decree, requirements to phase out older equipment, change fuels.	1. RTI will assume conservative emissions for the air permit. 2. The construction plan will include measures to ensure permit compliance.	RTI has submitted permitting information to TEC for air permit. Since construction is essentially complete (the exception is insulation), this item will be removed from the risk register.	RTI	September, 2015	
E_003	Threat	HSE	Event	Ret.	Air permit not received on time to allow construction to start per current schedule	Workshop	Delay of Construction until Air permit is received.	RTI will work with TEC to get air permit submitted to FDEP ASAP. Also, TEC will work with FDEP to ensure permit is received by March, 2012	Air Permit received in Nov, 2011	RTI	March, 2012	November, 2011
E_004	Threat	HSE	Event	Ret.	Getting the environmental permitting for the CO2 injection. (UIC)	Workshop	Preclude CO2 injection	1. TEC has started the UIC permit process early and worked with FDEP to get the permit pushed through the system. 2. RTI will work with Shaw to make sure the CO2 system can be by-passed in the event the CO2 permit is not ready in time for operations.	This item is closed since CO2 well has been descoped from the project.	TEC	February, 2012	March, 2012
E_005	Threat	HSE	Event	Ret.	EPA headquarters has challenged EPA regional office and FDEP's decision to classify the well permit as Class V. EPA headquarter wants to reclassify the well as Class VI.	Project Meeting	If EPA headquarters is successful converting the well to Class VI, then the project schedule is at risk since EPA has never approved a Class VI.	TEC and Jerry Hill are working with FDEP to respond to EPA headquarters. To date, EPA regional office has approved the Class V classification.	This is covered in the item above, therefore, this action will be closed out.	TEC	January, 2012	
E_006	Threat	HSE	Event	Ret.	Monitor SWPPP	Weekly Meeting	Failure to maintain SWPPP could result in fines. Depending on the severity, the project could be asked to stop.	AMEC has developed a SWPPP plan and submitted to TEC, who submitted to FDEP. TEC and AMEC walk the construction site down each week to ensure BMP's are being maintained.	To date, no violations have been reported by TEC.	AMEC	May, 2014	May, 2015
Health & Safety												
COST												
C_002	Threat	Cost	Event	Ret.	Due to the FOAK nature of this project and since this is the first time RTI has managed a project of this size, controlling project costs is a concern.	Workshop	Since there is a fixed budget, cost overruns would stop the project, stop technology development of the warm gas cleanup, and prevent DOE form meeting programmatic goals related to the CCS program.	1. RTI will work with AMEC and TECO to develop a bottoms up cost estimate before FEED begins. 2. RTI will maintain a working estimate that is updated throughout FEED, not at the end. 2. RTI will work with AMEC, TECO, and owner's engineer to start value engineering at the onset of FEED (i.e. look for skid design expectation, challenge specifications against five year life design expectation, challenge home office costs, etc....) 4. Additionally, RTI will bring in an owner's engineer to help manage change control and scope creep. 5. RTI will bring in additional contractors to develop shadow estimates	Since the CO2 sequestration portion of the project has been descoped, cost pressures for the project have been reduced. RTI project controls will continue to tightly monitor to ensure the project stays within budget. To date all major manufacturing equipment is running underbuget, construction productivity has been running above unity, and commodity prices have not escalated significantly above original budget. At this time the EPC budget is forecasting an underrun of ~$3 MM	RTI	September, 2015	May, 2015
C_003												
C_004												
C_005												

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
Procurement												
P_001	Threat	Procurement	Event	Ret.	Trying to capture long lead items early enough / Lack of a detailed procurement schedule at this point in the project	Workshop	Misprioritization on which materials are longest lead and should have higher priority.	1. Shaw will solicit quotes and delivery times for the projected long lead items early in FEED. 2. The delivery dates will be compared to current schedule assumptions. 3. If there is a negative impact to schedule, further mitigation will be required such as placing an order before detailed	AMEC has identified the long lead items. Until the project receives authorization to proceed into BP2, this item will be significant. The long lead items have been identified. However, the project has not been authorized to purchase these items. Therefore, the schedule is still at risk. This item has been moved up to the critical category.	AMEC	May, 2012	October, 2012
P_002	Threat	Procurement	Event	Ret.	Schedule is based upon high level schedule without strong detail on procurement	Workshop	Could see notable differences as the FEED work is completed and increased detail established	1. Shaw will develop a procurement plan during FEED to support EPC. 2. Shaw will solicit quotes and delivery times for the projected long lead items early in FEED.	Current schedule developed during FEED shows that the project should meet its schedule targets.	Shaw	August, 2011	August, 2011
P_003	Threat	Procurement	Event	Ret.	EPC Contracting strategy that came from FEED is not yet solidly locked down. If contracting strategy is changed down the road.	Workshop	Higher cost primarily due to increased levels of risk transference. Cost estimate currently does not support a contracting strategy beyond the reimbursable basis currently	RTI provide contracting philosophy to Shaw to develop FEED cost estimate.	Shaw was instructed to develop a cost estimate based reimbursable execution. This item is closed.	RTI	April, 2011	April, 2011
P_004	Threat	Procurement	Event	Ret.	Lack of a fully developed procurement approved vendor's list. Pieces have been developed - but is not complete.	Workshop	Additional time to find vendors who would qualify, or to qualify them after they have submitted proposal. Could have cost impacts to re-do requisitions and to survey/approve a vendor. Additionally, approved vendors may be higher cost on	1. Client provide vendor list. 2. Shaw will develop a project vendor's list during FEED.	RTI and TEC have provided a vendor's list to Shaw. Shaw will finalize project vendor's list during FEED.	Shaw	October, 2011	October, 2011
P_005	Threat	Procurement	Var	Ret.	General Commodities cost fluctuations - particularly steel.	Workshop	Differential from pre-Feed estimate	1. AMEC will monitor industry commodity pricing throughout the life of the project and project impact on escalation.	AMEC has received quotes for most of the commodities. Thus far this is no an issue. But if the project continues to delay, escalation could become significant. The project has experienced the impact of escalation as a result of delay in moving into BP2. The project budget was updated prior to moving into BP2. At this time commodity escalation does not seem to be an issue with the latest budget. The project will continue to monitor. All the major commodities have been purchased for this job. Therefore, this item will be closed out.	AMEC	March, 2013	July, 2013
P_006	Threat	Procurement	Var	Ret.	Shop time availability of approved vendors (correlated with P_004).	Workshop	Difficulty in preparing a accurate survey of vendor availability.	1. AMEC will survey the approved vendors shop space requirement. 2. If there is a high demand on shop space, AMEC will develop a mitigation plan.	Thus far AMEC is not reporting any significant shop issues. However, if the project continues to delay moving into BP2 good delivery schedules may be lost. All major equipment has been ordered. Delivery schedules are within schedule requirements.	AMEC	March, 2013	October, 2012
P_007	Threat	Procurement	Event	Ret.	Reactors are first of a kind - so challenges in producing them.	Workshop	Time to design and specify this configuration. (may need to be on Engineering Risk items rather than Procurement). Variability in fabrication time (actual vs. vendor proposed). Also, potential vendor price over-runs (vendor coming back		After reviewing with Shaw, the decision was made that this is not a first of a kind reactor design. Shaw does these designs on a regular basis. Therefore, this item is removed.	Shaw	April, 2011	April, 2011
P_008	Threat	Procurement	Event	Ret.	Buy-America requirements - will vendors in US be able to produce required equipment.	Workshop	Time to prepare variance and supporting back-up to obtain the Buy-America waiver.	1. Shaw will determine during FEED if any equipment manufacturing is required off-shore. 2. If off-shore design is required, then Shaw and RTI will prepare waiver well in advance of detailed engineering.	RTI has received communications from the DOE contracting officer in August, 2011 that Buy America act does not apply for this project.	Shaw	October, 2011	August, 2011
P_009	Threat	Procurement	Event	Ret.	SBE and MBE requirements under Federal procurement requirements	Workshop	Time to ensure on qualified lists. Potential disputes from firms who are not qualified but are MBE/DBE firms.		This is not an issue.; This item closed out.	RTI	March, 2013	March, 2011
P_010	Threat	Procurement	Var	Ret.	Difficulty in obtaining budgetary pricing from Vendors which is timely and reliable / committed.	Workshop	Effects preliminary planning and budgeting. Notably look at slide-valves which are a unique configuration. Most other equipment is relatively common.	Follow best practices for this level of detail. Develop appropriate level of detail / information which supports a Cl 3 level estimate. Provide sufficient time for quotation development. Approach multiple vendors. Cursory technical and commercial reviews upon receipt of quotations.	After reviewing this item with Shaw, this is not an issue. Due to the current economic climate vendors are motivated to provide reliable and time efficient quotes. This item is closed.	Shaw	April, 2011	April, 2011
P_011	Threat	Procurement	Var	Ret.	Lack of logistics plan. Unknown envelopes and points of origin.	Workshop	Impacts to cost and schedule forecasts (increases in variability). Only compressors currently have possibility of manufacture overseas. Rail damage or delay.	AMEC will develop a logistic plan as part of EPC.	AMEC is working with vendors as they develop their target price. Major equipment items have been ordered. All equipment items are U.S. based.	AMEC	august, 2012	October, 2012
P_012	Threat	Procurement	Var	Ret.	Overall EPC plan for procurement needs to be prepared. EPC phase must then accept.	Workshop	Until prepared - scheduling of EPC Activities has greater variability.	AMEC will develop procurement plan prior to EPC	RTI has selected AMEC as EPC contractor. AMEC is developing a target price for EPC. The procurement plan will be part of the package. Since the EPC contract has been	AMEC	May, 2012	July, 2012
P_013	Threat	Procurement	Event	Ret.	Logistics access to the brownfield site.	Workshop	Specialized carriers must be contracted (most likely), worst case - road or rail upgrade.	1. Shaw, RTI, and TEC will review road access to site and determine what, if any, upgrades are required.	Since TEC has built an existing IGCC plant and has several NG Combined Cycle plants on this site with much larger equipment, it has been determined that upgrades are not	Shaw	March, 2011	March, 2011
P_014	Opportunity	Procurement	Event	Ret.	Ability to encompass off-shore engineering	Workshop	Move to Contracting / Legal				March, 2011	March, 2011

Risk ID	Thrt/ Opp	Proj Category	Risk Type	Active / Retired	RISK DESCRIPTION	Source	Consequence Description	Risk Mitigation	Status	Risk Owner	Due Date	Close Date
P_015	Threat	Procurement	Event	Ret.	Issue during fabrication where an ISL or testing requirement is failed.	Workshop	Fabricator repairs (most likely), re-manufacture (worst case).	Prequalification of Vendors Good preliminary ISL checks Construction plans with alternative sequences.	AMEC is prequalifying reputable vendors. Thus far, this has not been an issue, but will continue to monitor. The last item to monitor is the refractory in the reactor systems. This item is closed out.	AMEC	September, 2013	October, 2013
P_016	Threat	Procurement	Event	Ret.	Fitting a SOW back into a hard budget limit during early FEED phase.	Workshop	Customary approach is the reverse. Iterative efforts to match SOW and budget.	Prioritize high-cost items early in the FEED and pricing exercise. Particularly process data sheets on the top handful cost elements (equipment purchases).	Since the CO2 sequestration portion of the project has been descoped, this item is no longer an issue. Therefore, this item will be closed out.	AMEC	March, 2013	April, 2012
P_017	Opportunity	Procurement	Event	Ret.	Locating previously purchased but "abandoned in procurement" equipment.	Workshop	Could bog FEED down in trying to chase. Obtain equipment at lower price.	1. Shaw will work with vendors to determine if they have any used equipment available.	This is not an issue. Therefore, this item will be closed out.	AMEC	March, 2013	February, 2012
P_018	Opportunity	Procurement	Event	Ret.	Use of AMEC purchasing power through alliance agreements or bulk purchasing agreements.	Workshop	Need to ensure enough quantities to really obtain these, consider future project quantities also in obtaining agreement to utilize.	1. AMEC will evaluate where bulk purchasing agreements are applicable during FEED and detailed engineering.	AMEC plans to put all the heat exchangers and pumps under one agreement to reduce cost and standardize operating spares. RTI will continue to monitor. All major purchase orders issued. This item is closed.	AMEC	March, 2013	
P_019	Threat	Procurement	Event	Ret.	Failure to return vendor documents timely back to vendors to support fabrication	Workshop	Slow response back to fabricator can delay fabrication.	1. AMEC, RTI, and CH2M Hill will develop a document review matrix during detailed engineering to ensure expedite response to vendors.	This item will be dealt with during EPC. Thus far this has not been an issue during detailed engineering. RTI will continue to monitor. All items are in fabrication; therefore this item is closed.	AMEC	March, 2013	
P_020	Threat	Procurement	Event	Ret.	Failure to invoke a strong vendor surveillance program that covers both quality and progress.	Workshop	ISL step missed in the Fabricator shop - post fab testing (most likely), re-fab/manuf. (worst case). Vendor late on delivery.	1. AMEC will develop a detailed procurement plan and QA process that ensures the vendors are performing per the terms of the agreements.	This item will be dealt with during EPC. This item is closed out since the EPC contract is signed.	AMEC	May, 2012	July, 2012
P_021	Threat	Procurement	Event	Ret.	Delay in document movement during FEED between engineering, procurement and vendors is magnified by compressed FEED schedule.	Workshop	Compressed FEED Schedule complicates estimating process and can we move the information between engineering, procurement, and vendors fast enough?	1. Shaw will develop a FEED schedule with appropriate review cycles. 2. Shaw, RTI, and CH2M Hill will perform collaborative reviews to shorten cycle.	This item is closed out since the engineering package for FEED is developed.	Shaw	September, 2011	August, 2011
P_022	Opportunity	Procurement	Event	Ret.	Can we capitalize on modularization / skidding cost and schedule efficiencies early in this FEED phase.	Workshop	Reduction in site work (generally more expensive). Less potential for impact to TEC Operations. Minor improvements to schedule and on-site HSE (shop environments generally safer).	AMEC will look for modularizastion options.	This has been evaluated and incorporated into the design. This item will be closed out.	AMEC	March, 2013	February, 2012
P_023	Threat	Procurement	Event	Ret.	Enerfab vessels (i.e. columns and water gas shift reactors) arriving late to site.	Project Meeting	Delay schedule and increase cost.	AMEC will provide additional expediting oversight.	AMEC has met with Enerfab to pull the schedule in. This item is covered in P_024; therefore it is closed.	AMEC	September, 2013	July, 2013
P_024	Threat	Procurement	Event	Ret.	Ensure each piece of equipment arrives on site per schedule	Project Meeting	Delay of equipment can cause a schedule slip and cost increase.	AMEC will provide additional expediting oversight to ensure all equipment arrives on site on time.	AMEC has brought in additional support to oversee the expediting process. AMEC continues to monitor Enerfab to ensure delivery of amine column does not impact schedule. Tapco Empro has slipped their schedule. AMEC has put a person full time in their shop.	AMEC	September, 2013	
P_025												

Appendix F

Operations Summary by Week and Quarter

April, 2014 to June, 2014

Below is a description of activities and findings of the Warm Gas Cleanup Demonstration Unit at Polk Power Station:

- **Week of April 7, 2014** – Lined up the system to start heating up the adsorber/regenerator units. During the heat up phase, a leak in the adsorber hot gas filter system was noted. The unit was brought down and the hot gas filter plenum was removed for inspection. Upon inspection, the filter media of one of the interior filters was found damaged. The filter element was removed and a new element was installed. The damaged filter element was sent to Pall filter for determination of the failure mechanism (See Appendix N for discussion of the root cause analysis). As a result of pro-longed leaking, the other filter elements started blinding as solids were back-pulsed into the clean side of the filter.
- **Week of April 14, 2014** – After the filter vessel was re-installed, the system was lined up again to restart the heat up process. The adsorber was heated up to 850 ^{o}F and the regenerator was heated up to 650 ^{o}F.
    - April 17, 2014 – syngas was introduced to the adsorber to verify the analyzer/DCS connections. The analyzer results showed representative values of the syngas composition from Polk Power Plant.
    - April 18, 2014 through April 21, 2014 – solid circulation in the adsorber was initiated to verify the pressure drop readings across the standpipes. During the test, the bed level in the adsorber stripper dropped below the trickle valve at the bottom of the cyclone dip-leg. This resulted in the solids by-passing the cyclone and a significant reduction in bed level. The slide valve was closed to stop circulation and allow operations to reload the adsorber stripper to increase the bed level above the trickle valve. This test established a baseline for the minimum bed level in the adsorber stripper.
- **Week of April 21, 2014** – started heating up reactor system with new heat up strategy. During the last reporting period, it was noted that the solids carryover from the adsorber cyclone to the hot gas filter was excessive. It was believed that the carryover was due to low velocities during the periods of low temperature when nitrogen (i.e. lower density

gas) was used as the circulation and heat up medium. Based on the initial learnings, a new heat up strategy was developed to heat up the system and achieve higher velocities in the cyclone before circulating solids. This appeared to work for the first few hours of circulation, but the solids carryover problem returned. The solids loading rate exceeded 400 lbs/hr at times. It became apparent that the cyclone dip leg was backing up solids into the vortex of the cyclone. Several tests were conducted to determine if gas was leaking by the trickle valve and spoiling the cyclone or if the trickle valve or dip leg was blocked impeding the flow of solids out. It was thought that the trickle valve was blocking the flow of solids and backing up into the cyclone. The project team began to work with Ken Pecatillo and Duane Goestch to develop strategies to correct the problem. [NOTE: It was later determined that some foreign matter was blocking the dip-leg and trickle valve. Removal of the foreign matter and establishing suitable aeration in the dip-leg to keep any fines from packing solved the problem.]

During this time of operation, the pressure drop across the filter system became excessive. This was due to the filter leak of the previous week. Solids on the clean side of the filter system were being back-pulsed into the clean side of the filters and blinding them. It was decided to continue running to achieve the milestones for the week; however, plans to remove/replace the filter elements were developed. The project team started working with Pall Filter and Carolina Filter to clean the blinded filter elements.

Throughout the heat up period, the startup heater started tripping on high exhaust stack temperature. After investigation, it was discovered that Tulsa Heater had set the trip point too low. In order to change the temperature trip set-point, special software and cables were required. These items were ordered but required three days to get to the site.

One of the goals for this week was to test the fuel oil heat up system with the regenerator. The fuel oil pump had issues achieving the desired pressure. It was determined that the orifice on the recycle line was too large; therefore, a new orifice was drilled and installed, which allowed the pump to achieve required pressures. Before the fuel oil system was tested, a seal on the regenerator air compressor failed. At this time the unit was shut down for outage work to repair the failed seal.

- **<u>Week of April 28, 2014</u>** – During this week, the following outage activities were performed:
    - o Pulled the adsorber filter elements for removal and replacement (See Figure 5). During the outage, Rick Range from Pall Filter was present to inspect the blinded filter elements and inspect the new filter elements as they were installed. RTI and Pall Filter worked with Carolina Filter to clean the blinded filter elements.

- Enerflex came on site to replace the failed seal on the regenerator air compressor. After investigation, Enerflex determined that the seal was installed improperly by the manufacturer. Enerflex replaced the seal and released the compressor back to operations.
- Continuous purge to cyclone dip-leg was installed. The existing system had a pulse mechanism on the cyclone dip-leg. However, this pulse line plugged since there was not a continuous purge to keep solids from backing up.
- Cyclone inspection – Cyclone was inspected during the outage. No issues were identified with the integrity of the cyclone. Also, no deposits were noted during the inspection, which indicated that the previous solids carryover was due to material backing up in the cyclone cone.
- Cleaned solids out of the clean side of the system. Due to the failed filter element solids migrated to downstream piping and knockout drums. This material was cleaned out during this outage.
- Reprogrammed the startup heater temperature trip setpoint.

- **Week of May 4, 2014** – Once the outage items were completed the unit was lined up for heat up. During this week, Ken Pecatillo was brought in to assist with startup. The strategy to reduce the solids loading from the cyclone was to reduce the bed level in the adsorber stripper and establish a continuous aeration to the trickle valve. This strategy seems to have worked as the solids loading was reduced to below 20 lbs/hr from levels that were as high as 400 to 800 lbs/hr. Also, Pall Filter provided filter support during this week. They were able to address some of the back-pulse logic issues and reduced the nitrogen consumption associated with back-pulsing the hot gas filters.
- **Week of May 11, 2014** – The system continued to operate with low solid loading from the cyclone. The filter vessel pressure drop was stable for four days. Also, the fuel oil system was tested. During the test, it was observed that the piping network needed to be modified to allow tighter control over the feed rate of fuel oil into the regenerator.

  During operation it was noticed that solids circulation through the adsorber J-Leg began to slug when aeration levels were reduced. In order to maintain the solids circulation, the nitrogen levels during startup are higher than the plant can provide. Therefore, a modification to the piping network was needed to get adequate aeration in the J-Leg. This change allowed syngas to be utilized to aerate the adsorber J-Leg rather than nitrogen.
- **Week of May 17, 2014** – The project team was able to establish sorbent circulation in the adsorber loop, regenerator loop and between the adsorber/regenerator. Syngas was

introduced to the adsorber – approximately 5,500 to 6,000 lbs/hr. The inlet sulfur was approximately 1% (H_2S – 9,800 ppmv, COS – 300 ppmv). During this initial test, the outlet sulfur concentration was below detectable limits. The main syngas inlet control valve tripped several times for the following reasons:

- Slow ramp up rate – there is an ESD trip that closes the control valve if a specified flow is not achieved within two minutes. Since the syngas ramp up rate was slow, this interlock tripped the valve closed.
- Low flow ESD trip – at low flow rates the flow meter does not read accurately and the signal is "noisy". As a result, the flow rate would drop below the trip point and shut the valve.
- Low differential pressures across valve during hot gas filter back pulse. When the hot gas filter initiates a back-pulse the pressure wave reduces the flow instantaneously, which resulted in the valve tripping closed.

May 18, 2014 – The project team continued circulating solids through the adsorber/regenerator system. Syngas was introduced at a flow rate of approximately 1,560 lb/hr for 1.33 hour and 3,260 lb/hr for 1.17 hour. The inlet sulfur content was approximately 1% (H_2S – 9,800 ppmv, COS – 300 ppmv). The outlet sulfur was less than 10 ppmv (H_2S < 5ppmv and COS < 1 ppmv). Operations continued to address ESD trips throughout this test.

May 19, 2014 – The project team continued circulating solids through the adsorber/regenerator system. Syngas was introduced to the system with an average flow rate of 50,000 lb/hr for approximately four hours. Sorbent was sampled and analyzed for sulfur loading. The sulfur loading to the sorbent was 3 wt%. During this test, syngas was tied back into the plant without any adverse reactions to Polk Power Plant.

May 20, 2014 – the team continued circulating solids through the adsorber/regenerator system. Syngas was introduced at a flow rate approximately 20,000 lb/hr for three hours. The sorbent was sampled and analyzed for sulfur loading. The sulfur loading on the sorbent was 5 wt%, which was the target loading.

- **Week of May, 25. 2014** – During this week, the focus was on getting the diesel combustion system operational. The tuning of the fuel to air ratio controller was difficult due to the air compressor tripping. The air compressor tripped on low lube oil pressure on multiple occasions. The vendor was contacted to assist with this issue. It turned out the lube oil temperature control valve was malfunctioning. The malfunction was driving the temperature control valve 100% open, which did not provide enough back-pressure for the lube oil pumps. After working with the vendor this issue was resolved. This system was eventually shut down due to a repair on TEC's flare.

- **Week of June 1, 2014** – During this week the process was not able to take syngas since the flare was being repaired. During this outage it was decided to improve the fuel oil system. These improvements included replacing the spray nozzle, reducing the fuel oil line to the reactor, and installing an isolation valve with bi-directional sealing capabilities.
- **Week of June 8, 2014** – During this week the goal was to heat up and start diesel burning to heat up the regenerator. The diesel fuel system was successfully operated to heat the regenerator up to the desired temperatures. Unable to take syngas because the isolation motor operated valves would not open. A faulty computer board was causing the valve to malfunction. A new board was ordered and replaced.
- **Week of June 15, 2014** – During this week the system was lined up to reduce the water gas shift (WGS) catalyst with hydrogen. The WGS catalyst was successfully reduced. Approximately, 20,000 to 40,000 lb/hr of syngas was sent to the process. Additionally, the regenerator oxidized the sulfur off of the sorbent. The SO_2 generated was sent to TEC's sulfuric acid plant. After approximately eight hours the syngas was shut off due to syngas leaks from the stem of several valves. Afterward, the main process was running with diesel to keep the temperatures up. It appears that the control valves downstream of the regenerator are not sized properly for the diesel fuel operation. Therefore, it was decided to bring the system down and change the trim out of the control valves.
- **Week of June 22, 2014** – Completed the trim change out of the control valves. Brought in Enerflex field representative to help with regenerator air compressor issues. During his visit, he corrected the valve tuning issues with the compressor. The syngas compressor tripped due to seal failure on the second stage. The seal was pulled and sent to Flowserve to perform a root cause analysis and repair. The system was down until the seal was returned.

July, 2014 to September, 2014

Below is a description of activities and findings of the Warm Gas Cleanup Demonstration Unit at Polk Power Station:

- **Week of July 1, 2014** – the process was down this week because the main seal of the second stage of the syngas compressor failed (see Figure below). This seal failed due to a regulator that provided seal nitrogen to the seal failed. This failure allowed syngas to migrate within the seal and resulted in corrosion. The seal was replaced and a pressure indicator was installed on the seal line. This indication signal was brought into the DCS, which allows us to determine when we lose seal nitrogen.

Failed seal on second stage of the syngas compressor.

- **<u>Week of July 6, 2014</u>** – Completed repairs to the syngas compressor. Lined system to start heat up cycle. Transition to syngas was delayed due to excess solids level in the cyclone dipleg resulting in solids carryover, which caused the lock-hopper system to overfill. The lock-hopper system was cleaned out and heat up resumed. However, on July 11, one of the RTD's on the syngas compressor motor winding failed. This resulted in tripping the compressor. The RTD was replaced.
- **<u>Week of July 13, 2014</u>** – System heat up was resumed. Before the process was transitioned over to syngas, the pressure control valve downstream of the regenerator plugged, which resulted in the valve sticking. The system was brought down in order to pull the valve and determine the cause of the plug. After the examination, the fouling appeared to be incomplete combustion products from the diesel oil system, which is utilized to heat the regenerator. It was determined that the fuel oil nozzle was oversized. The nozzle was resized and replaced into the regenerator. The system heat up was resumed, but it was noticed that the regenerator filter vessel pressure drop had increased above an acceptable level. The system was brought down and the filter elements removed. It was noted that the filter elements were plugged with incomplete combustion products. These filters were removed and replaced. The filter elements were sent to Carolina Filter (located in South Carolina) for cleaning.
- **<u>Week of July 20, 2014</u>** – System startup was attempted, but the syngas compressor would not startup due to vibration trips. The manufacturer (Sundyne) was contacted. The system was tripping during the startup phase of the compressor which goes through a harmonic. Sundyne recommended that we extend the timer that monitors vibration to

allow the machine to transition out of startup into normal operation. This did not resolve the issue; therefore, a Sundyne representative was sent to the site to assist with this problem. It was determined that the vibration probe was faulty; therefore it was replaced. Additionally, the air compressor vendor (Enerflex) was on site to assist with compressor issues. The compressor was having trouble maintaining reliable flow during warm days. The compressor was tripping on "high temperature". Enerflex replaced the thermostat that controls the amount of oil that by-passes the oil cooler. This change will force more oil to go through the oil cooler, which will bring the second stage discharge temperature down to normal ranges.

On July 22, syngas was introduced into the system. Below outlines the following process conditions:

- Syngas flow – 80,000 lb/hr
- Air Compressor – 10,000 lb/hr
- Flow to acid plant – 0 lb/hr
- Regenerator Temp. – 1,200 ^{o}F
- AAdsorber Temp. – 950 ^{o}F

The system was brought down due to a failed gasket on the syngas inter cooler, which leaked syngas to the atmosphere.

- **Week of July 27, 2014** – System heat up was resumed; however, issues with air compressor trips and syngas compressor surges prevented normal operations. Additionally, it was noted that a piece of the filter element was found in the lock-hopper surge bin. Therefore, it was determined to bring the system down and inspect the filter vessel. The filter system was pulled and the filter elements were removed and replaced with new filters.
- **Week of August 3, 2014** – System heat up was resumed. Nozzles on the regenerator were frequently plugging hindering operation. Standard procedures were updated for operation to make sure all isolation valves are closed before aeration is removed. This will ensure that the nozzles stay clear for the subsequent startup. Also, we continued having issues with the air compressor. The air compressor tripped on several occasions. Each time the compressor sprayed oil out of the vent line. The Enerflex site representative was brought back to address this issue. The mitigation was to slow down the time the vent valve opens in order to have a controlled depressurization.

  System heat up resumed. Before transition to syngas was initiated, it was determined that the heat exchanger downstream of the regenerator was damaged. It was further determined that the cooling water was not lined up to the heat exchanger. The gas exiting the regenerator is 1,300 ^{o}F. Without the cooling water, the tubes were exposed to these temperatures. The heat exchanger was removed and sent out for repair. Repair time for this exchanger was going to be about 3 weeks due to the metallurgy of this exchanger. Therefore, a pipe-in-pipe exchanger was designed and fabricated to replace the heat exchanger as a temporary fix. Additionally, a spare heat exchanger was purchased as a longer term fix.

- **Week of August 10, 2014** – system was down this week to install new pipe-in-pipe exchanger downstream of the regenerator.
- **Week of August 17, 2014** – System heat up was resumed. The new pipe-in-pipe heat exchanger downstream of the regenerator was able to adequately cool the regenerator off-gas. The system was transitioned to syngas, but was brought back down due to a flange leak on the syngas inner changer. This is the second time this gasket failed. The system was brought down to replace this gasket. Additionally, a third party contractor was brought in to weld a band around the flange to ensure that it doesn't leak again in the future. TEC (the host site) came down for a seven day outage.
- **Week of August 24, 2014** – system was down during this week while TEC outage occurred.
- **Week of September 7, 2014** – still having issues with the air compressor. While the site representative from Enerflex was tuning the air compressor, the oil separator caught on fire and resulted in a pressure excursion. After examination, it was determined that the oil separator coalescers were not grounded, which resulted in a static spark. The coalescers were replaced with grounded coalescers.

  The project team met with Enerflex management to resolve the issues with the air compressor. Enerflex developed a plan to address the issues with the compressor. Over the next couple of weeks Enerflex made the following corrections:

  - Added larger hydraulic valve on the first stage to assist with synchronizing the ability of both stages to load smoothly.
  - Performed pressure survey on the oil system to identify restrictions in the oil hydraulic circuit. This survey revealed that one of the pressure transmitters was not scaled correctly, which resulted in the compressor tripping inadvertently.
  - Tuned internal slide valves to reduce pressure swings between the two stages.
  - Raised low level switch in the oil separator.
  - Added relays on the oil heater to trip in the event the oil level in the oil separator vessel reads low.
- **Week of September 14, 2014** – system was down while Enerflex worked on air compressor.
- **Week of September 21, 2014** – continued to allow Enerflex to work on the air compressor to improve its reliability. During this week the compressor ran all week without any trips. System heat up resumed.
- **Week of September 28, 2014** – system was started up with the following conditions:

- Syngas flow – 82,000 lb/hr
- Air Compressor – 10,000 lb/hr
- Flow to acid plant – 14,000 lb/hr
- Regenerator Temp. – 1,200 ^{o}F
- AAdsorber Temp. – 950 ^{o}F

The system ran smoothly during this week accumulating over 170 hours of continuous operations.

October, 2014 to December, 2014

Below is a description of activities and findings of the Warm Gas Cleanup Demonstration Unit at Polk Power Station:

- **Week of October 1, 2014** – the process was up and running through this week. Process operation was smooth during this time period. The sorbent attrition rate during this time period was less than 5 lb/hr, which is about five time less than predicted, which has huge economic implications for future commercial units. The operation team will continue to monitor attrition as the sorbent gains hours to see if attrition increases over time. Below is a table with run data:

Date	Description	Amount
10/1/2014	Syngas Flow, lb/hr	~83,000
	Air Flow, lb/hr	~10,000
	Regenerator Temp, F	1,220
	Adsorber Temp, F	980
	Sulfur Capture	>99%
10/2/2014	Syngas Flow, lb/hr	~83,000
	Air Flow, lb/hr	~10,000
	Regenerator Temp, F	1,210
	Adsorber Temp, F	970
	Sulfur Capture	>99%
10/3/2014	Syngas Flow, lb/hr	~87,500
	Air Flow, lb/hr	~10,000
	Regenerator Temp, F	1,165
	Adsorber Temp, F	950
	Sulfur Capture	>99%
10/4/2015	Syngas Flow, lb/hr	~88,000
	Air Flow, lb/hr	~10,000
	Regenerator Temp, F	1,188
	Adsorber Temp, F	943
	Sulfur Capture	>99%

	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,000
	Sulfur Capture	>99%
10/9/2015	Syngas Flow, lb/hr	~88,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,000
	Sulfur Capture	>99%

- **Week of October 5, 2014** – During this week the process came down due to sulfur burn-off in the regenerator. Once the sulfur level decreased within the regenerator, the temperature dropped below 1,100 oF before more sulfur could be loaded and the furnace could be started up to maintain temperature within the reactor. While trying to startup the furnace it was determine that the ignitors needed to be cleaned which delayed the heat up of the reactor system.

  Once the issues with the furnace were resolved, we attempted the heat up process. However, the ROG recycle compressor tripped on many occasions due to a surge event. The surge was due to a control valve downstream of the compressor that was sticking and would jump resulting in a surge event. The valve was removed cleaned and reinstalled. The heat up of the system resumed. On October 8, syngas was resumed. The table below shows the operation parameters:

Date	Description	Value
10/8/2015	Syngas Flow, lb/hr	~88,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,000
	Sulfur Capture	>99%
10/9/2015	Syngas Flow, lb/hr	~88,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,000
	Sulfur Capture	>99%

  On October 10, the reactor lost temperature due to the slide valve between the adsorber and regenerator tripped. This was not caught in time and resulted in a loss of temperature. Also, during this time, TEC noted that they had a spike in their boiler feed water conductivity that we correlated to when the warm gas cleanup process started producing SO_2. After further inspection it was noted that the heat exchanger immediately downstream of the regenerator had a leak. The process was brought down in order to inspect the heat exchanger (E-121). Upon inspection, it was noted that the E-121 had a tube failure that allowed the SO_2 rich stream to infiltrate the boiler feed water system. The exchanger was sent out for repair.

Also, during this week a HAZOP was conducted on the changes made to the air compressor. During the last reporting period, it was reported that changes were made to the air compressor to improve its reliability. Therefore, a HAZOP was performed to ensure changes to logic and hardware were safe.

- **Week of October 12, 2014** – The failed heat exchanger was replaced by jacketed pipe and piped up to the cooling water system rather than the boiler feed water system. The unit was restarted. The table below shows the operating parameters:

Date	Description	Value
10/14/2014	Syngas Flow, lb/hr	~73,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,160
	Adsorber Temp, F	1,050
	Sulfur Capture	>99%
10/17/2015	Syngas Flow, lb/hr	~83,000
	Air Flow, lb/hr	~9,500
	Regenerator Temp, F	1,182
	Adsorber Temp, F	910
	Sulfur Capture	>99%

On October 18, the system tripped on low flow on the regenerator side of the process. It was noted that the air compressor was running, but air was not making it to the regenerator. It was determined that there was a leak in the recuperator (E-120) down-stream of the regenerator, which allowed the air to bypass the regenerator. Therefore the system was shutdown to determine the extent of the damage of the heat exchanger.

- **Week of October 19, 2014** – During this week the failed exchanger (E-120) was pulled for inspection. Upon inspection, it was noted that the exchanger experience catastrophic failure. The pictures below show the condition of the heat exchanger tubes.

E-120 Tubes after Failure

E-120 Tubes after Failure

It was noted that there were hot spots not only on the tubes but also on the shell. To enable a more detailed inspection of the heat exchanger, a dissection plan was developed and implemented by Precision Pipe and Valve (PPV). The exchanger was shipped to Denver on October 27, 2014. The following observations were made following the dissection of the heat exchanger:

- A number of the tubes were breached or completely parted. On several of the tubes the damage was observed to extend about 60% of the vertical length of the exchanger. The breaches in the tubes appeared to be melted.

- The nature of the breach appeared to be from the outer shell side towards the interior of the tube.
- The tubes that were not melted were buckled at the air inlet end due to excessive column loading. This would indicate that the tubes were subjected to higher temperatures than the design allowed for, or external forces would not allow the shell expansion joint to work as designed.
- There were areas of the tube especially on the lower end of the exchanger where build-up of the coating previously mentioned on the tube sheet was observed.
- Discoloration and evidence of extreme temperature of the tubes was most pronounced in the lower sections of the heat exchanger near the air inlet and confined to the failed tubes.
- Corrosion (exact mechanism not known) was observed in tube samples collected along the vertical length of the tubes.
    - The most aggressive corrosion was observed on the lower shell side of the exchanger (near the air inlet) and was predominately associated with undercoating corrosion.
    - This corrosion was observed to extend up along about 30% of the vertical length of the tubes.
    - Pitting corrosion was also observed, but extended along the entire length of the tubes.
    - No visible corrosion was apparent of the inside of the tubes which was in contact with the ROG containing approximately 6 vol% SO_2.

In addition to the direct inspection of the heat exchanger, the process data for the heat exchanger was also evaluated. The results from this evaluation include:

- As the shell side of the heat exchanger was at a higher pressure than the tube side, failure of the tubes from the outside to the inside of the tubes observed during visual inspection of the failed tubes is consistent with the process data.
- Process temperatures and product gas compositions show stable operation prior to a sudden event that lasted approximately 10 minutes.
- During this event, the outlet temperature for the ROG from E-120 rapidly increased to 800°F (maximum temperature reading) while the other temperatures of process streams in and out of E-120 decreased.
- The SO_2 concentration in the ROG (measured downstream of E-120) began to

decrease at almost exactly the time when the temperature changes were observed.

- The O_2 concentration in the ROG only began to increase when the SO_2 concentration had dropped to essentially zero and the effluent ROG temperature began to drop.

The most plausible explanation for these observations is that a hole developed in at least one of the heat exchanger tubes allowing the air on the shell side of the heat exchanger to reach the hot ROG rich in SO_2 on the tube side. The mixing of the air and hot SO_2-rich ROG allowed O_2 and SO_2 to react according the reaction $SO_2 + O_2 = SO_3$. This reaction is very exothermic (ΔH = -99 KJ/mol) and could generate the heat necessary to cause the tube damage and physical evidence of high temperature.

Because such a tube breach allows air to bypass REV-120, it would result in the sudden loss of the regeneration reaction and drop in the product gas temperature from REV-121. It would also reduce the flow rate through FUR -110-1B causing this furnace to trip. With no regeneration, SO_2 production would stop reducing the concentration of SO_2 in the ROG leaving the regenerator. With declining SO_2 concentrations in the ROG, the rate of the exothermic reaction producing SO_3 and temperatures would drop. The fact that the effluent SO_2 concentration begins to drop at the start of this incident and O_2 only begins to increase when SO_2 is essentially zero supports the theory of reaction between the SO_2 and O_2

In order to mitigate this event from happening again the following actions were taken:

- A jacketed pipe (tube-in-tube) exchanger was designed and installed as a temporary replacement for E-120. The jacketed pipe is a more robust design that is not as susceptible to failure. It is believed that during the multiple transient periods during recent operations, E-120 tube (which is thinned walled) lost structural integrity due to corrosion attack. [NOTE: The tube-in-tube design was also selected for design of the permanent replacement E-120 exchanger. The new exchanger design was a combination gas-gas and water-cooled tube-in-tube exchanger with 2X the heat transfer area of the temporary exchanger.]
- A chiller package was installed to the air compressor inner-cooler to knock out water that is in the ambient air. The corrosion pitting appears to be thionic corrosion, which results when SO_2, O_2, and free water come into contact. By removing the incoming water within the air, the dew point is significantly lowered.
- Remove the ROG recycle compressor from normal operation. The reason for this action is when the unit is shut down, it is difficult to remove all the SO_2 from the system due to the recycling of the ROG gas.
- Change the shutdown procedure to drop pressure of the system to reduce the dew point as a means to prevent corrosion during transients.

All of these changes combined, were expected to and did alleviate the mechanism that promoted the catastrophic failure.

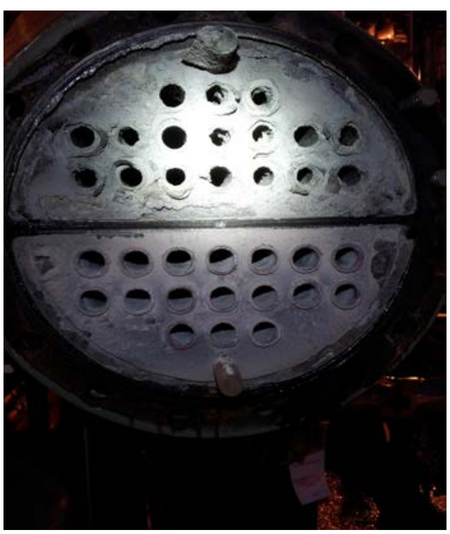
- **<u>Week of October 26, 2014</u>** – During this week the operation team continued to inspect equipment. Below is a discussion of the inspection:
  - o All the flow meters were removed and inspected to see if there was any build up. All the flow meters looked ok.
  - o ROG Recycle Compressor was inspected. The impeller showed minor signs of solids impingement (see figure below). This was a result of a previous filter failure. Overall the impeller and seals looked good.

ROG Compressor Impeller Inspection

  - o The furnace was inspected. The furnace tubes looked ok with no signs of corrosion noticed. Additionally, the refractory looked ok. The only thing noted was insulation partially blocked the burner on the A side of the furnace. This was repaired.
  - o Adsorber/Regenerator was inspected. The refractory looked ok upon inspection. The internal cyclones were inspected and appeared to be in good condition.
  - o Syngas compressor was inspected and realigned. The seals and impellers were in good condition.
  - o Verified all pump shafts were aligned.
  - o The hot gas filters were pulled and inspected. While the filters were out, fail safe devices (small filters within the larger filters) were welded. This action was to prevent solids from penetrating to downstream equipment in the event of a filter failure. The figure below shows one of these failsafe devices.

Failsafe Device

- New lock hopper interfaces were installed during the outage to help assist operations with troubleshooting lock-hopper issues. Also, all the lock-hopper valves were inspected for excessive erosion – none detected.
- The steam generators on both the adsorber and regenerator side were inspected. The adsorber side steam generator was in good condition. The regenerator steam regenerator started showing signs of surface corrosion on the process side. A new tube bundle was ordered. Additionally, there was some sorbent on the tubes as a result of a previous filter failure. The steam generator was cleaned and reinstalled.



Regenerator Steam Generator

- **<u>Week of November 2, 2014</u>** – During this week the process was still down awaiting the new heat exchanger design to be delivered.

  Additionally during this time the operations circulated potash in the aMDEA® unit to remove scale and debris within the process. BASF site representative sampled the water within the unit and it did not pass the solids test. Therefore, BASF recommended an additional chemical cleanse.

  Inspected the syngas return tie in valve and found that the control board within the MOV needed to be replaced. The manufacturer was called out and a new board was installed.

- **<u>Week of November 9, 2014</u>** – system was down during this week. During this time all the changes from MOC's were reviewed to ensure all documents were updated. The P&ID redlines were sent to AMEC to update and update the revision. Continued chemical and potable water rinses in the aMDEA® system.

- **<u>Week of November 16, 2014</u>** – system was down during this week. The technical and operation team started reworking the regenerator startup and shutdown procedure to take into account the changes to the system. The new pipe in pipe exchanger arrived during this period. The figure below shows the inner tube of the exchanger. This inner tube was lifted and installed into the shell side, which was already installed within the structure.

New Heat Exchanger Tube

  The plant was ready to startup; however, the host site shutdown for repairs to their process.

- **<u>Week of November 23, 2014</u>** – started heating up the system to test the new heat exchanger downstream of the regenerator. We had to shut the process down since the new heat exchanger was not able to cool the process gas below 645 F, which is above the design point of the hot gas filter vessel. Plans to put a water cooled jacketed pipe down-stream of the new cooler were developed.

- **Week of December 7, 2014** – plant down due to additional jacketed pipe installation.
- **Week of December 14, 2014** – system down due to host site down. Jacketed pipe installation completed.
- **Week of December 21, 2014** – system down due to host site down.
- **Week of December 28, 2014** – the chiller package for the air compressor was delivered and installed. Started heating system in preparation for operation on syngas.

January, 2015 to March, 2015

Below is a description of activities and findings of the Warm Gas Cleanup Demonstration Unit at Polk Power Station:

- **Week of January 4, 2015** – started heating the process up to start up operations early in the week and transferring sorbent into the reactor. The process was up and running through this week. The process operation started up on 1/5/2015. Process operation was smooth during this time period. The sorbent attrition rate during this time period was less than 5 lb/hr, which is about five time less than predicted, which has huge economic implications for future commercial units. The operation team will continue to monitor attrition as the sorbent gains hours to see if attrition increases over time. Challenges during this week included reworking the lock-hopper logic and working with the sorbent transfer system. Below is a table with run data:

Date	Description	Amount
1/5/2015	Syngas Flow, lb/hr	~86,000
	Air Flow, lb/hr	~8,200
	Regenerator Temp, F	1,223
	Adsorber Temp, F	1,094
	Sulfur Capture	>99%
1/6/2015	Syngas Flow, lb/hr	~93,000
	Air Flow, lb/hr	~9,000
	Regenerator Temp, F	1,223
	Adsorber Temp, F	1,071
	Sulfur Capture	>99%
1/7/2015	Syngas Flow, lb/hr	~89,000
	Air Flow, lb/hr	~9,100
	Regenerator Temp, F	1,233
	Adsorber Temp, F	1,094

	Sulfur Capture	>99%
1/8/2015	Syngas Flow, lb/hr	~91,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,207
	Adsorber Temp, F	1,059
	Sulfur Capture	>99%
1/9/2015	Syngas Flow, lb/hr	~91,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,105
	Sulfur Capture	>99%
1/10/2015	Syngas Flow, lb/hr	~91,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,105
	Sulfur Capture	>99%

- **Week of January 11, 2014** – During this week, the process ran smoothly. The sulfur concentration in the syngas dropped from 10,000 ppm to 8,500 ppm on 1/12//2015. In order to maintain sulfur balance the reactor, the operations team increased the syngas flowrate.

  Also, during this week the operations and on site engineering team prepared to get the aMDEA® process ready for operations. The team completed the final passivation of the system.

  The table below shows the operation parameters:

Date	Description	Value
1/11/2015	Syngas Flow, lb/hr	~93,500
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,260
	Adsorber Temp, F	1,116
	Sulfur Capture	>99%
1/12/2015	Syngas Flow, lb/hr	~98,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,275
	Adsorber Temp, F	1,080
	Sulfur Capture	>99%
1/13/2015	Syngas Flow, lb/hr	~98,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,275
	Adsorber Temp, F	1,080

	Sulfur Capture	>99%
1/14/2015	Syngas Flow, lb/hr	~104,000
	Air Flow, lb/hr	~9,200
	Regenerator Temp, F	1,228
	Adsorber Temp, F	1,100
	Sulfur Capture	>99%
1/15/2015	Syngas Flow, lb/hr	~104,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,257
	Adsorber Temp, F	1,100
	Sulfur Capture	>99%
1/16/2015	Syngas Flow, lb/hr	~106,000
	Air Flow, lb/hr	~8,200
	Regenerator Temp, F	1,243
	Adsorber Temp, F	1,082
	Sulfur Capture	>99%
1/17/2015	Syngas Flow, lb/hr	~106,000
	Air Flow, lb/hr	~8,200
	Regenerator Temp, F	1,243
	Adsorber Temp, F	1,082
	Sulfur Capture	>99%

- **Week of January 18, 2015** – The process continued run smoothly during this week. The aMDEA® process was started during this week. The startup and operation with no major issues to report. The CO_2 removal system performed as expected without any signs of foaming. The table below shows the operating parameters:

Date	Description	Value
1/18/2015	Syngas Flow, lb/hr	~99,600
	Air Flow, lb/hr	~8,800
	Regenerator Temp, F	1,235
	Adsorber Temp, F	1,115
	Sulfur Capture	>99%
1/19/2015	Syngas Flow, lb/hr	~99,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,239
	Adsorber Temp, F	1,113
	Sulfur Capture	>99%
1/20/2015	Syngas Flow, lb/hr	~99,500
	Air Flow, lb/hr	~8,000
	Regenerator Temp, F	1,220
	Adsorber Temp, F	1,035

	Sulfur Capture	>99%
1/21/2015	Syngas Flow, lb/hr	~104,500
	Air Flow, lb/hr	~8,200
	Regenerator Temp, F	1,228
	Adsorber Temp, F	1,078
	Sulfur Capture	>99%
1/22/2015	Syngas Flow, lb/hr	~95,000
	Air Flow, lb/hr	~8,250
	Regenerator Temp, F	1,241
	Adsorber Temp, F	1,107
	Sulfur Capture	>99%
1/23/2015	Syngas Flow, lb/hr	~97,000
	Air Flow, lb/hr	~8,300
	Regenerator Temp, F	1,240
	Adsorber Temp, F	1,130
	Sulfur Capture	>99%
1/24/2015	Syngas Flow, lb/hr	~105,000
	Air Flow, lb/hr	~8,500
	Regenerator Temp, F	1,230
	Adsorber Temp, F	1,102
	Sulfur Capture	>99%

- **Week of January 25, 2015** – the process was shut down due to a filter plug in the regenerator hot gas filter. The system was safely brought down. Operations purged and tagged out the unit to allow maintenance to pull the filter vessel for inspection. The filter plug was due to solids building up in the filter vessel. The solids were removed from the filter vessel and the filter elements were pulled for inspection. The filters appeared to be in good condition; however, new filters were installed since we had access. While the system was down, maintenance pulled several control valves (HTR-FV-565, HTR-PV-570, and HTR-PV-570) for inspection. The valves appeared to be in good condition and were put back into service. On January 27, operations started heating up the unit. While heating up, the slide valve between the reactors plugged. The unit was brought down to unplug the slide valve. During the inspection of the regenerator the packing was noted to be damaged (see figure below). It appears that the SO_2 gas is attacking the metal media. The engineering team is working on a solution. Also, during this week, the P&ID's were sent to AMEC to incorporate the latest redlines.

- **Week of February 1, 2015** – during this week, operations started heating up the unit. The heat up cycle took longer than anticipated due to pressure differential transmitters plugging. The unit came online on 2/3/2015. The aMDEA® unit was successfully started and operated. The unit tripped on 2/5/2015 due to a shut-off valve being closed on one of the pressure differential transmitters. Operations was having difficulty getting solids out of the sorbent sampling system. When they isolated the system to unplug the sorbent sampling system, a shut off valve to one of the legs on a pressure differential transmitter was closed. This particular PDT is tied to the emergency shutdown system. This action brought the unit down. The startup heater began to heat the system up. Also, during this week, TEC operations noted a high concentration of CO and H_2S in the cooling water return. The CO and H_2S came from a leak with the surge cooler on the syngas cooler. The unit was brought down to plug the leaking tube. The unit was off syngas for the remainder of the week in order to plug the failed heat exchanger tube.

Date	Description	Value
2/3/2015	Syngas Flow, lb/hr	~98,000
	Air Flow, lb/hr	~8,100
	Regenerator Temp, F	1,240
	Adsorber Temp, F	1,115
	Sulfur Capture	>99%
2/4/2015	Syngas Flow, lb/hr	~98,000
	Air Flow, lb/hr	~7,600
	Regenerator Temp, F	1,244
	Adsorber Temp, F	1,128
	Sulfur Capture	>99%
2/5/2015	Syngas Flow, lb/hr	~95,000
	Air Flow, lb/hr	~8,100
	Regenerator Temp, F	1,242
	Adsorber Temp, F	1,242
	Sulfur Capture	>99%

- **Week of February 8, 2015** – after repairs were made to the syngas inner-cooler, operations started heating the unit. During this week, operations achieved 1,000 hours of runtime. During this run-time, the back-pulse compressor tripped due to high temperature. After inspection it was learned that he cooling water line was plugged. The line was unplugged and the compressor restarted without having to shut down the unit.

  The Warm Gas Cleanup unit was forced to shut down due to TEC plant shutdown 2/12/2015. The Warm Gas Cleanup unit came off of syngas and stayed on warm standby.

Date	Description	Value
2/10/2015	Syngas Flow, lb/hr	~84,000
	Air Flow, lb/hr	~8,350
	Regenerator Temp, F	1,250
	Adsorber Temp, F	1,105
	Sulfur Capture	>99%
2/11/2015	Syngas Flow, lb/hr	~80,000
	Air Flow, lb/hr	~8,000
	Regenerator Temp, F	1,270
	Adsorber Temp, F	1,120

	Sulfur Capture	>99%

- **<u>Week of February 15, 2015</u>** – syngas was introduced to the unit on 2/15/2015. The unit was brought down on 2/17/2015 due to a plug in the slide valve. The unit was tagged out and a vacuum truck was brought in to clean out the reactors in order to remove the plug. The plug was due to coarse sorbent sitting on the slide valve.

Date	Description	Value
2/15/2015	Syngas Flow, lb/hr	~79,000
	Air Flow, lb/hr	~7,900
	Regenerator Temp, F	1,224
	Adsorber Temp, F	1,090
	Sulfur Capture	>99%
2/16/2015	Syngas Flow, lb/hr	~80,000
	Air Flow, lb/hr	~8,200
	Regenerator Temp, F	1,261
	Adsorber Temp, F	1,079
	Sulfur Capture	>99%

- **<u>Week of February 22, 2015</u>** – after the plugs were removed, operations resumed heatup and started operations. Syngas was introduced on 2/24/2015. However, the unit was brought down again due to plugs in the slide valves. The plug was cleared and heat up resumed.

Date	Description	Value
2/24/2015	Syngas Flow, lb/hr	~85,000
	Air Flow, lb/hr	~7,600
	Regenerator Temp, F	1,265
	Adsorber Temp, F	1,118
	Sulfur Capture	>99%

- **<u>Week of March 1, 2015</u>** – syngas was reintroduced to the unit. During this week, the water gas shift unit was successfully heated up and syngas introduced. The unit was brought down due to TEC planned outage. The planned outage is scheduled for six weeks. During this time, the technical, operations, and maintenance team will begin inspecting the unit.

Date	Description	Value
3/1/2015	Syngas Flow, lb/hr	~82,000
	Air Flow, lb/hr	~7,300
	Regenerator Temp, F	1,208
	Adsorber Temp, F	1,122
	Sulfur Capture	>99%
3/2/2015	Syngas Flow, lb/hr	~99,300
	Air Flow, lb/hr	~8,977

	Regenerator Temp, F	1,193
	Adsorber Temp, F	1,000
	Sulfur Capture	>99%
3/3/2015	Syngas Flow, lb/hr	~89,500
	Air Flow, lb/hr	~7,200
	Regenerator Temp, F	1,242
	Adsorber Temp, F	1,143
	Sulfur Capture	>99%
3/4/2015	Syngas Flow, lb/hr	~85,000
	Air Flow, lb/hr	~7,400
	Regenerator Temp, F	1,246
	Adsorber Temp, F	1,135
	Sulfur Capture	>99%
3/5/2015	Syngas Flow, lb/hr	~78,000
	Air Flow, lb/hr	~6,800
	Regenerator Temp, F	1,232
	Adsorber Temp, F	1,132
	Sulfur Capture	>99%

- **March 6, 2015 through March 31, 2015** – the Warm Gas Cleanup outage was initiated during this week. During this outage it is intended for the following activities to take place:
    - Pull all relief valves and recertify
    - Replace seals on major pumps
    - Inspect all compressors and change oil
    - Pull all heat exchanger tube bundles and perform visual inspection and eddy current testing
    - Pull filter elements out for inspection
    - Inspect refractory in the reactor vessels.
    - Inspect the furnace
    - Install new heat exchangers after the regenerator reactor
    - Install new process condensate system

  Below is a brief description of the outage inspections during March, 2015:

  REV-110: Inspection by Ken Pecatillo:

    - 5 jets/nozzles on twiers are plugged. Appears to be coke-like/stone-like material.
        - The 5 plugged jets were marked with white-paint-stick as/for identification
    - Refractory on bottom looks fairly good; typical cracking.

- Recirculation-line to REV 111 shows evidence of spalling and erosion around aeration-nozzles.
- Expansion joint field weld? Looks to evidence of spalling, Monitor.
- Lift/return line from REV-121 shows evidence of erosion and spalling especially around the vertical lift-nozzle Monitor.

<u>REV-111</u>:

- Cyclone trickle valve looks good:
  - Plate not warped
  - No evidence on erosion on plate
  - Rings good, no wear/flat spots
  - No evidence of erosion to/on sealing surfaces (trickle or dip-leg)
- Cyclone inlet duct refractory looks excellent, no evidence/sign of erosion
- Cyclone dustbowl-to-dip-leg transition area, external, looks good, no evidence of erosion/hole(s)
- Refractory looks very good, typical cracking
- Elephant trunk, interior, evidence of spalling at lower-most 2 joints
- Appears to be evidence of significant spalling at either the bi-metallic weld or the field joint
  - Still trying to ascertain/determine if spalling is at the field joint or the bi-metallic weld.
- Spargers were removed due to damage. The new spargers are refractory coated to protect them in the future.
- Inspected sorbent transfer lines utilizing large bore-scope.
  - All aeration jets/nozzles had indications of minor refractory damage surrounding the jet/nozzle
    - Since there is no way to access these jets/nozzles to effect repairs, MONITOR.
  - Flange connection areas had evidence of refractory damage.
    - Since there is no way to access these jets/nozzles to effect repairs, MONITOR.
  - <u>LONG-TERM</u>: Due to the inability to access the sorbent transfer-lines internally, it will eventually become necessary to replace the sorbent transfer lines whenever the refractory around the aeration jets/nozzles become too damaged to continue.

- The guides and gates within the slide-vales appeared to be in very good condition, little-to-no erosion/wear were evident.

  LONG-TERM: Since the slide-valve are operated 100% open, it is recommended that the slide-valves be "re-ported". This is defined as the orifice plate is removed from the internal portion of the slide-valve and the orifice port is enlarged. The reconfigured orifice-plate.

<u>REV-110</u>:

- Re-inspected the J-legs with the bigger bore-scope. It appears that the vertical lift N2 nozzles are experiencing evidence/signs of erosion.
  - Cannot be repaired.
  - Need to monitor these areas.
  - Need to ensure that the back-end lift nozzles is clear and then re-balance the lift N2 flows.
- The sorbent transfer line (J-leg) from REV-110 to REV-111 *appears* to have evidence/signs of erosion above the expansion joint. (inspection performed via bore-scope).
  - Recommendation—NO ACTION to be TAKEN at this time
  - Continue to monitor the area utilizing the FLIR
- Inspected the top portion of REV-110 (Will climbed and utilized the larger bore-scope for pictures).
  - The top section appeared to be in good/serviceable condition.
  - The cross-over connection to the elephant trunk (down-comer) corner appeared to be in good condition.
  - The field-joint in the elephant-trunk/down-comer, the section containing the hand-packed refractory was damaged. This area was visually inspected via ladder built up from within REV-111.
    - This area will require repairs.
    - Need to ascertain/determine which refractory (type & manufacturer) was utilized initially in this field joint *before* making repairs.

<u>REV- 121</u>:

- Cyclone dip-leg flapper valve was checked for proper counter weight operation (see figure below).
  - Specification 11.0 Lbs
  - Actual 11.6 Lbs

- Recommendation—NO ACTION to be TAKEN with respect to the weight.
- Recommendation—clean the pin & bushing area with utilizing a brush

- Inspected sorbent transfer lines utilizing large bore-scope.
  - All aeration jets/nozzles had indications of some refractory damage surrounding the jet/nozzle
    - Since there is no way to access these jets/nozzles to effect repairs, MONITOR.
  - Flange connection areas had evidence of refractory damage.
    - Since there is no way to access these jets/nozzles to effect repairs, MONITOR.
  - There was a section, approximately mid-way down line 140 that had evidence of refractory damage at multiple locations within the line. These damaged areas appeared to be from spalling. Some of the spalled areas appeared to have been from thermal- shock spalling.
    - Since there is no way to access this area to effect repairs, MONITOR.
  - **<u>LONG-TERM</u>**: Due to the inability to access the sorbent transfer-lines internally, it will eventually become necessary to replace the sorbent transfer lines whenever the refractory around the aeration jets/nozzles

become too damaged to continue.

- The guides and gates within the slide-vales appeared to be in very good condition, little-to-no erosion/wear were evident.
- **LONG-TERM**: Since the slide-valve are operated 100% open, it is recommended that the slide-valves be "re-ported". This is defined as the orifice plate is removed from the internal portion of the slide-valve and the orifice port is enlarged. The reconfigured orifice-plate.

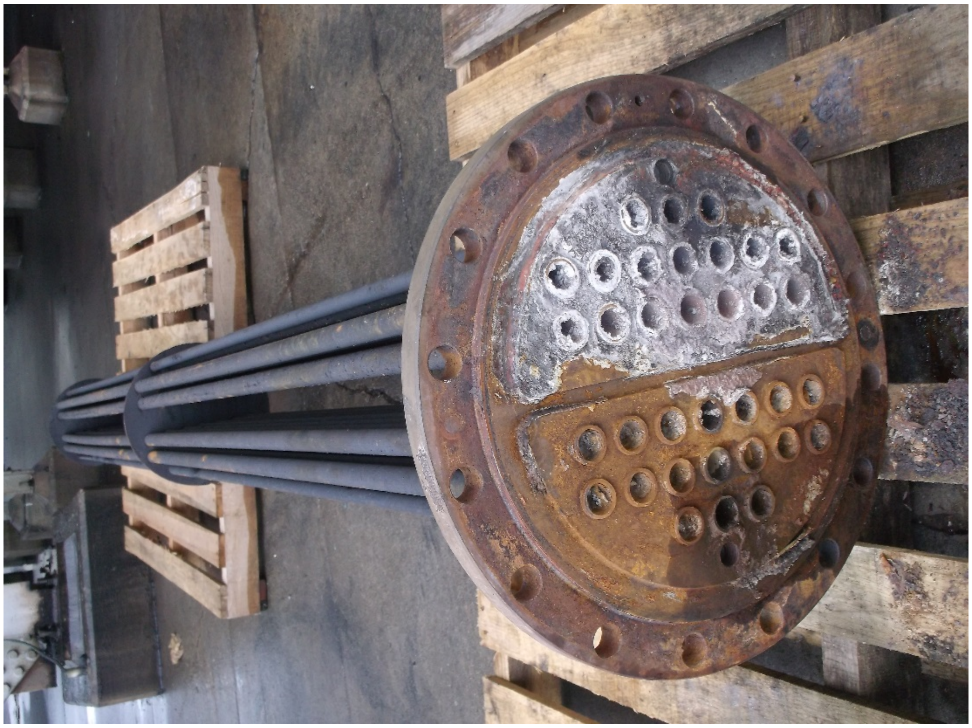
- The refractory within the vessel (i.e. the walls) appeared to be in excellent condition.
- The refractory within the outlet of the elephant trunk appeared to be in very good condition.
- The refractory within the inlet duct of the cyclone appeared to be in excellent condition.

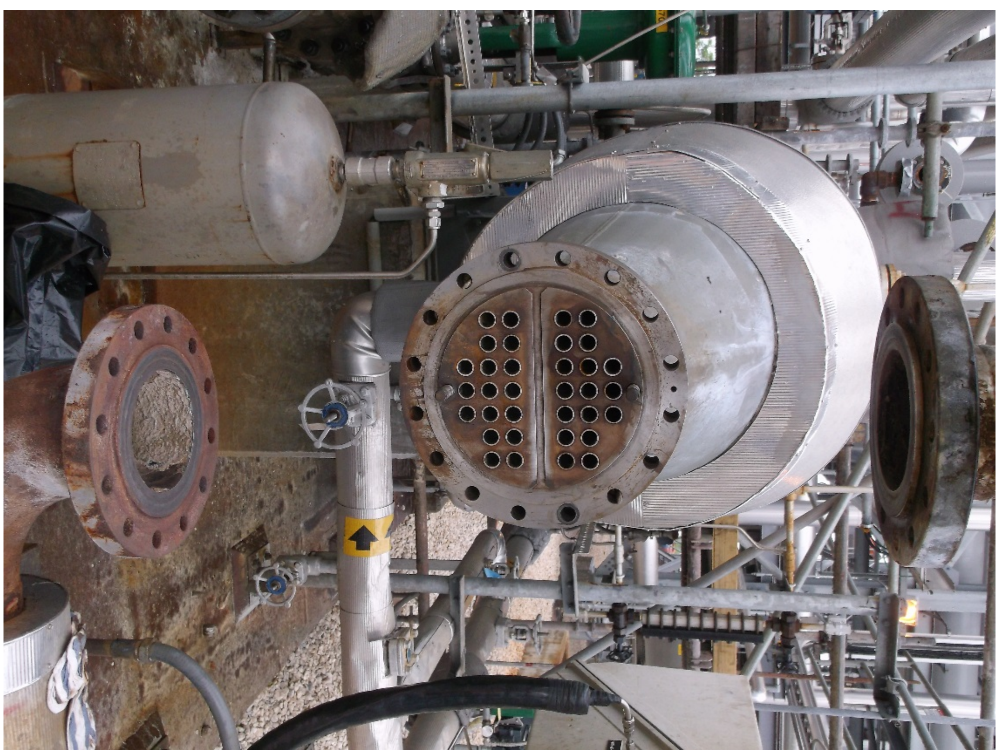
FUR-110-1A:

- There was some surface spalling of the insulating refractory at the outlet.
  - Recommendation—NO ACTION to be TAKEN at this time
  - Continue to monitor the area utilizing the FLIR

E-120 and E-121 – the new heat exchangers to recuperate heat on the regenerator side of the process were installed during the outage. The photo below shows the new heat exchangers before installation.

SG-121 – a new tube bundle was installed since the initial tube bundle showed signs of wall thinning. See photos below for the old bundle that was pulled and the new installation.





<u>SG-501 &502</u>:

- There was evidence of sorbent on the tube-sheets and in the lower tubes (see figure below)
    - Recommend that these be brushed off & blown clean

<u>GENERAL</u>:

- AVP pulled relief valves for inspection and recertification.
- Expansion joints inspected. The expansion joint above P-502 needs to be replaced.
- All filter elements were pulled and the fuses cut out of the filter elements.
- D-110, which is a knockout drum ahead of the syngas compressor, was inspected. The demister pad, deflector plate, and vortex breaker were in good condition. During the inspection the level transmitter legs were inspected to ensure they were cleaned out.
- D-152 was inspected. No significant issues noted.
- The SO_2 line between RTI and TEC was inspected. The inspection revealed that the tie point at the TEC sulfuric acid plant had developed wall thinning (See figure below). This section was replaced and redesigned to prevent acidic liquid build up from occurring.

- Added continuous nitrogen purges to the diesel nozzles. This is to prevent erosion and plugging.
- The startup furnace was inspected. The heating tubes were in good condition (See picture below). The burner assembly was inspected and appeared to be in good condition. During the furnace inspection, the ignitor was found damaged. The ignitor was pulled and repaired.

April, 2015 to June, 2015

During this time period, TEC's annual outage was supposed to be over by mid-April; however, due to failures with the gas turbine and air separation plant, the outage extended through July. Therefore, the Warm Gas Cleanup plant did not operate during this quarterly time period.

July, 2015 to September, 2015

Once TEC provided utilities such as nitrogen in late July, RTI proceeded to dry out the Warm Gas Cleanup system, add RTI-3 sorbent to the adsorber/regenerator reactors, and start the heat up sequence.

- **Week of June 29, 2015** – TEC's gasifier was finally started after the outage. In preparation for starting the WDP, the system was thoroughly dried by heating to about 400°F with circulating nitrogen for approximately 24 hours. After drying the system, the sorbent removed during the outage was feed back into the system. When the system had been refilled with sorbent. The furnaces were started to preheat the system for taking syngas from TEC.
- **Week of July 6, 2015** – During this week, TEC's system developed a problem with their gas turbine that required the system to be shutdown for repair. Because this shutdown was anticipated to occur within between 24 and 72 hours, the decision was made not to press forward and start up WDP. When starting the WDP system after previous shutdowns, sorbent circulation was one of the key issues during start up. This was believed to be a result of steam condensation from the syngas in the sorbent bed as the system was cooled after shut down. To avoid this problem, the syngas solution was shut off and the system was put into the hot standby operating mode. In hot standby mode, sorbent circulation was maintained at start up temperatures using nitrogen for at least one shift. The system was then depressurized and three dilution purges completed prior to shutting the system down and allowing the system to begin cooling. Fully implementing this procedure would take between 24 and 48 hours, which would prohibit implementing it prior to TEC's planned shutdown. Although TEC made the necessary preparations for this shutdown, problems at one of their other power generation facilities delayed TEC shutting their gasifier down.
- **Week of July 13, 2015** – TEC gasification system was shut down for repairs.
- **Week of July 20, 2015** – TEC gasification system was still down for repairs.
- **Week of July 27, 2015** – TEC gasification system was brought back online. The WDP system was restarted and began taking syngas on July 29. WDP operated on syngas for approximately 59 hours prior to TEC shutting down to work on their convective syngas cooler (CSC) cooling system.
- **Week of August 3, 2015** – TEC was able to get their CSC coolers repaired and restart the gasifier towards the end of the week. The WDP system was heated up in anticipation of restarting.
- **Week of August 10, 2015** – Twice during this week, the WDP system was restarted. For each of these restarts, the regenerator had been heated to full operating temperature (>1,200°F) and syngas started before sorbent carry over from the regenerator essentially plugged the regenerator filter shutting off flow. The key signature for each of these events was a sudden increase in the effluent temperature that marked the start of sorbent transfer out of the regenerator stripper. After each of these event the sorbent had to be cleaned out of the filter and associated piping prior to restarting. The maximum operating

time achieved with these two runs was about 18 hours.

- **Week of August 17, 2015** – The WDP system was restarted. One of the key observations from the two prior attempts was a high diesel flow during the diesel heating of the regenerator prior to light off. During this restart attempt, the diesel flow was minimized during the diesel heating sequence. This appeared to be effective as the regenerator filter did not plug after the diesel was shut off and stable operation was maintained until another issue stopped operation.
- **Week of August 24, 2015** – WDP was operated for 87 hours prior to shutting down. This shut down was the result of indications of tube failure in the E-110 syngas interchanger. In E-110, the cool, but dirty syngas, is heated by the hot clean syngas leaving the WDP system. A tube leak would allow dirty (high sulfur) syngas into the clean syngas. The operating conditions that indicate this are a sudden jump in effluent sulfur concentrations without any other operations changes. At the start of this run, the effluent sulfur concentration was running at about 40 to 50 ppmv (> 99% removal). This effluent concentration suddenly jumped to over 100 ppmv indicating the failure of an exchanger tube. The system was shut down to inspect the heat exchanger tubes. Several leaks were found within 1 to 5 inches below the tube sheet where the clean syngas enters the tubes. Additional testing of the exchanger tubes indicated a significant loss of thickness on a large number of the tubes. WDP system down for E-110 repair. This repair consisted of plugging off the tube with leaks and any other tube with a thickness loss over 60%. A total of 32 tubes were plugged to eliminate the existing leaks and minimize the potential for future leaks developing.
- **Week of August 31, 2015** – Towards the end of this week, the repairs on E-110 were completed. The WDP system was restarted. The WDP system operated for 17 hours prior the failure of the gasket seal on E-10 and a sudden jump in the sulfur effluent concentration from E-110 indicating a tube failure. The most interesting feature of this run was the effluent sulfur concentration from WDP prior to the tube failure was consistently < 20 ppmv.
- **Week of September 7, 2015** – After removing the top head on E-110, one new failed tube and leaks on 5 tubes previously plugged were identified. These tubes were plugged. As all the tube failures appeared to be very near the connection of the tubes and the tube sheet, a rapid and relatively simple fix to eliminate these leaks was to get longer ferrules made which would extend past the bottom of the tube sheet and provide additional thickness and strength to the tubes near the tube sheet. During this run, the activated amine system was also restarted. Unfortunately, an issue developed while operating which forced this system to be shut down. The issue consisted of a large carry over of amine solution out of the COL-503 and the CO_2 stack. This issue appeared to be due to an upset in the levels of the amine solution in several of the vessels. Ultimately, the issue was linked to foaming and modifications of the anti-foaming system were implemented to provide better control of the addition of the anti-foaming agent.
- **Week of September 14, 2015** – The WDP system was restarted. WDP operated for a total of 53 hours until another E-110 tube failure was detected. During this run, the effluent sulfur concentration was consistently between 5 and 15 ppmv. During this run, the activate amine system was also operated without any incidents.

- **September 21, 2015 through end of September, 2015** – The regular repetition of E-110 tube failures required a more lasting solution than simply plugging the failed tubes. Although the potential to install longer ferrules that extended beyond the tube sheet was considered, this was ultimately rejected as several of the tube failures occurred below the section that would be sealed by the longer ferrules. During the attempt to find an effective solution, the exact nature of the failure of the tubes was identified. A combination of high sulfur concentration (> 10,000 ppmv) and high temperature had resulted in the sulfidation of one of the metals in the alloy used in the existing tubes. This sulfidation had significantly reduced the thickness of the tubes in E-110 in the upper third of the heat exchanger where the high sulfur syngas is hottest just before leaving E-110. Based on this tube failure mechanism, an alternative material was selected for the new tubes. This selection was based on recommendations from several materials/heat exchanger experts and operations experience showing no change in tube thickness in the tubes in Furnace A downstream of E-110 which used a similar material to the suggested replacement material. The use of a new material for the tubes also resulted in the need to replace the heat expansion joint on E-110 to accommodate the difference in the expansion between the two materials. With all of these changes, the most effective and rapid means of repairing E-110 was to remove it and rebuild it a local machine shop. This work had started, but was not completed prior to the end of September, which was the end of the period of performance for this project.

Appendix G

Process Sampling and Analysis Systems

Process Analytical Systems

The purpose of the process analytical systems was to provide measurement of compounds of interest in the gaseous process streams in the warm syngas desulfurization process (WDP) unit, solid sorbent from the WDP, and liquids from the BASF activated methyldiethanolamine (aMDEA®) process unit. On-line instrumentation was used for the WDP gas streams analysis and off-line measurements of solid sorbent samples and aMDEA® liquid samples were performed in a lab in the Tampa Electric Company (TEC) administration building. All on-line instrumentation was housed in a 10 ft. x 18 ft. analyzer shelter. The external components of the shelter were designed for Class I, Division 2, Groups BCD. A pressurization unit on the building provided a Type Z pressurization, to reduce the classification within the building from Class I, Division 2, Groups BCD to Non-Hazardous. Gaseous samples for on-line analysis were transported to the analyzer shelter through heated or unheated sample probes on the plant process piping and heated or unheated tubing connecting the probe outlets to the sample conditioning systems at the shelter.

Gaseous Sample Transport and Conditioning

Streams 1-USY-AE-500A (Adsorber inlet) and 1-USY-AE-528 (Adsorber outlet)

A heated sample probe (Welker Charlie-Horse probe) was mounted on the process gas pipe. The Welker Charlie-Horse probe has a 5 ¾ in. standoff to allow cooling of the process stream, separation of condensed water with a coalescing membrane filter, and draining of water back into the process pipe. The vaporizing regulators are heated to a temperature well above the expected dewpoint (nominal control temperature of regulator is 200 F). Reduction of process gas pressure with the vaporizing regulator to 30 psig results in further lowering of the dewpoint. The estimated dewpoint of each process stream was 115 F. The heat tracing was operated at a temperature of 200 F (well above the expected dewpoint) but not so hot that the temperature could not be reduced to 80 F as it entered the sample conditioning system (SCS) enclosure at the shelter. Cooling the gas in the SCS enclosure was performed to enable further water removal with a Swirlklean membrane filter. The gas pressure was reduced to about 5 psig before metering it through the inlet to bypass port of the Swirlklean filter at a flow of about 5 slpm. The bypass flow was directed through an Armstrong automatic draining water trap before venting to the flare header manifold. The analyzer flow was taken from the clean side of the membrane filter at about 100 sccm to the process gas chromatograph. All wetted surfaces of these sample transport systems were Sulfinert treated.

Streams 1-TSY-AE-515A (Water gas shift inlet), 1-TSY-AE-515B (Water gas shift outlet 401), 1-TSY-AE-515C (Water gas shift outlet 402), and 1-TSY-AE-515D (Water gas shift outlet 403)

The same sampling approach as described above using the Welker Charlie-Horse probe was used on these streams, however the wetted surfaces were not Sulfinert treated.

Streams 1-HTR-AE-560B (Regenerator outlet), 1-HTR-AE- 560A/559/561 (Regenerator outlet), 1-HPN-AE-550 (Heating nitrogen), 1-TSY-AE-587 (Outlet of aMDEA® process)

ACSI sample probes were mounted on the process pipe for each location to be sampled. These consisted of a 3/8 in. OD stainless steel probe that passed through a Conax gland fitting and isolation valve into the process pipe. The outlet of the probe was connected to a particulate filter and line regulator to reduce process gas pressure to 30 psig before being transported through sample tubing to the analyzer shelter. All wetted surfaces of these sample transport systems were Sulfinert treated. The sample tubing for these streams was insulated but not heated.

Streams 1-TSY-AE-516 (Outlet CO2 product from aMDEA® system), 1-TSY-AE-517 (Outlet from low temperature gas cooler), and 1-TSY-AE-586 (Outlet syngas from aMDEA® system)

The same sampling approach as described above using the ACSI probe was used on these streams, however the wetted surfaces were not Sulfinert treated.

Gaseous Sample Analysis

Stream 1-USY-AE-500A (Adsorber inlet)

This stream was analyzed on an ABB PGC5000 gas chromatograph equipped with a thermal conductivity detector (TCD) and a flame photometric detector (FPD). The TCD was used for detection of H_2S in the 5,000-10,000 ppmv range. The FPD was used for detection of carbonyl sulfide in the 10-500 ppmv range and sulfur dioxide in the 10-500 ppmv range. A second ABB PGC5000 gas chromatograph with a TCD was used to measure hydrogen in the 40-100% range, carbon monoxide in the 0-10% range, carbon dioxide in the 0-50% range, and nitrogen in the 0-100% range.

Stream 1-USY-AE-528 (Adsorber outlet)

This stream was analyzed on the same ABB PGC5000 gas chromatograph as the 500A stream, but as an independent sample stream. The FPD was used for detection of H_2S in the 1-50 ppmv range, COS in the 1-50 ppmv range, and SO_2 in the 1-50 ppmv range. This stream was also analyzed on an Ametek 4000 UV photometer for measuring H_2S in the 0-1000 ppmv range. The main purpose for the Ametek measurement was to provide continuous monitoring of the adsorber outlet to avoid missing a spiking H_2S concentration between the 20 minute cycles of the gas chromatograph.

Stream 1-HTR-AE-560B (Regenerator outlet)

This stream was analyzed with an ABB AO2040 Limas-11 UV photometer for SO_2 in the 0-15% range and an ABB AO2040 Magnos-206 paramagnetic analyzer for oxygen in the 0-2% range.

Streams 1-TSY-AE-515A (Water gas shift inlet), 1-TSY-AE-515B (Water gas shift outlet 401), 1-TSY-AE-515C (Water gas shift outlet 402), and 1-TSY-AE-515D (Water gas shift outlet 403)

These streams were analyzed on an ABB PIR3502 process infrared multi-wave photometer. For stream 1-TSY-AE-515A, CO was measured in the 0-40% range and CO_2 was measured in the 0-20% range. For the other three sample streams, CO was measured in the 0-10% range and CO_2 was measured in the 0-30% range. Stream 1-TSY-AE-515A was also analyzed for hydrogen in the 0-100% range using an ABB PGC5000 gas chromatograph with TCD and for methane in the 0-2000 ppmv range with an ABB AO2040 non-dispersive infrared (NDIR) analyzer.

Stream 1-TSY-AE-517 (Outlet from low temperature gas cooler) and Stream 1-TSY-AE-586 (Outlet syngas from aMDEA®)

These streams were analyzed with an ABB PGC5000 gas chromatograph equipped with a TCD and FPD. The TCD was used for detection of hydrogen in the 0-100% range, carbon monoxide in the 0-10% range, carbon dioxide in the 0-50% range, and nitrogen in the 0-100% range. The FPD was used for detection of H_2S in the 0-10 ppmv range and COS in the 0-1 ppmv range. These streams were also analyzed for methane in the 0-2000 ppmv range using an ABB AO2040 NDIR analyzer.

Stream 1-TSY-AE-516 (Outlet CO2 product from aMDEA® system)

This stream was analyzed with an ABB PGC5000 gas chromatograph equipped with a TCD and FPD. The TCD was used for detection of hydrogen in the 0-5% range and carbon dioxide in the 0-100% range. The FPD was used for detection of hydrogen sulfide in the 0-50 ppmv range and carbonyl sulfide in the 0-500 ppbv range. This stream was also analyzed for carbon monoxide in the 0-1000 ppmv range using an ABB AO2040 NDIR analyzer.

Streams 1-HPN-AE-550 (Heating nitrogen), 1-USY-AE-528 (Adsorber outlet), 1-TSY-AE-586 (Outlet syngas bypass piping), and 1-TSY-AE-587 (Outlet of aMDEA® process)

During nitrogen purge of the process, these streams could be routed by switching hand valves to analyze for residual oxygen using an ABB AO2040 Magnos-206 paramagnetic oxygen analyzer.

Solid Sorbent Analysis

Solid samples of RTI-3 sorbent were periodically collected from the process unit for analysis of sulfur content. An Oxford Instruments Lab-X3500 x-ray fluorescence (XRF) analyzer located in the analytical lab of the TEC administration building was used for determining the weight percent loading of sulfur on the sorbent. The analyzer was calibrated using standards prepared from RTI-3 sorbent having a known concentration of sulfur with fresh RTI-3 sorbent to produce a series of standards covering the concentration range expected for samples to be analyzed. The known concentration of sulfur for the highest standard was determined using a wave dispersive XRF analyzer at RTI in Research Triangle Park.

aMDEA® Process Quality Control

Samples of the lean solution from the BASF aMDEA® process unit were analyzed periodically to determine the operating status and system health. Analytical procedures for these quality control tests were provided to RTI by BASF under confidentiality.

Modifications to Analytical Systems

During the project, several modifications to the gaseous sample transport techniques and configuration of gas analyzers were made to improve the quality and reliability of the measurements.

Stream 1-HTR-AE-560B (Regenerator outlet)

Due to problems with corrosion of components in the ACSI probe box for sampling points 560A and 560B including regulators, 2-way valves, and tubing, a new approach for gaseous sample transport was implemented on August 18, 2014 to avoid reaching the dewpoint for the sample stream. (These streams were much wetter than anticipated, probably due to the initial use of air for the regenerator from a compressor without any drying of the compressed air.) The corrosion was probably caused by contact of the high concentration SO_2 stream with condensed water, forming sulfurous or sulfuric acid. The proposed remedy was to reduce the pressure of the sample gas in the hot process pipe by using a choke flow orifice. A pressure downstream of the orifice that was ½ or less than the process pressure would produce a constant flowrate. The original open 3/8 in. OD sample probe was replaced with a 3/8 in. OD stainless steel probe with an orifice in the end that was inserted into the process pipe. This probe was fabricated from 3/8 in. OD tube, 2 inches long with a 150 micron hole in the closed end drilled by Lenox Laser. These tubes were welded onto 13 inch long 3/8 in. OD SS tubes to produce a 15 inch long probe. The probe had a set of 3/8 in. Swagelok ferrules attached near the orifice end to serve as a stop collar for the Conax fitting to prevent ejection of the probe if the Conax fitting were loosened under system pressure. After initial testing, the orifice size was increased to 200 microns using a pin vise and 0.2 mm drill bit. The regulator was removed from the probe box and the regulator in the sample conditioning system at the shelter was also removed. The umbilical line pressure was then controlled by how much flow was metered through the bypass valve and the three analyzers fed by the 560B sample (Limas SO_2, Magnos O_2, and Multi-wave). At a dewpoint of 140 F and a system pressure of 450 psig, the water concentration was 0.62% in stream 560B. With 6 lpm bypass flow and 1 lpm each for the analyzers, the line pressure was 5 psig. At this pressure, the dewpoint of this stream was 40 F. The corrosion was being caused by liquid water condensation as the gas cooled upon entry to the probe assembly at the high process pressure. By dropping the pressure across the choke flow orifice within the process pipe at high temperature, the dewpoint of the gas was reduced significantly, preventing water condensation and subsequent corrosion. Occasionally the orifice has plugged with solid material, but it could usually be cleared by back-pulsing with 1000 psig nitrogen from a gas cylinder. [NOTE: A drying chiller was later installed on the air compressor feeding the regenerator, so the initial suspected cause of dewpoint corrosion was eliminated.]

1-USY-AE-528 (Adsorber outlet) and Streams 1-TSY-AE-515A (Water gas shift inlet), 1-TSY-AE-515B (Water gas shift outlet 401), 1-TSY-AE-515C (Water gas shift outlet 402), and 1-TSY-AE-515D (Water gas shift outlet 403)

In early December of 2015, a new sample probe was installed near the original sample point. The new probe consisted of a 3/8 inch OD stainless steel tube with a 200 micron laser drilled orifice on the inlet side. The regulator in the sample conditioning system was removed and the umbilical line pressure was controlled by adjusting the amount of bypass flow. This change was intended to improve the consistency of the stream composition analysis by preventing water condensation until the process gas reached the sample conditioning system.

Water Management Issue with Swirlkleen Filters

Flooding of the Swirlkleen filter housings in the sample conditioning system for streams 1-USY-AE-500A (Adsorber inlet) and 1-USY-AE-528 (Adsorber outlet) was observed in early October, 2014. Upon investigation of the cause, it was noticed that the Armstrong water trap was installed at a height similar to the Swirlkleen. The Armstrong water trap was tested and it was determined that 160 mL of water fill was needed to raise the float and open the drain to the sump system. The total volume of the Armstrong trap is 220 mL so approximately 75% filling was necessary before water was drained. Based on the position of the water trap, this would result in flooding of the Swirlkleen filter housing to a level about half way up the membrane filter, resulting in water being pushed across the membrane and into the transfer tubing to the chromatographs. To remedy this problem, the Armstrong traps were relocated to positions lower than the Swirlkleen filters.

Atmospheric Vent Header

In early September, 2014, it was noticed that water had been draining from the atmospheric pressure vent header into the exhaust lines for the Limas 11 SO_2 analyzer and the Magnos O_2 analyzers. We had been purging this header with instrument air to avoid intrusion of moist outside ambient air into the header, however the instrument air must have had a dewpoint that enabled condensation in the cool atmospheric pressure vent header inside the shelter. To avoid this, the purge gas for the vent header was changed to UHP nitrogen from a cylinder. The flow was set at about 200 mL/minute.

PGC5000 Controller Programming Error

On October 2, 2014, a programming error on the PGC5000 controller for GC ovens A and B was discovered. The stream step time control function (TCF) in analysis ANALYS_920249-030B1 was set at 20 seconds. The stream step is the time that the next stream in the schedule queue begins purging. Purging with this stream continues until the next stream step command which occurs in the analysis method for the next stream in the queue. The stream step should always occur after all sample loops have been injected for the current analysis. Valves 1, 2, and 4 are the sample injection valves in this analysis. Valves 1 and 4 are injected at 5 seconds, so these samples were not affected by the stream step. However, valve 2 is injected at 75 seconds. This means that this sample was being injected after the stream step command had begun flowing sample gas for the next stream. To correct this error, the stream step time was changed to 80 seconds so that the next stream began purging 5 seconds after the last sample was injected for the current analysis. The same issue was corrected in analysis ANALYS_920249-030A1. (30A1 is used for Oven B, streams 1, 3, and 4 which is 1-TSY-AE-517, 1-TSY-AE-515A, and 1-USY-AE-500A and 30B1 is used for Oven B, stream 2 which is 1-TSY-AE-586).

A similar error was found with analysis ANALYS_920249-020B (Oven A, stream 2 which is 1-USY-AE-528). The stream step TCF was set to 130 seconds. Valves 2 and 4 are the injection valves. Valve 4 was being switched before the 130 second stream step but valve 2 was switched at 140 seconds. To correct this issue, the stream step time was increased to 145 seconds. Only valves 1,3, and 6 were injected during analysis ANALYS_920249-020A and all occur before 130 seconds, so there was no problem with this analysis method.

There were no problems found with analysis ANLYS_920249-050 which is used for GC C, Stream 1-TSY-AE-516.

Any analyses before these changes were made in the analysis methods for GC A and GC B could have errors due to sampling of a different stream than indicated in the analysis report and data transmitted to the DCS over MODBUS.

Cross Contamination of GC Samples

In early 2015, it was determined that analysis of stream 1-USY-AE-500A on GC B was causing cross contamination of the next sample in the sequence from stream 1-TSY-AE-517. Stream 1-USY-AE-500A typically contains about 10,000 ppmv H_2S. Stream 1-TSY-AE-517 was expected to contain less than 200 ppbv H_2S, but values typically reported were about 2-3 ppmv. Given that H_2S can exhibit a high level of adsorption onto stainless steel surfaces, it was theorized that adsorbed H_2S from the high concentration stream was desorbing during analysis of the low concentration stream, causing a high bias in the concentration measurement. To prevent this cross contamination, stream 1-USY-AE-500A was switched to an Inficon 3000 Micro GC in early June of 2015 for analysis of H_2S, COS, SO_2, H_2, CO, CO_2, and N_2. Because of this change, the time between analyses of stream 1-USY-AE-528 was reduced from 20 minutes to 10 minutes, providing better tracking of the adsorber outlet H_2S concentration.

Appendix H

DEVELOPMENT OF RTI TRACE CONTAMINANT REMOVAL PROCESS (TCRP) SORBENTS AND THEIR DEMONSTRATION VIA MICROREACTOR TESTING USING TREATED SYNGAS

1.0 Introduction

Gasification systems convert feedstocks such as coal, petroleum coke, natural gas, biofuel, and municipal waste to synthesis gas (syngas) containing highly desirable components such as carbon monoxide, hydrogen, and steam that can effectively be used to produce electricity or value-added chemicals in a very efficient and environmentally friendly process. Challenges faced when utilizing gasification-produced syngas for both power and chemical production include the presence of contaminants in the feedstock that survive the high temperatures and pressures of the gasification step either in their elemental state or are converted to more stable species when the gas is cooled for subsequent use. The presence of these contaminants can be problematic for syngas utilization because they can attack vital metal components in advanced gas turbine systems used to produce power and can also poison expensive catalyst materials used to produce high-value chemicals. In addition, if contaminants survive the utilization step then they may be released to the environment and potentially trigger regulatory issues. For these reasons, control systems designed to reduce syngas contaminants to acceptable levels for both downstream conversion processes and to control emissions is crucial for gasification systems to be a viable alternative to conventional power generation and to be used in chemical production.

Syngas can be relatively free of contaminants if derived from clean feedstocks such as refined natural gas, but it also can contain a myriad of contaminants that vary widely in their concentrations if derived from coal, petroleum coke, or municipal waste. In the case of coal-derived syngas, results from previous research has led to a fairly good understanding of the contaminant species and expected concentrations for the major contaminants including sulfur, nitrogen, and chlorine. For the minor contaminants, those present at trace-level concentrations (commonly referred to as trace contaminants) such as mercury, arsenic, and selenium, much less is known about the species type and their concentrations at a specified gas cleaning condition. To overcome this lack of knowledge, researchers have relied on thermodynamic equilibrium calculations to predict chemical species and coal feedstock analyses to predict concentrations for the design of trace contaminant control systems. Conventional trace contaminant removal approaches have relied primarily on use of physical absorption solvents that require refrigerated temperatures and thus lower process efficiencies.

RTI's approach to trace contaminant removal is based on the interaction of the gaseous contaminants with fixed beds of disposable sorbent materials at warm temperatures above 400°F and pressures above 600 psig. This system, known as the trace contaminant removal process (TCRP), has been developed in the laboratory using simulated syngas, has been tested on-stream using actual coal-based syngas at Eastman Chemical Company's gasification facility in Kingsport, TN, and is currently being pre-commercially tested along with RTI's warm temperature desulfurization process (WDP) at Tampa Electric Company's Polk Power Station located in Mulberry, Florida. These two processes (WDP and TCRP), when combined, comprise RTI's warm syngas cleanup package capable of producing ultra-clean syngas ideally suited for either power or chemical conversion.

The sections that follow describe activities associated with determining the cleanliness of the WDP and TCRP-treated syngas at Polk Station by demonstrating chemical production via microreactor testing and gas-phase testing to determine contaminant distribution upstream and downstream of the WDP and TCRP systems. In addition, laboratory studies involving hydrogen chloride tolerance of RTI's desulfurization sorbent, RTI-3, and parametric testing to provide guidance for designing removal systems for HCl and NH_3 are discussed.

2.0 Microreactor Testing

In addition to power production, chemicals produced from syngas is another key area of interest for gasification applications. One limitation for this application, however, is the presence of contaminants in the syngas feedstock, which can poison expensive catalyst materials used in syngas to chemicals systems. These contaminants, which survive the gasification step either in their elemental form or transition to other more chemically stable species, are known to poison the mixed metal oxides used in the production of value-added chemicals and fuels. For example, sulfur species such as H_2S should be below 1 ppm and preferably below 0.1 ppm to inhibit deactivation of copper containing catalysts used to produce methanol [Twigg] and metal species such as arsenic poison Fischer-Tropsch catalysts based on iron and cobalt. [Bartholomew]

The objective of this task was to demonstrate the efficacy of syngas contaminant removal using RTI's warm syngas cleanup technology installed at Tampa Electric's Polk Station facility by feeding a slipstream of treated gas to small-scale reactor systems containing commercial catalysts and monitoring the catalysts performance over time. To meet this objective, three separate microreactors were configured to generate methanol and Fischer-Tropsch (FT) chemicals from the treated syngas feed using specific catalyst materials. The experimental approach was based on determining baseline catalyst deactivation rates while feeding contaminant-free simulated syngas from compressed gas cylinders for 500 hours of testing and then determine whether the deactivation rate changes when the feed was switched to treated syngas. The sections that follow describe the catalyst materials, experimental systems and procedures, and results from the catalyst deactivation studies.

2.1 Catalyst Materials

Three catalyst materials were selected for study based on their expected sensitivity to common syngas contaminants. Table 1 provides a description of the selected materials. The three materials were provided by Clariant.

Table 1. Catalyst Materials

Product Code	Target Product	Composition	Form (as received)
Megamax 700	Methanol	Cu/Zn	4x6 Tabs
D-1140	FT Chemicals	Co	0.0625 CDS Extrudates
D-1139	FT Chemicals	Fe	0.125 Round Extrudates

Prior to testing, the particle size of each material was reduced by grinding and sized between 250 and 355 microns using test sieves. Each material was then diluted to nominal 3 parts (by weight) of 250 micron gamma-alumina to one part (by weight) catalyst and mixed well. The dilution was performed to aid in dissipating heat associated with the expected exothermic reactions when exposed to syngas.

2.2 Experimental Systems

Three Micromeritics (Norcross, GA) PID/Particulate Systems Effi Microreactors were used for the testing. Each PID Effi Microreactor consists of an oven containing two furnaces, three 500 mL/minute mass flow controllers for introducing feed gases, a temperature controlled wax trap, a thermoelectrically cooled gas/liquid/liquid separator for condensation and collection of condensable hydrocarbons and water, and a back pressure control valve for maintaining reactor pressures of up to 100 bar. The oven that houses the reactor furnaces also houses the switching valves and connecting tubing. Housing these devices in a heated oven prevents condensation of hydrocarbon product species before they reach the liquid condensers designed for collection of condensable components in the product gas stream. One furnace in the oven housed a 17 mm ID stainless steel reactor vessel. This reactor was packed with approximately 12 cm^3 of Clariant ActiSorb® S2 (G-72 D) that was heated to 725° F as a guard bed to remove hydrogen sulfide and carbonyl sulfide from syngas. The other furnace housed a 9.1 mm ID stainless steel reactor vessel packed with about 3 cm_3 of catalyst mixed with alpha-alumina. These reactors were run in series with the gas flow passing through the guard bed before entering the catalyst reactor.

In addition to the G-72D guard bed, an unheated stainless steel vessel containing about 50 cm^3 of 20/40 mesh SKC activated carbon was installed on the inlet used to feed either syngas or a bottled gas mixture of H_2, CO, and CO_2.

Analysis of the reactor outlet gas stream was performed with an Inficon 3000 Micro gas chromatograph (GC). Components measured for the FT catalyst systems included H_2, CO, CO_2, N_2, C1-C6 alkanes, and C2-C6 alkenes. Components measured for the methanol synthesis catalyst system included H_2, CO, CO_2, N_2, and methanol. The N_2 concentration in the product gas compared with the N_2 concentration in the feed gas was used to determine the outlet gas flowrate.

Liquid hydrocarbons collected from the condensers of the FT catalyst systems were analyzed at RTI by GC with flame ionization detection to determine the carbon number distribution of the hydrocarbon liquid product. The liquid collected from the methanol synthesis catalyst system was analyzed by GC with mass spectrometry to determine purity of the methanol product.

2.3 Procedures

2.3.1 Catalyst Loading

The amount of catalyst loaded in each reactor furnace was based on a nominal L/D of 5, which resulted in a bed volume of around 3.2 cm^3. Because of differences in the catalyst packing densities, the actual weight of each material loaded in the reactor varied. Once the materials were loaded in the reactor furnace, N_2 was used to initially purge room air from the reactors. The reactors were then pressurized with N_2 to their expected maximum operating pressure to leak check the system.

2.3.2 Catalyst Reduction

Procedures used to chemically reduce the catalyst materials were a compromise between specific instructions provided by the catalyst manufacturer and hardware limitations of the microreactor system. It was anticipated that the most important parameter to control during the reduction procedure was temperature, especially with the Cu/Zn methanol synthesis catalyst because the surface morphology of the active metals can change if the temperature exceeds that specified by the manufacturer.

The Co and Fe FT catalyst materials were reduced using similar gas compositions and temperature profiles but the pressure used during reduction and the final hold temperatures were different. Incremental increases in temperature and gas composition were used to minimize temperature excursions during the reduction step. For both materials, the reduction gas consisted of 5 sccm H_2 and 95 sccm N_2 during each incremental increase in temperature. Once the temperature had reached the desired set point and the GC analyses indicated that the H_2 concentration had stabilized, the reduction gas was changed to 15 sccm H_2 and 85 sccm N_2 and held until the H_2 concentration had stabilized and then changed to 25 sccm H_2 and 75 sccm N_2 until the H_2 concentration was stable. To prepare for the next temperature increase, the gas composition was changed back to 5 sccm H_2 and 95 sccm N_2 and the gas composition cycle was repeated. Again, this method was used in an attempt to control the temperature during reduction.

The Co catalyst was reduced at 13 bar. Once pressurized, with the reducing gas composition of 5 sccm H_2 and 95 sccm N_2, reduction began by increasing the reactor furnace temperature. For the Co catalyst, reactor furnace temperature set points were 221, 248, 428, and 572°F. Note that the initial temperature ramp for the Co catalyst from ambient to 221°F resulted in ballistic heating of the furnace to 347 °F. Subsequent GC analyses indicated very little change in H_2 concentration during this temperature spike. The reactor was cooled to 248°F and the designated temperature increases were continued using the temperature ramp feature on the microreactor to minimize temperature overshoot. The Fe catalyst was reduced at 3.45 bar and the reactor furnace set points were 221, 302, and 428°F.

For the Megamax 700 methanol synthesis catalyst, the reactor was purged with 100 sccm N_2 and pressurized to 8 bar. The temperature was increased to 302°F at 34°F/min, followed by beginning flow of 5 sccm H_2 and 95 sccm N_2. After confirming that the H_2 concentration at the reactor outlet was no longer increasing, the temperature was ramped to 356° F at 34°F/min. When the H_2 concentration of the outlet gas stabilized at 5 percent, the temperature was increased to 464°F at 32°F/min. After the reactor temperature had reached 446°F and H_2 concentration in outlet gas was 5 percent, the H_2 in the feed was increased to 7 percent. The outlet concentration of H_2 quickly reached 7 percent indicating no further reduction. The reactor pressure was increased to 40 bar and the reactor temperature was increased to 482°F in preparation for testing.

2.3.3 Baseline Testing

Prior to exposure to real syngas cleaned by RTI's warm syngas cleanup technology, catalyst materials contained in each of the three microreactor systems were exposed to simulated syngas generated from commercially available high-purity compressed gas mixtures for a nominal 500 hours to determine the syngas conversion rate under ideal conditions. Table 2 provides the baseline exposure conditions. The bottled gas syngas mixture was diluted with N_2 for feeding to the catalyst reactors to limit the mass of products formed and thus minimize the risk of reactor system plugging due to wax and liquid condensate.

Table 2. Test conditions for baseline tests

Catalyst	**Co-FT**	**Fe-FT**	**Methanol**
α alumina: catalyst ratio (mass)	3:1	3:1	3:1
Catalyst bed volume (cm^3)	3.23	3.23	3.23
Pressure (bar)	24	24	40
Reactor Temperature (°F)	428	482	482
GSHV * (h^{-1})	1858	1858	3716
Syngas Composition (mol%)			
H_2	16.0	16.0	22.0
CO	7.8	7.8	10.8
CO_2	1.3	1.3	1.7
N_2	Balance	Balance	Balance
Wax Trap (°F)	248	248	
LT Liquid trap (°F)	41	41	41

* GHSV is defined as the gas flow at atmospheric pressure and 32°F based on the catalyst bed volume.

2.3.4 Syngas Testing

For tests performed with syngas feed from the 50 MW process unit, H_2 and/or CO were blended with the syngas to adjust the H_2, CO, and CO_2 concentrations in the feed to be similar to that used in the baseline testing. As a consequence of the minimum flow capability of the mass flow controllers used for H_2 and CO, the gas hourly space velocity was 3716 hr-1 for all three catalyst systems. Due to limitations in the pressure of the process gas available from the 50 MW process unit, all tests with syngas were performed at 23 bar pressure. Conditions for testing with syngas feed from the 50 MW process unit are shown in Table 3.

Table 3. Test conditions for clean syngas tests

Catalyst	**Co-FT**	**Fe-FT**	**Methanol**
α alumina: catalyst ratio (mass)	3:1	3:1	3:1
Catalyst bed volume (cm^3)	3.23	3.23	3.23
Pressure (bar)	23	23	23
Reactor Temperature (°F)	482	482	482
GSHV * (h^{-1})	3716	3716	3716
Syngas Composition (mol%)			
H_2	18-22	18-22	18-22
CO	9-11	9-11	9-11
CO_2	0.4-0.6	0.4-0.6	0.4-0.6
N_2	Balance	Balance	Balance
Wax Trap (°F)	248	248	
LT Liquid trap (°F)	41	41	41
* GHSV is defined as the gas flow at atmospheric pressure and 0°C based on the catalyst bed volume.			

2.4 Microreactor Testing Results

For comparison of deactivation of each of the catalysts between bottled gas feed and clean syngas feed (from 50 MW process unit), the CO conversion was tracked over time. The charts presented in Figures 1, 2, and 3 show performance of each of the three catalysts during baseline testing.

Figure 1. CO Conversion for Iron-based FT Baseline Testing

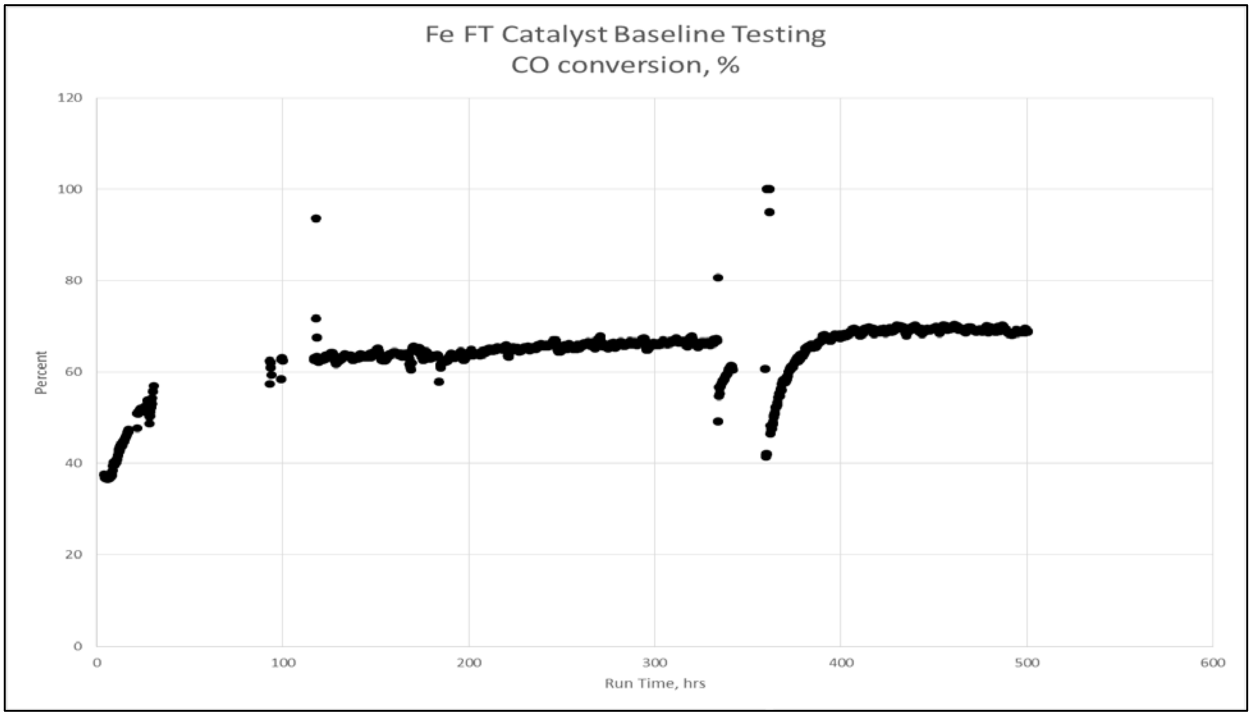


Figure 2. CO Conversion for Cobalt-based FT Baseline Testing

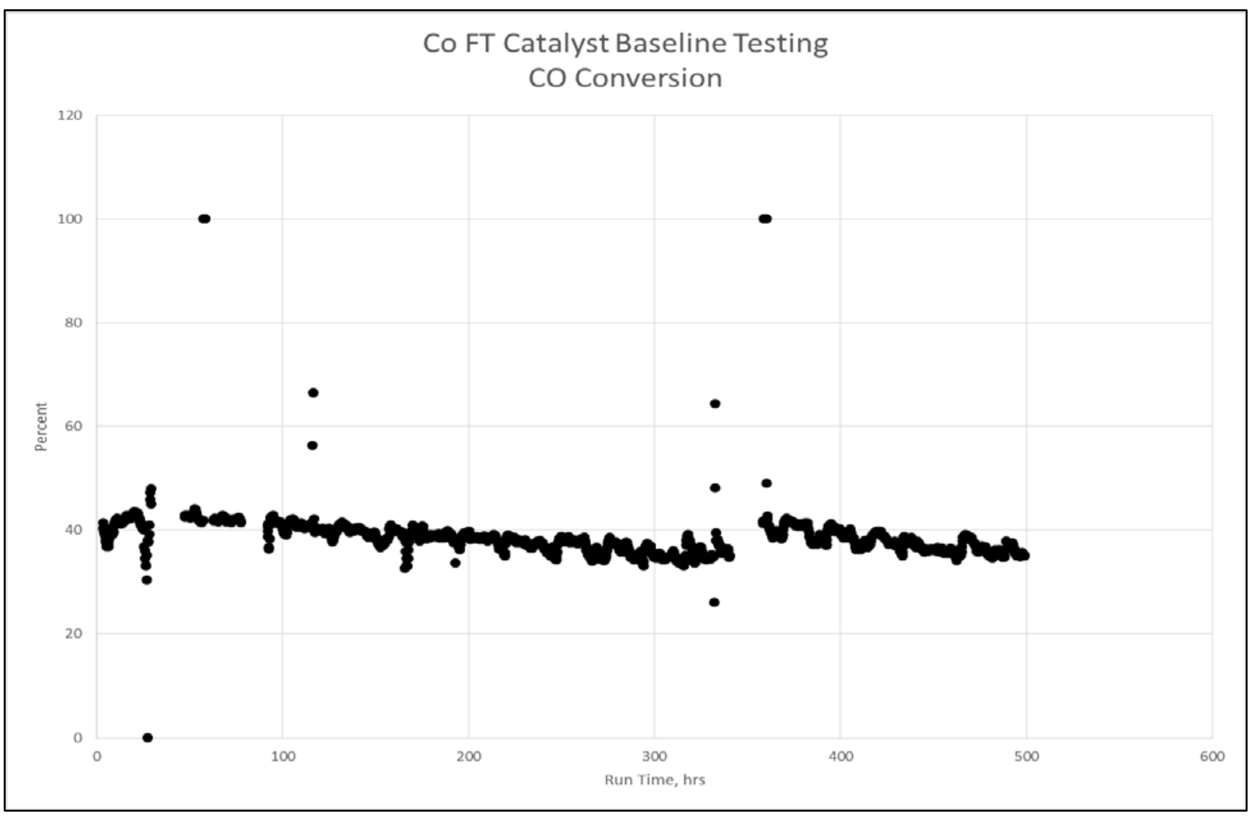
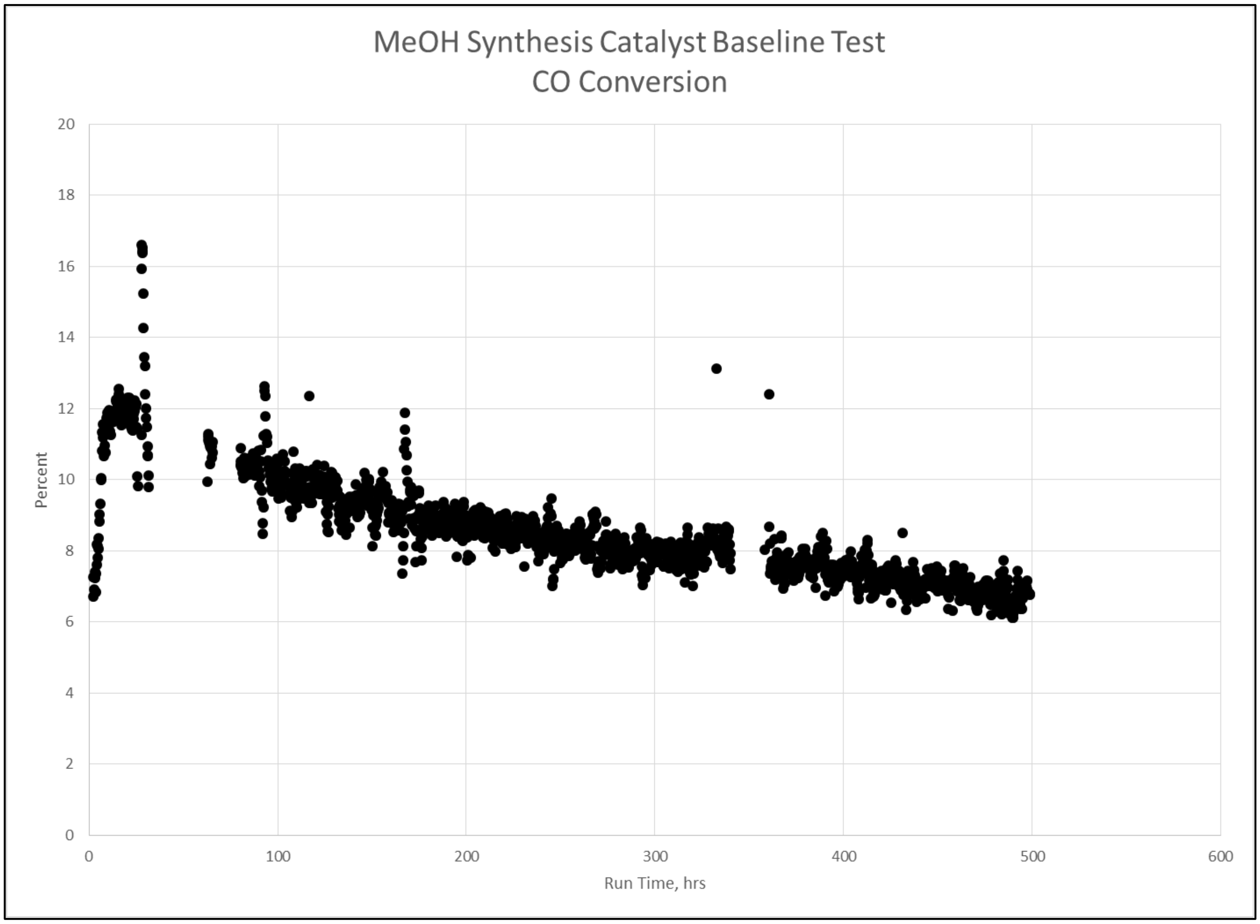


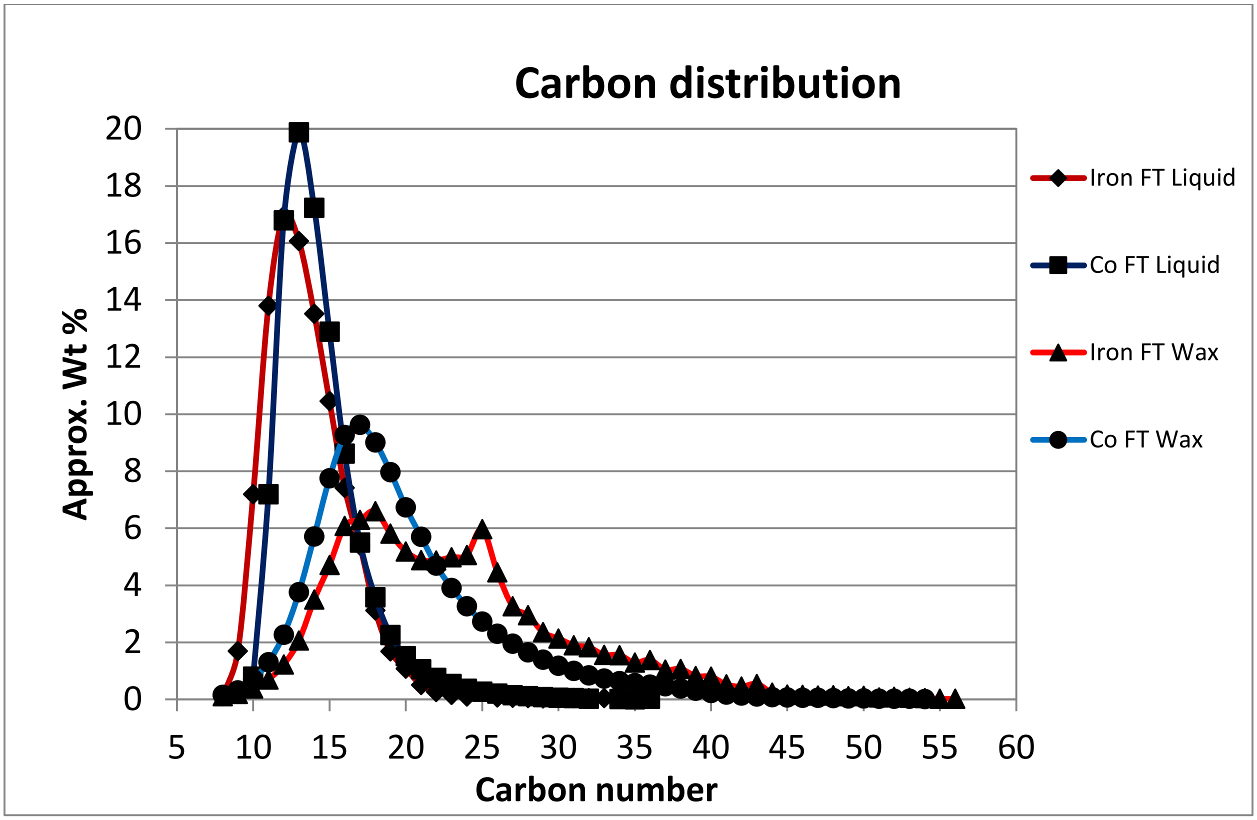
Figure 3. CO Conversion for Methanol Baseline Testing



Hydrocarbon liquid and wax products from the baseline tests were analyzed to enable comparison with similar products that were produced during the testing with clean syngas feed. The chart presented in Figure 4 shows the carbon number distribution for the liquid hydrocarbons and waxes produced in the FT synthesis using the Fe and Co catalysts during baseline testing.

Operation of the microreactors with clean syngas will be continued under Cooperative Agreement DE-FE-0026622 and results from this testing will be reported at the conclusion of this Agreement.

Figure 4. FT Carbon Distribution During Baseline Testing



3.0 Trace Contaminant Testing

One of the many complexities encountered with syngas cleaning is determining whether the presence of one or more non-target contaminants affects the removal efficiency of a specific gas cleaning technology. For example, results from trace contaminant testing using gas-phase determinations at the inlet and outlet of WDP during pilot-scale testing at Eastman indicated that the RTI-3 sorbent removed a significant portion of two non-targeted contaminants, As and Se, from the coal-derived syngas. Analysis of spent RTI-3 sorbent indicated that the As and Se contaminants were irreversibly adsorbed and not removed during the sulfur regeneration step. Accumulation of these trace contaminants could potentially lead to changes in the desulfurization characteristics of the RTI-3 sorbent or interfere with the sorbent regeneration step over long periods of time. A better understanding of any interaction that these non-target contaminants can have on a gas cleaning technology is best realized through a detailed characterization of the upstream and downstream syngas composition during actual operation. Continuous operation of RTI's warm syngas cleaning technologies at

Tampa Electric provided a unique opportunity to determine whether the presence of trace contaminants has a detrimental effect on WDP, water gas shift (WGS), and CO_2 removal.

Validated methods that can be used to determine the gas-phase concentrations and contaminant species in syngas are scarce. The closest companion methodologies are those used by stationary sources such as power plants, incinerators, and chemical plants to comply with state and federal emissions regulations. Sampling methods for the determination of trace contaminants in syngas prior to utilization presents unique challenges compared to conventional emissions testing at stationary sources for the reasons shown below.

- The target gas streams are sampled at elevated temperatures and these higher temperatures usually lead to test gases with much higher dew points. As the test gas is cooled for sampling, care must be taken to recover any water soluble species from the sampling train.
- Syngas is utilized at high pressures and these pressures must be reduced without loss of target analytes prior to sample collection.
- Syngas contains high concentrations of CO and H_2 and is inherently a reducing gas. Most stationary source methods for trace contaminants such as Hg, As, and Se are based on oxidizing the contaminant species for collection in aqueous based impinger solutions and for this reason their applicability to the syngas reducing environment is limited.

AECOM's environmental services division (formally URS Corp.) based in Austin TX has demonstrated expertise in developing and utilizing sampling methodologies for the determination of trace contaminants in syngas and was instrumental in providing these services during the pilot-scale testing at Eastman. Based on their prior experiences, AECOM was selected to conduct further testing during WDP and TCRP demonstrations at Polk Station.

3.1 AECOM Sampling Methodology

A general description of the sampling and analysis methodologies that AECOM uses for syngas streams is provided in this section. For the Polk Station site, two main areas were identified for testing. The first area was sample gas streams entering the analyzer shed that housed GCs and continuous environmental monitors for CO, CO_2, H_2, H_2S, COS, SO_2, and O_2 determination to support the continuous operations of WDP, WGS, and CO_2 removal. The second area was upstream and downstream of vessels containing sorbent materials on the TCRP test skid. Target contaminants for the gas-phase trace contaminant testing were the same for both areas of study and included NH_3, HCN, Hg, As, and Se. The NH_3 and HCN contaminants are collected in impinger solutions and the Hg, As, and Se are collected on charcoal cartridges.

3.2 Trace Contaminant Testing Analysis Results

A portion of the planned gas-phase sample collection campaign was completed under Cooperative Agreement DE-FE0000489 but the testing was halted due to availability of syngas from the WPD. The syngas production and sampling campaign has been continued under new Cooperative Agreement DE-FE-0026622. For this reason, the complete set of trace contaminant testing analysis results will be reported under this new Agreement.

4.0 Trace Contaminant Sorbent Testing

A significant amount of research has been conducted on the development and testing of gas cleaning technologies for the removal of major contaminants from syngas such as H_2S, COS, and HCl but much less attention has been focused on the removal of contaminants present at trace levels such as Hg, As, and Se. Although the trace contaminants concentrations in syngas are much lower compared to sulfur and chlorine species, their presence can still be problematic if not removed prior to gas utilization. In collaboration with our industrial partners and with funding provided by the Department of Energy National Energy Technology Laboratory (DOE/NETL), RTI has been actively developing control technologies for the trace contaminants at temperatures higher than 400°F and pressures greater than 600 psig that can be used in conjunction with WDP to produce ultra-clean syngas to meet performance goals for new EPA emission limits.

Because Hg, As, and Se are present in syngas at low concentrations, removal technologies developed by RTI have focused on the use of fixed beds of solid sorbent materials with sufficient capacity that makes disposal of the spent sorbent at the end of its life cycle a cost effective option. Emphasis has also been placed on identifying candidate sorbents that currently exist in the commercial domain in hopes of avoiding the all too common problems encountered with material scale-up from small experimental batches to larger commercial batches. During the initial phase of sorbent development conducted under laboratory conditions, two materials were identified as candidates for contaminant control at temperatures above 400°F: an impregnated carbon material for mercury removal and a mixed metal oxide for arsenic removal. Laboratory testing indicated that these sorbents removed 90 percent of the challenge concentration in simulated syngas, which was the DOE performance goal at that time. During pilot testing of the WDP technology at Eastman, the two candidate sorbents were exposed to raw syngas at 400°F and 850 psig for 500 hours. A detailed description of development and testing of the first generation of Hg and As sorbents can be found in the Final Report entitled *Novel Technologies for Gaseous Contaminants Control* submitted under DOE Contract No. DE-AC26-99FT40675.

Work continued on further development of the trace contaminant sorbent materials on DOE Contract No. DE-FC26-05NT-42459. This work included detailed analyses of the sorbent materials exposed to Eastman syngas to determine the distribution of syngas contaminants across different sorbent materials and development of a newer generation of trace contaminant sorbents to improve sorbent capacities and to meet the more challenging DOE performance goals for chemical production and new EPA emission limits. This work resulted in the identification of a new source of impregnated carbon for Hg removal that showed equivalent Hg capacity compared to the first generation sorbent and reduced the concentration of Hg in simulated syngas under laboratory conditions from a challenge concentration of 2000 ppbw to below 3 ppbw, which is the lower limit needed to meet the new EPA emission regulations. The first generation As sorbent had significant capacities for commercial use but did not meet the more stringent performance goals for the new EPA emission limits. To address these requirements, further studies were conducted under laboratory conditions to identify commercially available materials that exhibited high contaminant capacities and that met the new performance goals. The product of this research was the identification of a mixed metal oxide with an As capacity greater than 4.5 weight percent and it reduced the arsenic concentration from 10,000 pppbv to less than 5 ppbv, which is the lower limit needed to meet the new EPA emission regulations. As an added bonus, this material also retained Se, which was added to the target contaminant list by DOE during this time. Up to a Se loading of 4.5 weight percent, the material reduced the Se concentration in simulated syngas under laboratory conditions from 10,000 ppmv to less than 25 ppbv, which met the EPA emission limits.

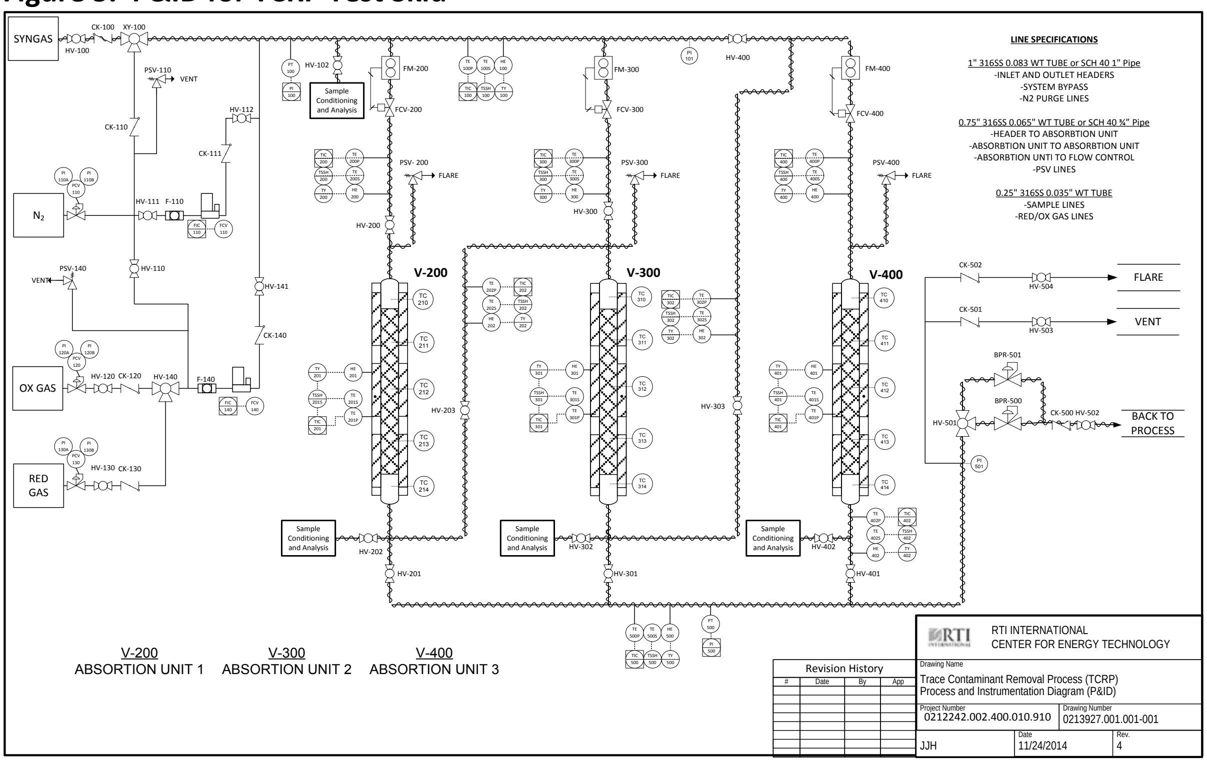
In order to gain a better understanding of the removal efficiencies of the newer generation of trace contaminants sorbents in real syngas, preparations were made to expose these materials to a slipstream of the Tampa Electric Polk Station syngas downstream of WDP. This work involved the design, construction, and operation of a test skid to expose multiple beds of trace contaminant sorbents to desulfurized syngas at 400°F and 350 psig at a flow rate of around 1000 scfh. The sections that follow describe the design specifications, operational parameters, and testing results for the TCRP test skid.

4.1 Design and Construction of the TCRP Test Skid

A brief description of the TCRP test skid follows. Major components of the skid were acquired and assembled by AMEC personnel on-site at Polk Station.

A P&ID of the TCRP test skid configured for the exposure of RTI's trace contaminant sorbents to a slipstream of desulfurized Polk Station syngas is shown in Figure 5. The skid was designed to expose up to three materials in separate reactor vessels to syngas at 400°F and 600 psig at a flow of up to 1000 scfh per vessel. Each reactor had its own flow control and internal plumbing and was oriented so that the materials could be exposed either parallel to one another or in series, which provided added flexibility for skid operation. Process control systems for temperature and flow control were located on the test skid (for future portability) and process variables were communicated back to the WDP DCS located in the Polk Station control room.

Figure 5. P&ID for TCRP Test Skid



One of the major challenges with the design and construction of the TCRP skid was the need to return the treated syngas back to the WDP process at a point where the pressure differential between feed and return was less than 50 psig. To complicate matters further, the closest available return point was located approximately 200 feet from the skid, which required a significant run of tubing to complete. This arrangement required careful attention to each component in the process flow path to minimize the total pressure drop across the system. Another challenge in the design and operation of the skid was supplying enough heat to each skid component in the process gas flow path to maintain the temperature above the dew point of the syngas. Under normal circumstances, this would not have been an issue but the test skid was located within Area 100 of WDP and, as such, was within a Class I Division 2 electrical classification. This required specialized heat tracing that could be operated in the presence of flammable gases.

4.2 TCRP Test Skid Commissioning and Operation

Initial commissioning of the TCRP test skid commenced on June 18, 2015 with system orientation by RTI personnel, charging the reactor with candidate sorbent materials, and flow checks with dry N_2. Several issues were identified during this initial commissioning including minor system component leaks and minor problems with the control system, but these issues did not inhibit the scheduled activities for this stage of testing. A significant finding during these activities was that the pressure drop calculations performed by RTI for the initial design phase were confirmed during flow checks performed with N_2 and full design flow with syngas should be realized when the gas densities at operating temperature and pressures were considered.

The second stage of commissioning was started on July 27, 2015 with an attempt to chemically reduce the sorbent materials and place the system in standby under a N_2 blanket until desulfurized syngas was available for testing. Unfortunately, major roadblocks were encountered during this phase of commissioning. Initially, problems were identified with electronic mass flow controllers intended to meter the reducing gases supplied from a compressed gas mixture. After workarounds for the reducing gas flow were implemented, attempts at preheating the reactor vessels indicated that the heat source was not capable of achieving the desired operating temperature. This problem was attributed to a combination of insufficient power supplied to the heaters, insufficient insulation, and exposure of insulated components to intermittent torrential rains. The reactor heaters were operating at their full capacity so very little could be done to increase the heat supplied to the reactor vessels. Additional insulation was added to the skid components and a tarp was constructed over the structure to minimize water intrusion into the insulation.

Due to the extended gasifier outage and problems with exchanger E-110 on WDP, operation of the TCRP test skid did not commence before the end of DE-FE0000489. TCRP testing has been continued under new Cooperative Agreement DE-FE0026622 and results from this testing will be included in the final report for this new Agreement.

5.0 RTI-3 HCl Tolerance Testing

Extensive laboratory and pilot-scale testing of RTI's WDP has shown that this technology reduces the concentration of sulfur species contained in simulated syngas, under laboratory conditions, and in real syngas, produced from an operating gasifier, from 10,000 ppmv or more to less than 10 ppmv at temperatures ≥900°F and system pressures to 850 psig. The centerpiece of this technology is the RTI-3 sorbent material, which contains ZnO as an active ingredient that chemically reacts with H_2S to form ZnS and H_2O and COS to form ZnS and CO_2. Among the many key features of the technology is the ability to reduce the oxidation state of the ZnS species back to ZnO using air at around 1275°F, which is a critical step considering the relatively high sulfur contaminant levels encountered in syngas produced from some gasification feedstocks such as certain types of coal and petroleum coke. Another key feature of the technology is the ability to operate WDP in a fluidized-bed mode within a transport reactor. Although fluidized-bed reactors offer several benefits over packed-bed configurations in large commercial-scale applications, sorbents with high attrition rates render this approach cost prohibitive. The ZnO active ingredient contained in RTI-3 is supported on an attrition-resistant support, which allows for fluidized-bed operation with manageable attrition rates.

RTI's approach to producing ultra-clean syngas for power and chemical production is based on separate modules that remove the sulfur species (WDP), recover the sulfur (DSRP), and remove the trace contaminant species (TCRP). Most conceivable configurations for the individual modules of RTI's warm syngas cleanup technology package positions WDP as the first treatment stage in the gas cleaning process. As such, the RTI-3 sorbent will be exposed to the full spectrum of feedstock contaminants that survive the gasification step and make it to the point where the gas will be cleaned. One of the many contaminants that may be present in the syngas at the point of warm syngas cleaning is HCl, especially in instances where the gas does not pass through a quench step before gas cleaning. Prior to the work performed under this task, very little research had been reported on the effects of HCl on the desulfurization performance of ZnO-based sorbents in syngas environments. Gupta (2000) found no deleterious effects on the capability of a zinc titanate sorbent to remove H_2S from a simulated syngas stream containing up to 1500 ppmv HCl at temperature between 1000 and 1200°F, but did note some loss of Zn at higher exposure temperatures.

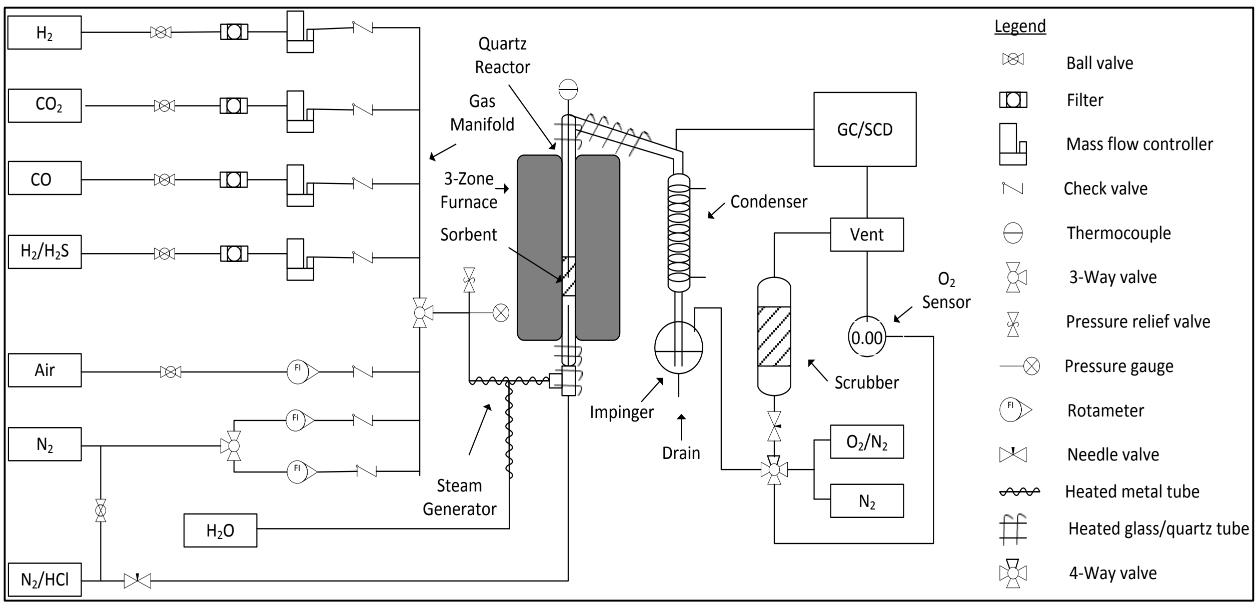
The goal of this task was to assess whether the presence of known amounts of HCl contained in simulated syngas under laboratory conditions changes the desulfurization and regeneration characteristics of the latest formulation of RTI-3 sorbent used in the WDP at Polk Station. The sections that follow describe the laboratory experiments conducted to make this assessment and the results of this study.

5.1 RTI-3 HCl Tolerance Testing Experimental Apparatus

A schematic of the test apparatus is shown in Figure 6. Main components of the system included a gas blending manifold, steam generator, quartz reactor, glass condenser, glass impinger, O_2 sensor, and GC with sulfur chemilluminescence detection (SCD). The gas manifold was equipped with electronic mass flow controllers for metering the flow of simulated syngas components CO, H_2, CO_2, and H_2S supplied from compressed gas cylinders. An upstream reference pneumatic flow controller was used to meter the flow of HCl from a compressed gas mixture containing HCl in N_2. This flow of HCl and N_2 was supplied to the system using Teflon tubing, which was transitioned to quartz tubing prior to entry into a preheated zone within the bottom of the quartz reactor. Steam was supplied to the system by vaporizing a flow of deionized (DI) H_2O supplied to a heated stainless steel tube packed with quartz wool using a liquid chromatography pump. Simulated syngas from the gas manifold was used to carry the steam to the bottom of the quartz reactor where these components were mixed with HCl and N_2. Compressed air for sorbent regeneration and compressed N_2 for regeneration air dilution and standby purges were supplied to the gas dilution manifold using calibrated rotameters. This supply of N_2 was also used to purge the regulator connected to the compressed gas mixture containing HCl to remove trace levels of moisture before use and completely purge residual HCl after use.

The custom made quartz reactor, which measured 25 mm I.D. x 900 mm long, was configured with a quartz frit positioned 305 mm from the bottom to act as a gas distributor and to keep the sorbent bed in the proper position during testing. A three-zone furnace was used to maintain the reactor at the desired exposure temperature, which was monitored using an Inconel thermocouple inserted through the top of the reactor down into the fluidized sorbent bed. Quartz wool was packed into the bottom of the reactor below the quartz frit to promote mixing of the simulated syngas components and enhance heat transfer. Test gases exited the reactor through the top and over to a glass arm connecting the reactor to a glass condenser and associated impinger. The quartz reactor top and a portion of the glass extension arm were heated to maintain the test gas above the dew point until condensed steam flowed freely down through the condenser for collection in the impinger. A port for directing a slipstream of simulated syngas through Teflon tubing over to the GC analytical system during sorbent sulfidation was located just upstream of the condenser. The impinger was constructed from a 1000-mL round bottom boiling flask equipped with an adaptor at the top that directed the reactor effluent from the condenser down through 450 mL of DI H_2O. A drain was located at the bottom of the impinger. After exiting the impinger, the test gas flowed through a fixed-bed scrubber containing ZnO during the sulfidation step to remove any H_2S prior to venting through the building exhaust system. During regeneration, the 4-way valve located at the scrubber inlet was switched to allow the entire test gas stream exiting the impinger to flow to the O_2 sensor and then on to the building exhaust. The opposite side of the 4-way valve directed dry N_2 through the scrubber. Note that fresh H_2O was added to the impinger during regeneration, which removed SO_2 before the test gas was directed to the O_2 sensor.

Figure 6. Schematic of RTI-3 HCl Tolerance Testing Apparatus



5.2 RTI-3 HCl Tolerance Testing Experimental Procedures

For all test results reported here, a bubbling fluidized bed of nominal 50 g of RTI-3 sorbent with an approximate fluidization height of 1.3 times the resting bed height was sulfided with either 10,000 or15,000 ppmv H_2S at 900°F and regenerated with 6 percent O_2 in N_2 at 1200°F during multiple alternating cycles. The test gas compositions used for sulfidation and regeneration are shown in Table 4. The test gas flow was usually around 0.9 L/min measured at room temperature and ambient pressure, which provided a linear velocity of about 0.25 ft/sec at actual sulfidation conditions. Because of the need to use quartz, glass, and Teflon components to minimize the loss of HCl to system components, all exposures were conducted slightly above atmospheric pressure. Prior to the start of each sulfidation cycle, 450 mL of DI H_2O was added to the glass impinger catch pot to collect any HCl not retained on the RTI-3 sorbent. This impinger solution was recovered after each sulfidation step and a final volume was obtained before analysis by ion chromatography (IC) to determine the chloride ion content.

Table 4. Simulated Syngas and Regeneration Gas Compositions

	Concentration (Volume %)	
Component	**Sulfidation**	**Regeneration**
CO	40.0	-
CO_2	10.0	-
H_2	26.5	-
H_2S	See Note 1	-
HCl	See Note 2	-
Steam	19.0	-
N_2	4.0	94.0
O_2	-	6.0
Note 1: H_2S concentration was either 1.0 % or 1.5 %, depending on the test.		
Note 2: HCl concentration was either 0, 7.5, or 15 ppmv.		

A typical sulfidation/regeneration cycle involved fluidizing the sorbent with a standby flow of N_2 and heating the reactor to 900°F the night before beginning the test. Sulfidation was started by switching from standby N_2 to simulated syngas and starting GC/SCD measurements to monitor for H_2S breakthrough. The sulfidation step was allowed to continue until the H_2S concentration in the reactor effluent reached 100 ppmv, which was the designated concentration level used to stop the sulfidation step and transition the system to regeneration mode. For tests conducted in the absence of HCl, this took about 280 min using simulated syngas containing 10,000 ppmv H_2S and about 165 min for tests using 15,000 ppmv. The test gas was switched to N_2 between sulfidation and regeneration steps to purge the system and allow the operator to safely drain and recharge the impinger catch pot. The regeneration cycle required around 100 min for the reactor effluent O_2 concentration to increase from 0 percent (O_2 consumed to form SO_2) to slightly less than 2 percent. Regeneration was stopped by switching the test gas to N_2 prior to the reactor effluent exceeding 2 percent to minimize sulfate formation on the RTI-3 sorbent material at the high regeneration temperatures.

After multiple cycle tests were completed on each sample of RTI-3 sorbent, the reactor system was dismantled to remove the sorbent and rinse the reactor and glass arm with DI H_2O to recover any residual Cl ion species. The amount of Cl ion retained on the exposed RTI-3 sorbent was determined by sonicating the sorbent in DI H_2O for 60 minutes, filtering the supernatant, and determining the amount of ion present by IC. The rinse solutions were also analyzed for Cl ion content by IC. A portion of the exposed sorbent was also analyzed by x-ray diffraction to confirm the Cl ion digestion and IC analysis results. In addition, an aliquot of the RTI-3 sorbent was digested with Unisolve and the resulting solutions were analyzed by inductively coupled plasma spectroscopy (ICP) to determine the amount of Al and Zn present.

5.3 RTI-3 HCl Tolerance Testing Experimental Results

Three multiple cycle sulfidation/regeneration tests were conducted for this study. The first test consisted of 12 cycles in the absence of HCl to provide a baseline of the desulfurization and regeneration characteristics of this particular formulation of RTI-3. For these 12 cycles, the first 6 were conducted with the test gas containing 10,000 ppmv H_2S and the remaining 6 were conducted with the test gas containing 15,000 ppmv H_2S. The H_2S concentration was increased after the sixth cycle to decrease the time required to load S on the sorbent material to near saturation, which allowed for two sulifidation/regeneration cycles each exposure day. For the second of three multiple cycle tests, the simulated syngas contained 15,000 ppmv H_2S and 15 ppmv HCl. For the third multiple cycle test, the simulated syngas contained 15,000 ppmv H_2S and no HCl for cycles 1-3 and 15,000 ppmv H_2S and 7.5 ppmv HCl in cycles 4 through 13.

A compilation of H_2S breakthrough curves for the baseline test (no HCl present) is shown in Figure 7. This sample was identified as 13900-24A. As expected, the curves clearly indicate that the breakthrough time was longer for cycles 1-6, which were conducted with 10,000 ppmv H_2S, compared to cycles 7-12, which were conducted with 15,000 ppmv. This observation is further illustrated by the data presented in Table 5 that shows the breakthrough time, defined as the elapsed exposure time when the H_2S effluent concentration measured by GC reached 100 ppmv, and the corresponding calculated theoretical total S loading at the experimentally determined breakthrough time. The average total S loading at the breakthrough times for cycles 1-6 was 6.13 wt. % with a standard deviation of 0.21 wt. % and the average S loading for cycles 7-12 was 5.58 wt. % with a standard deviation of 0.30 wt. %, indicating a slight decrease in S capacity at the higher H_2S challenge concentration. Note that the H_2S leak rate was, on average, slightly higher for the 15,000 ppmv H_2S cycles compared to the 10,000 ppmv H_2S cycles. Yet for both exposure conditions, the sulfur leak rate was well below 20 ppmv until the sorbent became saturated and breakthrough commenced.

Figure 7. Compilation of Breakthrough Curves for RTI-3 HCl Tolerance Baseline Testing

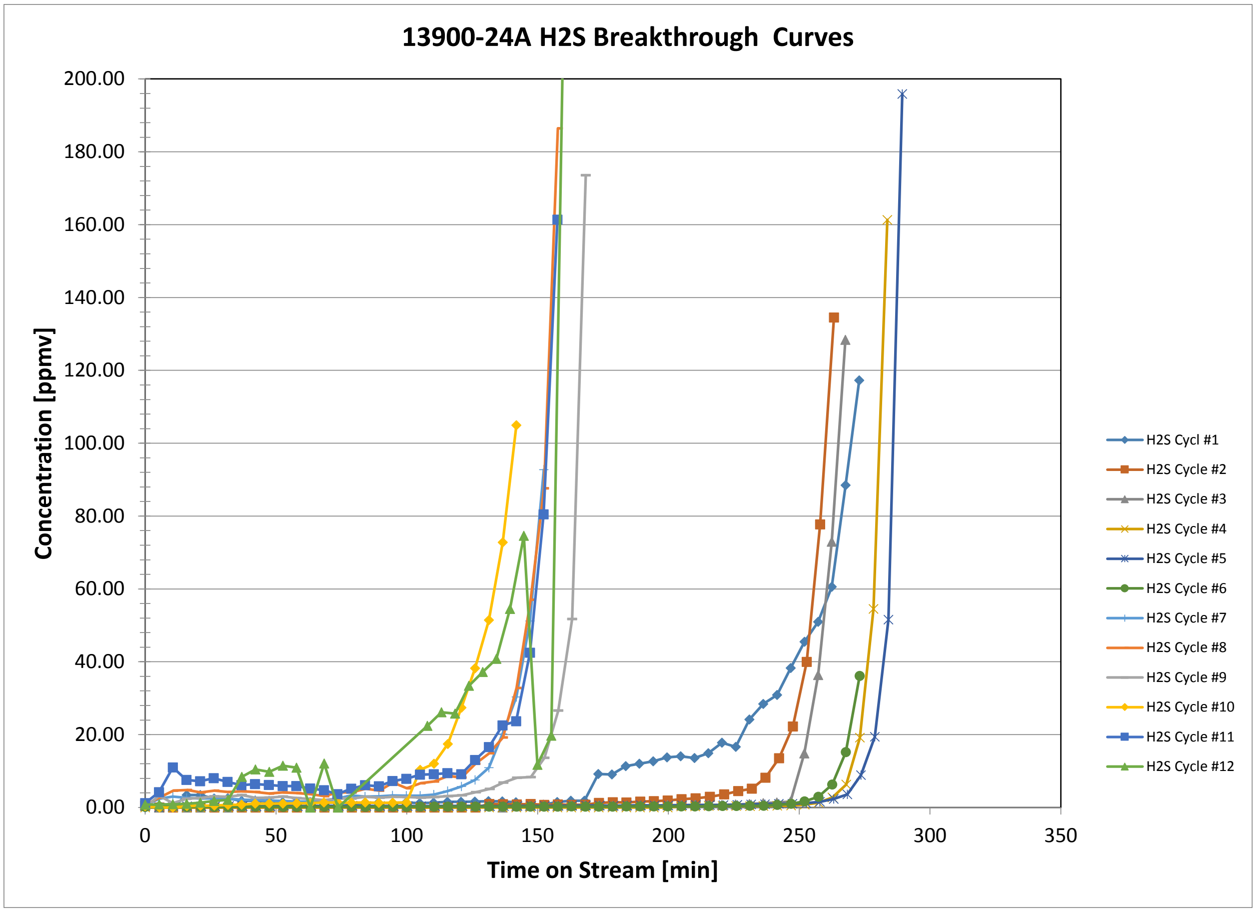


Table 5. Total Sulfur Loadings for Baseline Testing (13900-24A)				
	Feed Concentration (ppmv)			
Cycle	H_2S	HCl	Breakthrough Time (min)[1]	Calculated Total Sulfur Loading (wt. %)
1	10,000	0.00	270	6.08
2	10,000	0.00	260	5.86
3	10,000	0.00	265	5.97
4	10,000	0.00	280	6.31
5	10,000	0.00	285	6.42
6	10,000	0.00	275	6.19
7	15,000	0.00	150	5.48
8	15,000	0.00	155	5.66
9	15,000	0.00	165	6.02

10	15,000	0.00	140	5.11
11	15,000	0.00	150	5.48
12	15,000	0.00	157	5.73
[1] Elapsed exposure time when reactor effluent concentration was ≥100 ppmv H_2S.				

The H_2S breakthrough curves for the second set of sulfidation/regeneration cycles, identified as 13900-40A, are shown in Figure 8. For this set, a fresh batch of RTI-3 was sulfided with 15,000 ppmv H_2S in the presence of 15 ppmv HCl over 10 sulfidation cycles. The experimentally determined breakthrough times at effluent concentrations of 100 ppmv H_2S and associated calculated total S loadings are presented in Table 6. In additions, the distribution of Cl ion across the exposure system components and total Cl ion mass balance calculation are presented in Table 7. These data indicate that there was very little difference in the S capacity for cycles 1-4 of this test with 15 ppmv HCl present (average S capacity was 5.87 with a standard deviation of 0.04 wt. %) compared to cycles 7-12 of the baseline test (average S capacity was 5.58 wt. % with a standard deviation of 0.3 wt. %). There was, however, a noticeable decrease in the total S capacity in cycles 5-10 where the RTI-3 sorbent was continually exposed to 15 ppmv HCl during additional sulfidation steps. The average total S loading decreases from 5.87 wt. % for cycles 1-4 to 4.69 (standard deviation of 0.36 wt. %) for cycles 5-10 with a sharp decrease occurring after the fourth cycle. It appears as though the presence of HCl decreased the total S loadings over multiple sulfidation cycles but the decrease was not immediate and occurred only after Cl ion accumulated on the sorbent over time. Mechanistic reasons for the decrease in sulfur loadings are not known at this time but analysis of the exposed sorbent at the end of cycle 10 indicated that 351 ppmw Cl ion had accumulated on the sorbent, which clearly indicated that there was some type of interaction between the Cl ion and one or more components of the sorbent. However, the detected concentration seemed relatively low, especially considering that the Cl ion concentration detected on the baseline (no HCl) after 12 sulfidation cycles was 101 ppmw. But if the adsorbed ion is predominantly located on the RTI-3 surface and that in some way inhibits formation of ZnS during sulfidation, then the noted changes are certainly feasible. Also note that this interaction appears to be rate limited at these particular exposure condition because the Cl ion distribution shown in Table 7 indicates that only 41.3 percent of the feed was retained on the exposed sorbent. Furthermore. analysis results from the impinger solutions collected during each individual sulfidation indicates that the rate of Cl ion uptake on the sorbent is fairly stable through the first four cycles but starts to declines for cycles 5-10. Although the rate of uptake declined during these cycles, there is still evidence that Cl ion continued to accumulate on the sorbent during the last cycle based on the impinger solution analysis results This observation indicates that the RTI-3 sorbent was not fully saturated with Cl ion after the last sulfidation step and the decrease in S loadings may have continued, but probably at a much slower rate. To see if there was a correlation between the decrease in total S capacity on this particular formulation of RTI-3 and HCl challenge concentration, a third sulfidation/regeneration cycle test was conducted with a HCl concentration of 7.5 ppmv in the simulated syngas.

Figure 8. Breakthrough Curves for RTI-3 HCl Tolerance Testing Conducted with 15 ppmv HCl

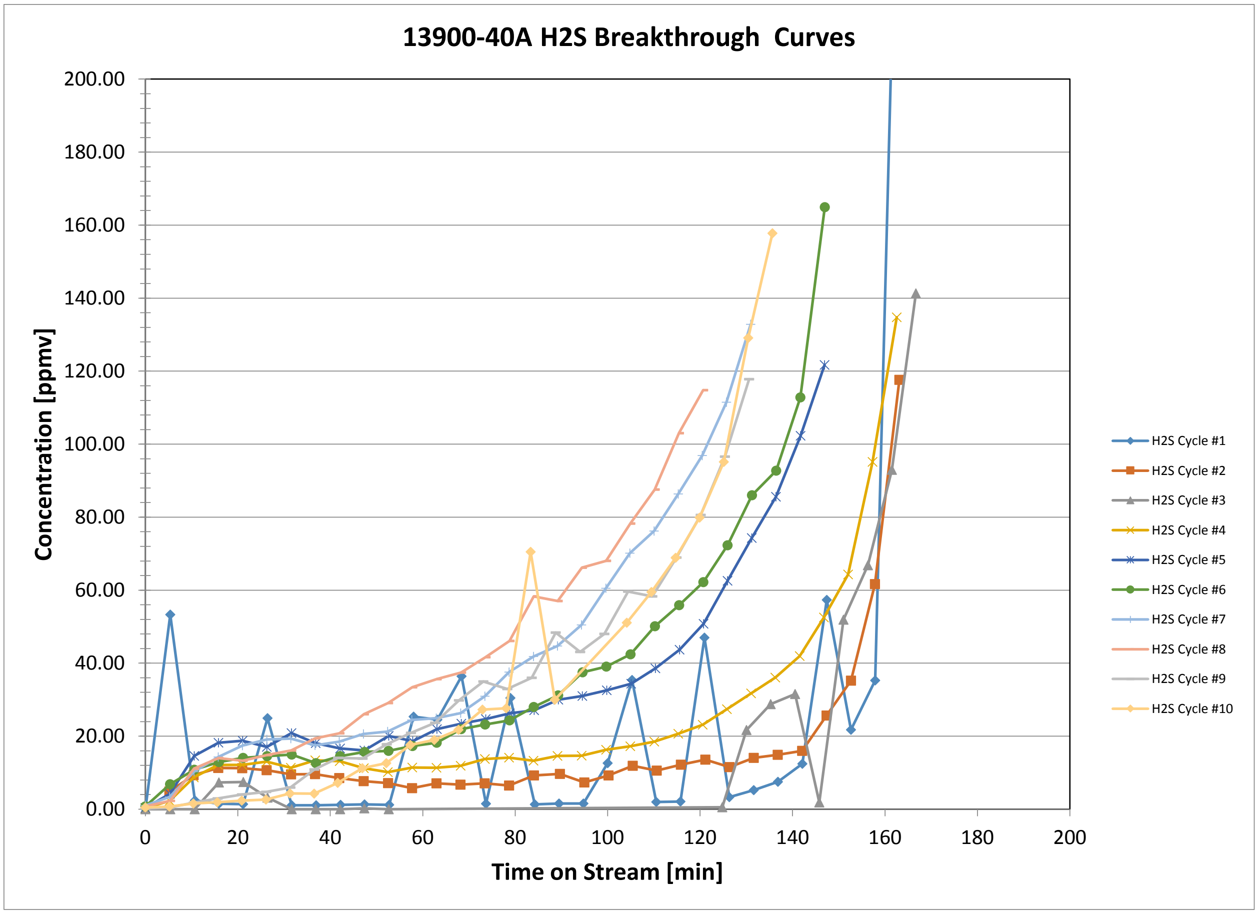


Table 6. Total Sulfur Loadings for Cycles Conducted with 15 ppmv HCl (13900-40A)				
	Feed Concentration (ppmv)			
Cycle	**H_2S**	**HCl**	**Breakthrough Time (min)[1]**	**Calculated Total Sulfur Loading (wt. %)**
1	15,000	15.0	160	5.85
2	15,000	15.0	160	5.85
3	15,000	15.0	162	5.93

4	15,000	15.0	160	5.85
5	15,000	15.0	140	5.12
6	15,000	15.0	140	5.12
7	15,000	15.0	125	4.57
8	15,000	15.0	115	4.21
9	15,000	15.0	125	4.57
10	15,000	15.0	125	4.57
[1] Elapsed exposure time when reactor effluent concentration was ≥100 ppmv H_2S.				

Table 7. Cl Ion Distribution for Cycles Conducted with 15 ppmv HCl (13900-40A)		
Component	**Amount Detected (µg)**	**% Feed**
Exposed Sorbent	12,065	41.3
Glassware Rinses	1,325	4.4
Impinger Solution	7,107	24.6
Totals	20,497	70.3

Figure 9 shows the H_2S breakthrough curves for the third and final set of sulfidation/regeneration cycles identified as 13900-52A. A fresh batch of RTI-3 was loaded in the reactor and sulfided three times in the absence of HCl followed by 10 sulfidation cycles in the presence of 7.5 ppmv HCL. Breakthrough times at H_2S effluent concentrations of 100 ppmv and corresponding calculated theoretical total S loadings after each sulfidation cycle are presented in Table 8 and the total Cl ion distribution and mass balance calculation for this exposure are presented in Table 9. For the first three sulfidation cycles conducted in the absence of HCl, the average S loading was 5.82 with a standard deviation of 0.0 wt.%. These values agreed well with the average loading of 5.58 wt. % (standard deviation of 0.3 wt. %) for baseline testing Cycles 7-12, which were generated under the same exposure conditions. The total S loadings declined slightly for Cycles 4-13 conducted in the presence of 7.5 ppmv HCl with an average loading of 5.50 wt. % and standard deviation of 0.36 wt. %, but it was not until the end of sulfidation cycle 12 that a noticeable reduction in capacity was observed. At that point, the theoretical Cl ion loading on the sorbent was equivalent to the theoretical loading after Cycle 4 of the 15 ppmv exposure, which is where the significant drop in total S loading for that test was observed. The actual Cl ion concentration detected on the exposed RTI-3 after the 7.5 ppmv test was 251 ppmv, which agreed well with the amount detected for the 15 ppmv test when compensated for the lower HCl concentration and exposure time. Based on these findings, there appears to be a strong correlation between HCl contaminant concentrations, time on-line, and decrease in total S loadings. Furthermore, a decrease in the total S loadings can be expected after as little as 250 ppm of Cl ion has accumulated on the sorbent material.

Figure 9. Breakthrough Curves for RTI-3 HCl Tolerance Testing Conducted in the Absence of HCl and with 7.5 ppmv HCl

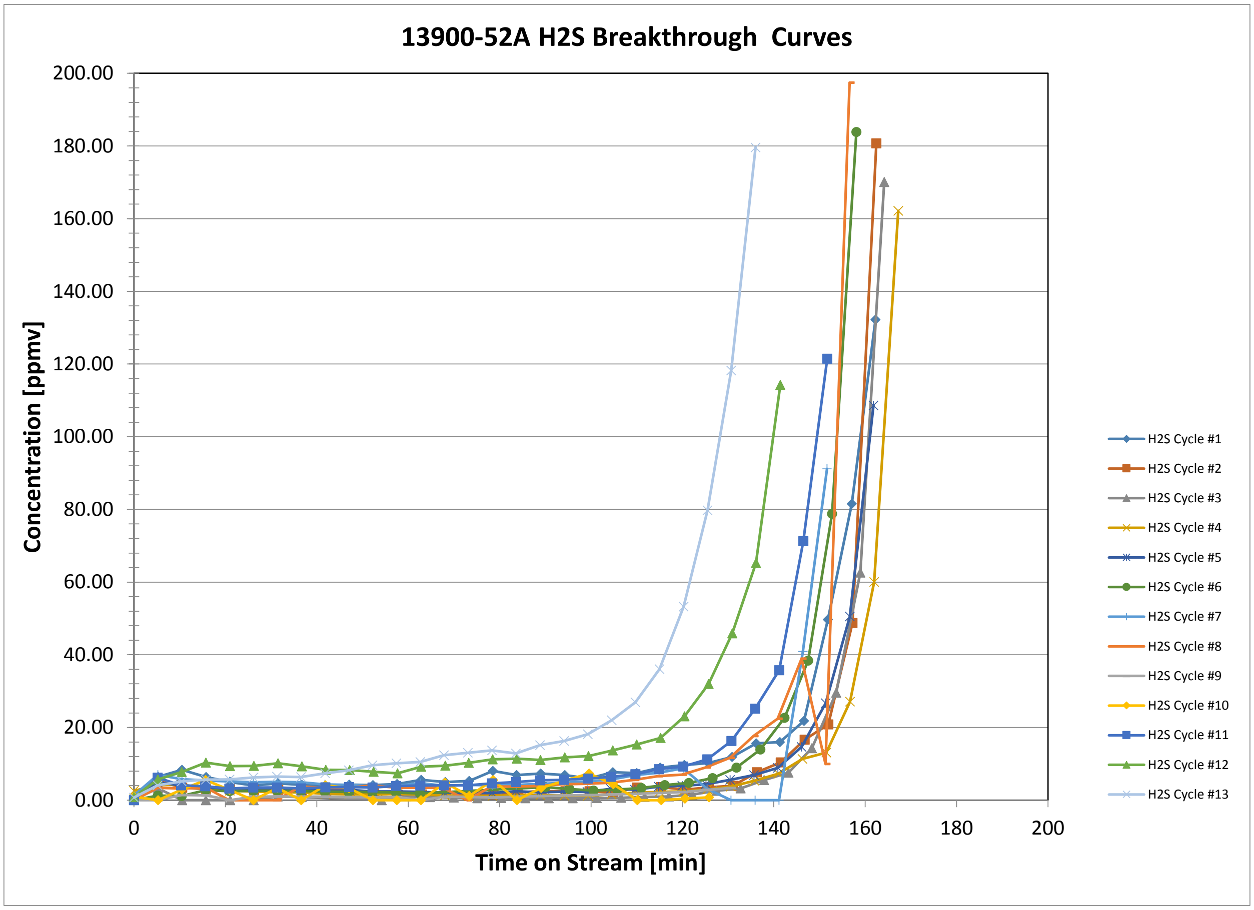


Table 8. Total Sulfur Loadings for Cycles Conducted in the Absence of HCl and with 7.5 ppmv HCl (13900-52A)				
	Feed Concentration (ppmv)			
Cycle	H_2S	HCl	Breakthrough Time (min)[1]	Calculated Total Sulfur Loading (wt. %)
1	15,000	0.00	160	5.82
2	15,000	0.00	160	5.82
3	15,000	0.00	160	5.82
4	15,000	7.5	165	6.00

5	15,000	7.5	160	5.82
6	15,000	7.5	155	5.64
7	15,000	7.5	152	5.53
8	15,000	7.5	150	5.45
9	15,000	7.5	155	5.64
10	15,000	7.5	155	5.64
11	15,000	7.5	150	5.45
12	15,000	7.5	140	5.09
13	15,000	7.5	130	4.73
[1] Elapsed exposure time when reactor effluent concentration was ≥100 ppmv H_2S.				

Table 9. Cl Ion Distribution for Cycles Conducted with 7.5 ppmv HCl (13900-52A)		
Component	**Amount Detected (µg)**	**% Feed**
Exposed Sorbent	7,554	49.1
Glassware Rinses	771	5.0
Impinger Solution	2,904	18.9
Totals	11,229	73.0

One reason for the reduction in S loadings on RTI-3 observed in the presence of low levels of HCl may be attributed to the loss of Zn during the sulfidation and regeneration cycles. Gupta (2000) provided a thorough discussion of the complex interaction between ZnO, HCl, and any alkali salts present on ZnO-based sorbents and encountered some Zn losses from zinc titanate sorbents at exposure temperatures much higher than those studied here. For this study, however, the loss of Zn does not appear to be the reason for lower total S loadings based on the results from compositional analysis of exposed RTI-3 shown in Table 10. This table shows the concentration of Al and Zn detected in aliquots of RTI-3 after multiple cycle sulfidation and regenerations for the baseline, 15 ppmv and 7.5 ppmv tests. The data indicate that there was very little change in Al and Zn concentrations that could be attributed to the presence of HCl in the simulated syngas. Because the compositional analysis results were not available until the completion of each multiple cycle test, a decision was made to analyze the impinger solutions after each sulfidation step to not only determine the Cl ion content but to also determine the Al and Zn content. The amounts of Al, Zn, and Cl retained in the impinger solution during sulfidation for the baseline, 15 ppmv, and 7.5 ppmv HCl tests are presented in Table 11. The amount of Zn detected in any one impinger solution for the HCl tests was much greater than that the loss determined by compositional analysis of the exposed material. For this reason, it was concluded that the source of Zn detected in the impinger solutions was not from vaporization from the exposed sorbent but most likely from unintentional carryover of sorbent fines from the reactor during testing.

Table 10. Compositional Analysis of Exposed RTI-3 Sorbent

	Concentration (wt. %)	
Test	**Al**	**Zn**
Baseline	30.3	59.7
15 ppmv HCl	28.8	56.5
7.5 ppmv HCl	29.0	56.9

Table 11. Impinger Solution Analysis Results for Baseline, 15, and 7.5 ppmv HCl Exposure

		Amount Detected (µg)		
Test	**Cycle**	**Al**	**Zn**	**Cl**
Baseline	10	115	162	22.0
15 ppmv HCl	1	16.0	369	178
	2	10.0	435	242
	3	12.0	389	434
	4	10.0	236	381
	5	8.00	145	715
	6	7.00	130	1100
	7	6.00	113	880
	8	7.00	148	1250
	9	7.00	126	307
	10	6.00	103	1630
7.5 ppmv HCl	1[1]	8.00	121	31.0
	2[1]	8.00	246	19.0
	3[1]	8.00	283	24.0
	4	8.00	131	48.0
	5	0.00	260	83.0
	6	0.00	134	134

	7	0.00	142	211
	8	0.00	206	267
	9	0.00	76.0	231
	10	0.00	89.0	555
	11	NA	NA	212
	12	NA	NA	525
	13	NA	NA	565
NA = Not analyzed.				
[1] No HCl present in simulated syngas.				

6.0 Design Data for Warm HCl Removal System

As mentioned in Section 5.4, HCl is one of many contaminants that may be present in gasification-derived syngas and its expected concentration at the point of gas cleaning depends on the concentration of chloride species in the feedstock, the gasifier type, and the extent of gas quenching prior to the cleanup step. Because of the corrosive effects of chloride species contained in syngas, control of this contaminant is imperative to protect heat exchangers, gas turbine components and fuel cell components located downstream of the gasifier. To use coal feedstock as an example, a data survey of four gasifier types indicated that the expected concentrations of HCl in the syngas could range between 170 and 830 ppmv. (Bakker 1998). Long-term exposures of certain metal alloys at operating gasifiers have shown accelerated corrosion rates via chloride scale spallation when HCl is present along with chloride containing deposits near the metal surface. (Bakker 2004) Not only is corrosion of metal components a concern when HCl is present in syngas but this contaminant is also toxic, which raises concerns with plant emissions after gas utilization. Because of this concern, the Environmental Protection Agency (EPA) has established guidelines that stipulate that no more than 1.9 ppmv of chloride containing species can be present in syngas prior to its utilization. (77FR 9304)

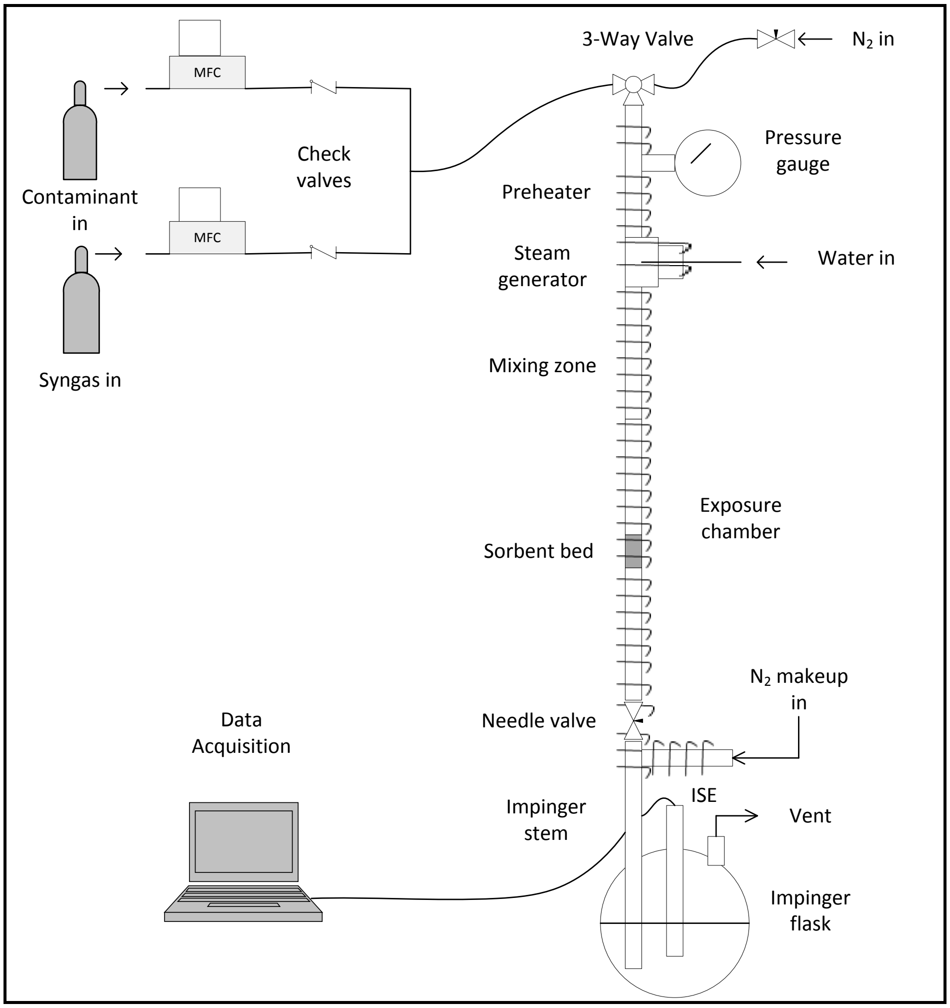
Unlike vapor phase elemental mercury, which is a relatively unreactive species in the syngas reducing environment at the targeted warm gas cleaning temperature of >392°F, vapor phase HCl is a reactive species that can readily form ionic bonds with alkali and alkaline earth metals and transition metals at elevated temperatures. For this reason, several options are available for HCl removal from syngas at warm gas cleaning conditions including solid sorbent materials containing Ca (Lee 2012), Mn (Tseng 2012), and Na (Krishnan 1999, Howard 2013). Strategies for HCl removal at warm syngas cleaning conditions based on the use of naturally occurring and synthetic formulations of Na-based materials appear to be the most advanced option to date. Results from bench and pilot-scale testing performed by SRI International and RTI have shown that nahcolite ($NaHCO_3$) can effectively remove HCl from coal-derived syngas and Pacific Northwest National Laboratory has shown that this material can be used to remove HCl from syngas derived from biomass.

Although the bench and pilot-scale testing of Na-based solid sorbent materials performed by SRI and RTI showed the feasibility of this approach to removing HCl from syngas at warm gas cleaning conditions, additional parametric testing is needed to facilitate the design of a commercial scale control system. To meet this need, RTI assembled a small-scale test system that could quickly be heated and cooled to expose aliquots of Trona T-50, a 1:1 mixture of $NaHCO_3$ and Na_2CO_3, to HCl contained in simulated syngas at different temperatures and pressures. Retention characteristics of HCl on the Trona T50 material were studied under various exposure conditions by monitoring the chloride content at the reactor outlet. The sections that follow describe the experimental procedures and results from the parametric testing of Trona T50 material for the removal of HCl from simulated syngas.

6.1 Warm HCl Removal Experimental Apparatus

A schematic of the warm HCl removal test apparatus is shown in Figure 10. Main components of the system included a gas blending manifold, steam generator, exposure chamber, needle valve, glass impinger, ion selective electrode (ISE), and data acquisition system. The gas manifold was equipped with one electronic mass flow controllers for metering the flow of simulated syngas components (CO, H_2, and CO_2) supplied from a compressed gas cylinder and another electronic mass flow controller to meter the flow of contaminant from a separate compressed gas mixture. Steam was supplied to the system by vaporizing a flow of DI H_2O supplied by a liquid chromatography pump to a stainless steel tube packed with quartz wool and maintained at constant temperature by a heat tape. The exposure chamber, maintained at the desired temperature by a separate heat tape, was constructed from 316 stainless steel tubing and measured 0.25 in O.D. x 0.153 in I.D. x 6 in long. A quartz wool plug was used to hold the fixed bed of candidate sorbent at the correct position within the exposure chamber during each exposure. The needle valve positioned downstream of the exposure chamber was used to restrict the flow of test gas through the system, which caused back pressure to build in the system allowing for exposures to be conducted at elevated pressures. Test gas effluent from the needle valve was mixed with heated makeup N_2 and allowed to vent to near atmospheric pressure before being impinged through 200 mL of water contained in a 500 mL three-neck round-bottom flask where the contaminant was retained. Changes in chloride ion content in the water impinger solution during a test were measured using a Hach (Loveland, CO) Model ISECL 18103 chloride ion electrode and the signal was processed using a Hack HQ40d portable meter. The processed signal was acquired and stored using Hach HQ40d PC Application software.

Figure 10. Contaminant Removal Test Apparatus



6.2 Warm HCl Removal Experimental Procedures

The Trona T50 material used for this study was tested as received with no pretreatment prior to the start of each exposure. The average particle size of the T50 material was 250 to 300 µm. Prior to the start of each exposure, nominal 0.15 g of material was loaded in the exposure chamber, which resulted in sorbent bed length of around 0.5 in (L/D = 3.3). The chamber was purged with 100 mL/min dry N_2 at room temperature for 30 min so that each exposure began under inert conditions. After purging with dry N_2, the three-way valve was switched to supply test gas from the gas manifold and the needle valve downstream of the exposure chamber was closed to build system pressure to the desired set point. The exposure chamber was heated to the desired test temperature during pressurization. Adjustments were made to the needle valve to maintain the desired pressure and flow rate once the designated temperature and pressure set points were achieved. Water flow to the steam generator, impinger sampling of the exposure chamber effluent, and data acquisition of the chloride ion measurements in the impinger solution were also started at the time. Total flow through the system was 100 mL/min measured at ambient conditions, which resulted in the Trona T50 material being exposed at a gas hourly space velocity (GHSV) of nominal 40,000 hr^{-1} to the test gas shown in Table 12. Chloride ISE measurements were made and recorded continuously every 5 min. For each exposure condition tested, fresh aliquots of the Trona T50 were exposed to the test gas until the first order derivative of the retention isotherm over a 1 hour period indicated that the material was at, or near, full saturation. After testing, the exposed sorbent was extracted with 100 ml of DI H_2O and the resulting solution along with the H_2O impinger solution were analyzed for chloride content using ISE and IC to determine total chloride mass balance.

Table 12. Warm HCl Removal Simulated Clean Syngas Composition

Source	Component	Source Concentration (%)	Flow Rate (mL/min)	Blended Concentration (%)
Syngas mix	CO	48.3	40	19.3
	CO_2	14.9	-	6.0
	H_2	36.8	-	14.7
Contaminant mix	N_2	100	50	50
	HCl	0.0388	-	0.0194
Steam	H_2O	100	10	10
		Total =	100	100

6.3 Warm HCl Removal Experimental Results

Prior to the start of material exposures, quality control (QC) checks were performed on the system to assess losses of vapor phase HCl to system components. The first check involved collecting impinger samples of a test gas stream containing 194 ppmv HCl in dry N_2 at the outlet of a blank exposure chamber maintained at 392° C and 40 psig for 90 min without the addition of the N_2 makeup flow. The plot of measured chloride concentration and theoretical expected concentrations based on the certified HCl concentration in the compressed gas mixture over time is shown in Figure 11. The good agreement between measured and expected chloride ion concentrations indicated very little loss of HCl to the exposure system components. Steam was added at 20 volume percent and a second blank reactor test was generated with 194 ppmv HCl in N_2. Poor agreement between expected and measured chloride ion was observed and the erratic and nonlinear response of the measured concentration indicated intermittent loss of the ion prior to the impinger flask. Further troubleshooting indicated that condensation of the test gas was occurring in the impinger stem, which acted as a chloride sink because of the high solubility of the HCl vapor in water. To circumvent this problem, the steam concentration was reduced to 10 volume percent and a heated makeup flow of 100 mL/min of N_2 was added just after the needle valve to keep the test gas temperature above the dew point until it reached the impinger solution. The second blank reactor test was repeated with the additional makeup flow by initially collecting impinger samples in dry N_2 for 30 min and then 10 volume percent steam was added for the next 30 min. Steam generation was halted while increasing the system pressure to 50 psig during the next 60 min and then it was started again at 10 volume percent at 120 min. Allowed the test to continue at steady state conditions for another 60 min. The plot of theoretical expected and measured chloride ion concentrations over time for the second blank reactor test is shown in Table 12. Good agreement between the expected and measured chloride ion concentrations for the first 30 min indicated that the extra makeup flow added to the test gas did not result in a reduction of chloride ion retention in the aqueous impinger solution and this heated makeup flow kept the test gas temperature above the dew point with 10 percent steam present between 30 and 60 min. After the system pressure was increase to 50 psig and steam was reintroduced to the test gas, it appears as though the measured concentration was slightly higher than expected between 120 and 180 min but the step change was linear over this period. This was an important finding because the reliance of the ISE measurement for online measurements was based on reliable determinations of incremental changes in concentrations and not so much on an absolute accuracy of the measurement. Results from these QC checks provided confidence that this exposure system could be used to expose materials to gas streams containing known amounts of HCl and that the impinger collection system and associated ISE could reliably measure changes in chloride ion concentration in the exposure chamber effluent.

Figure 11. Measured and Theoretical Expected Chloride Ion Concentrations for a Blank Reactor Test in Dry N_2

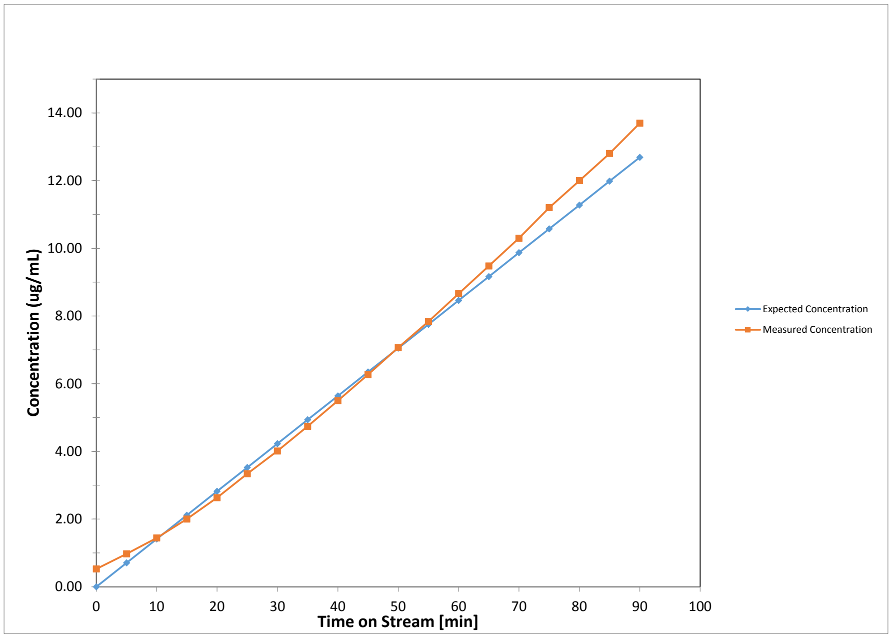
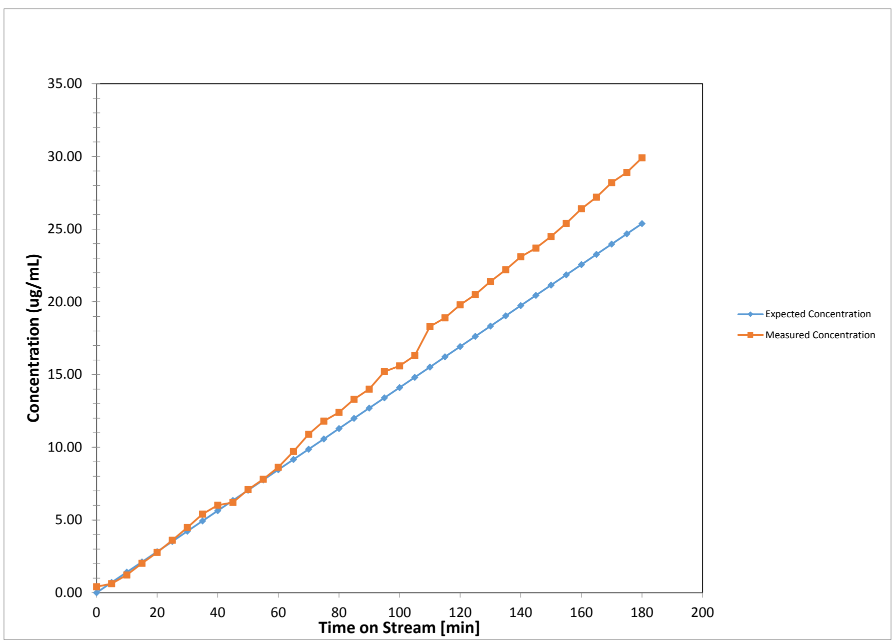


Figure 12. Measured and Theoretical Expected Chloride Ion Concentrations for a Blank Reactor Test in Wet N_2



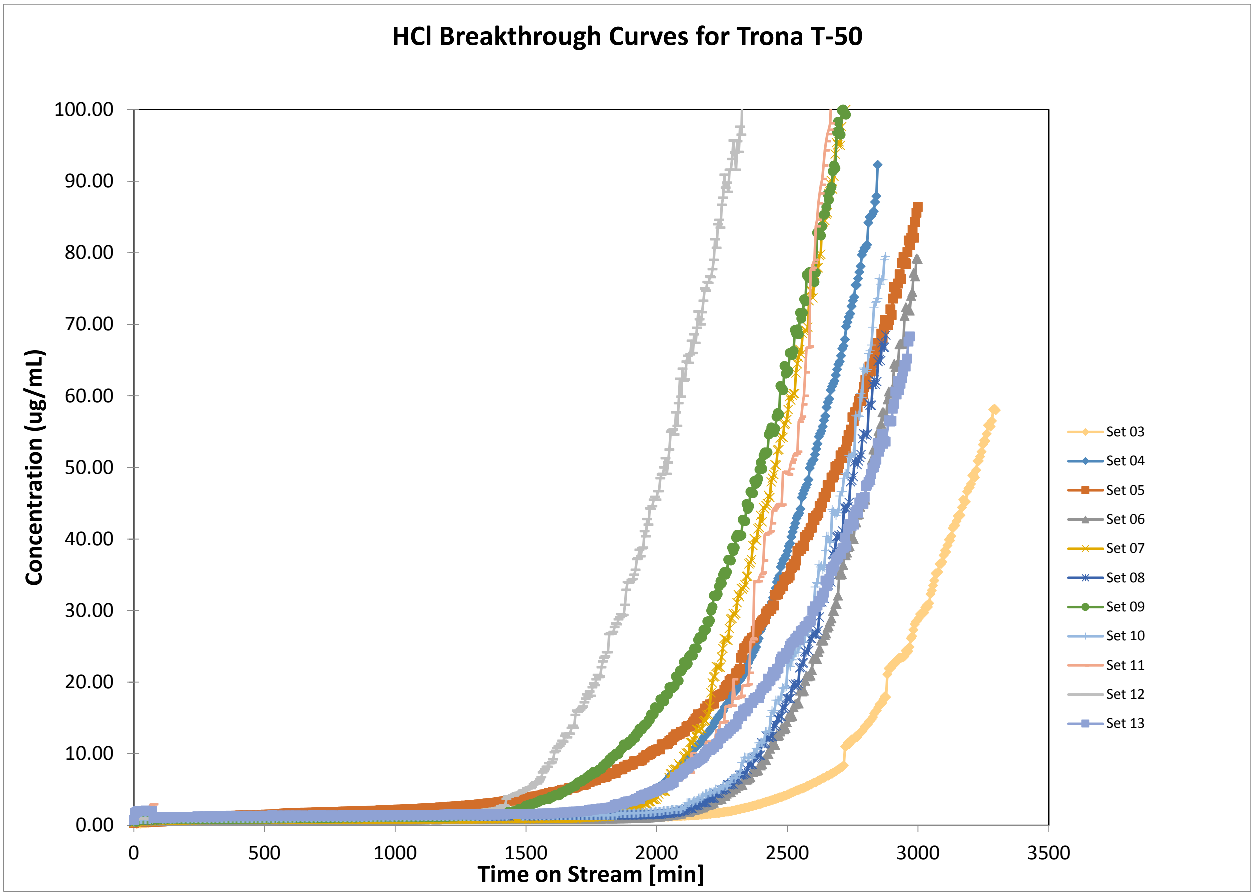
Once the warm HCl removal system QC checks were completed, material exposures were started. A summary of the test conditions, and results of chloride ion capacities and calculated mass balances are shown in Table 13 and a compilation of retention isotherms, which were plots of the consecutive measured chloride ion concentrations in the impinger flask versus time on stream, are presented in Figure 13. As can be seen from the test conditions noted in Table 13, the Trona T50 material was exposed to HCl in the presence of dry nitrogen in Set #3 and the test gas for the remaining exposures was clean syngas with the exception of Set 15. For Set 15, the test gas was dirty syngas, which contained similar concentrations of H_2, CO, CO_2, N_2 HCl and steam but also contained 5000 ppmv H_2S. For the warm HCl removal testing, the exposure temperatures ranged from 392 to 842°F and the exposure pressures ranged from 50 to 150 psig. Capacity values reported in Table 13 represent the theoretical HCl loadings on a known amount of Trona T50 material at the exposure time that corresponds to the detection of 10 percent breakthrough in the exposure chamber effluent. This breakthrough time was experimentally determined by monitoring the step change in chloride ion concentration in the impinger solution determined by ISE over a set time period. The targeted step change, or first order derivative, represented one-tenth of the change in chloride concentration expected if no sorbent was present in the exposure chamber. A one hour step change period was used, as opposed to the individual 5 min sampling intervals, to minimize the influence of measurement noise on the breakthrough time. Overall mass balances were calculated by comparing the total amount of chloride ion detected in the exposed sample extracts to the total theoretical amount of chloride ion delivered to the system after compensating for the breakthrough amount detected by IC in the impinger solution.

Table 13. Summary of Warm HCl Removal Conditions and Test Results

Set #	Temperature (°F)	Test Gas	Pressure (psig)	Capacity (wt. %)[1]	Mass Balance (% Recovery)
3	392	Nitrogen	50	40.7	35.3
4	392	Clean syngas	100	39.6	66.2
5	482	Clean syngas	100	38.9	69.0
6	572	Clean syngas	100	38.3	69.6
7	572	Clean syngas	100	34.4	79.8
8	572	Clean syngas	100	37.2	77.2
9	662	Clean syngas	100	29.0	89.7
10	752	Clean syngas	100	33.8	101
11	842	Clean syngas	100	36.5	Sample Lost
12	572	Clean syngas	50	27.5	102

13	572	Clean syngas	150	31.0	68.9
15	572	Dirty syngas[1]	100	NC	58.7
NC = Not calculated. The presence of H_2S interfered with the ISE chloride measurement. [1] HCl capacity defined at 10 percent breakthrough based on ISE measurements.					

Figure 13. Warm HCl Removal Retention Isotherms for Trona T50



Capacity values for the exposures conducted in clean syngas presented in Table 13 ranged from 27.5 to 39.5 weight percent. The capacity value for the exposure conducted in dry nitrogen was slightly higher at 40.5 weight percent and the value for the exposure conducted in dirty syngas was not calculated because the presence of H_2S retained in the water impinger solutions interfered with the chloride measurements determined by ISE. Overall, it appears as though the Trona T50 material had a significant capacity for HCl retention for all conditions tested. The average capacity value for all exposures conducted in clean syngas (Sets 4-13) was 34.6 weight percent with a standard deviation of 4.3 weight percent. To ascertain the amount of spread in the calculated capacities that could be attributed to experimental precision, triplicate exposures of the Trona T50 were completed in Sets 6-8 using the same exposure conditions. Capacity values for this triplicate exposure averaged 36.6 weight percent with a standard deviation of 2.0 weight percent, which was not much less than the 4.3 weight percent standard deviation value obtained for all exposures. The lowest calculated capacity value of 27.5 weight percent was obtained in Set 12 conducted at an exposure temperature of 572° F and a pressure of 50 psig and the next lowest capacity value of 29.0 weight percent was obtained in Set 9 conducted at 662° F and 100 psig. It appears as though these two values are statistically different at the 95 percent confidence interval if one was to assume that there should be no differences in calculated capacities across the pressure and temperature parameters studied. All other experimentally determined capacities do not appear to be a significantly different at the 95 percent confidence interval. When compared to capacity values determined for Set 8 and Set 10 conducted at 100 psig and 572 and 752°F, respectively, the capacity value for Set 9 was expected to be higher than 29.0 weight percent and for this reason was considered to be suspect. If this was the case then it appears as though the only parameter tested that produced a calculated capacity value that was significantly different from all parameters tested was Set 12, which was conducted at the lowest pressure tested (50 psig). Although the capacity value of 27.5 obtained for Set 12 may be lower compared to the other values, from a practical standpoint it still indicates that the Trona T50 material has a significant capacity for HCl uptake at 572°F and 50 psig.

As an ongoing accuracy check, mass balance calculation were performed for each exposure. Results from these mass balance calculations shown in Table 13 for the exposures conducted in clean syngas ranged from 66.2 percent recovery for Set 3 to 102 percent recovery for Set 12. There was no apparent reason for the lower mass balance result of 35.3 percent recovery obtained in Set 2, which was conducted in N_2 containing 10 volume percent steam. Note also that even though the chloride ion concentration in the exposure chamber effluent for Set 15 conducted in dirty syngas was not available due to the accumulation of H_2S in the impinger solution, the experimentally determined mass balance of 58.7 percent recovery was not much less than those obtained when testing in clean syngas. For this reason, it is believed that the Trona T50 material has a significant capacity to retain HCl when exposed in the presence of simulated syngas containing nominal 5000 ppmv H_2S at 572°F and 100 psig.

Overall conclusions from the above-mentioned warm HCl removal parametric testing results indicate that there was basically very little difference in the chloride capacity of the Na-based material, Trona T50, between exposure temperatures of 482 to 842°F and pressures between 100 and 150 psig when exposed in the presence of clean syngas. The results are consistent with those observed by SRI and RTI for fixed bed testing of a similar Na-based sorbent, nahcolite. SRI determined that there was no significant difference in the HCl uptake on a pelletized form of nahcolite containing 10 percent binder when exposed between 752 and 932°F at atmospheric pressure in the presence of clean simulated syngas (no H_2S) of similar composition to that reported here and the same was observed for a pelletized nahcolite containing 5 percent binder when exposed between 752 and 1112°F in the presence of clean syngas containing 25 percent steam. A decrease in HCl capacity was observed when exposed in the presence of simulated syngas containing 3000 ppmv H_2S, but the temperature effect between 752 and 1112°F with the H_2S present was small. A separate exposure under similar conditions but at 150 psig instead of atmospheric pressure indicated the elevated pressure had only a small effect on HCl retention.

The addition of several new experimentally determined HCl capacities under various exposure conditions when combined with the feasibility data generated previously by SRI and RTI should provide a sound basis for modeling and design of a commercial scale warm HCl removal system. Although actual parametric boundaries for operation such as exposure temperature and pressure extremes that would lead to significant reduction of HCl capacity were not experimentally determined here, the data do suggest that Na-based sorbents can be effective at removing HCl under a wide range of operating conditions within RTI's targeted warm syngas cleanup package.

7.0 Design Data for Warm NH_3 Removal System

In addition to the trace-level and HCl contaminants mentioned earlier in this section, the presence of NH_3 in syngas can be problematic, especially when the gas is utilized for the production of value added chemicals such as in FT synthesis and methanol production and its presence can also lead to NOx production that triggers environmental concerns when the gas is burned in a turbine for power generation. Similar to other contaminants, the concentration of NH_3 expected in syngas depends on the properties of the feedstock, type of gasifier used to produce the syngas, and much like with HCl, the amount of gas quenching that occurs prior to the point of gas cleaning. Nitrogen containing compounds in the syngas feedstock are the primary sources of NH_3 in syngas and a survey of eight U.S. coals used in NETL's Quality Guidelines for Energy System Studies indicated that the nitrogen content ranged from 0.89 weight percent for a subbituminous Powder River Basin coal to 1.50 weight percent for a Pittsburg No. 8 bituminous coal. (NETL 2012). Under the reducing conditions of syngas, a majority of the nitrogen in coal is converted to NH_3 and HCN and the concentrations of NH_3 in syngas can range from 100 to 1000 ppmv for certain coal feedstocks. (Hasegawa 2010). At these concentrations, NH_3 will have a detrimental effect on Co-based FT catalysts used for C5+ hydrocarbon synthesis, which preferably should be fed with synthesis gas containing less than 100 ppbv total of NH_3 and HCN to maximize the catalyst half-life. (WIPO Patent WO 2005/071044) For these reasons, removing NH_3 to levels that decrease catalyst deactivation rates and reduce NOx emissions prior to syngas utilization is an important component of RTI's ultraclean warm syngas cleanup technology package.

Development of control technologies for NH_3 in syngas have taken a parallel path to that for HCl in that the most advanced technical approach, outside of physical removal during gas quenching, has focused on the use of gas-phase interactions with solid sorbent materials at temperatures above 400°F and pressures greater than 600 psig. As with the development of HCl control technologies, SRI and RTI, through bench and pilot-scale testing, have investigated several options for the removal of NH_3 from syngas. (Turk 2008 and Turk 2012) Based on this work, a Type Y zeolite, CBV 712 (Zeolyst Corporation, Conshohocken, PA), was identified as the leading candidate sorbent for NH_3 removal. Although this material had a relatively low NH_3 adsorption capacity of 2-4 x 10^{-3} g NH_3/g CBV 712 between 392 and 446°F, testing indicated that the material was easily regenerated at 752°F and multiple adsorption and desorption cycles in the presence of 50 percent steam did not change the sorbent performance. Pilot-scale testing of the NH_3 removal process was attempted during RTI's WDP testing campaign at Eastman but the results of adsorption and regeneration were inconclusive because of water management problems in the analytical instrumentation.

Major portions of the development work performed by SRI were devoted to identifying appropriate candidate sorbents for the removal of NH_3 from syngas at temperatures above 392°F and pressures above 300 psig and less effort was directed toward parametric testing that could be used to optimize the removal process. Deployment of an industrial NH_3 removal process will require additional parametric testing to guide the design and construction of a commercial-scale system. To meet this requirement, RTI converted the small-scale exposure system described earlier in Section 5.5.1 to expose aliquots of CBV 712 to NH_3 to determine changes in material capacities, if any, at different exposure temperatures and pressures. The sections that follow describe the test conditions and results obtained from this parametric testing.

7.1 Warm NH_3 Removal Experimental Apparatus

The CBV 712 material was exposed to NH_3 test gas streams using the same test apparatus that was used for warm HCl removal testing. A schematic of the apparatus is shown in Figure 10 and its components are described in detail in Section 5.5.1. NH_3 was supplied by a compressed gas cylinder containing NH_3 in N_2 and, when diluted in clean syngas, resulted in a test gas with a composition shown in Table 14. Note also that the impinger solution was 200 mL of DI H_2O acidified with concentrated HCl to pH = 3 instead of DI H_2O, which was used for collection of HCl. Changes in ammonium ion content in the acidified water impinger solution during a test were measured using a Hach Model ISENH4 18103 ammonium ion selective electrode. The signal was processed and values stored using the same instrumental set up that was used for the warm HCl removal testing.

Table 14. Warm NH_3 Removal Simulated Clean Syngas Composition

Source	Component	Source Concentration (%)	Flow Rate (mL/min)	Blended Concentration (%)
Syngas mix	CO	48.3	40	19.3
	CO_2	14.9	-	6.0
	H_2	36.8	-	14.7
Contaminant mix	N_2	100	50	50
	NH_3	0.00475	-	0.00238
Steam	H_2O	100	10	10
		Total =	100	100

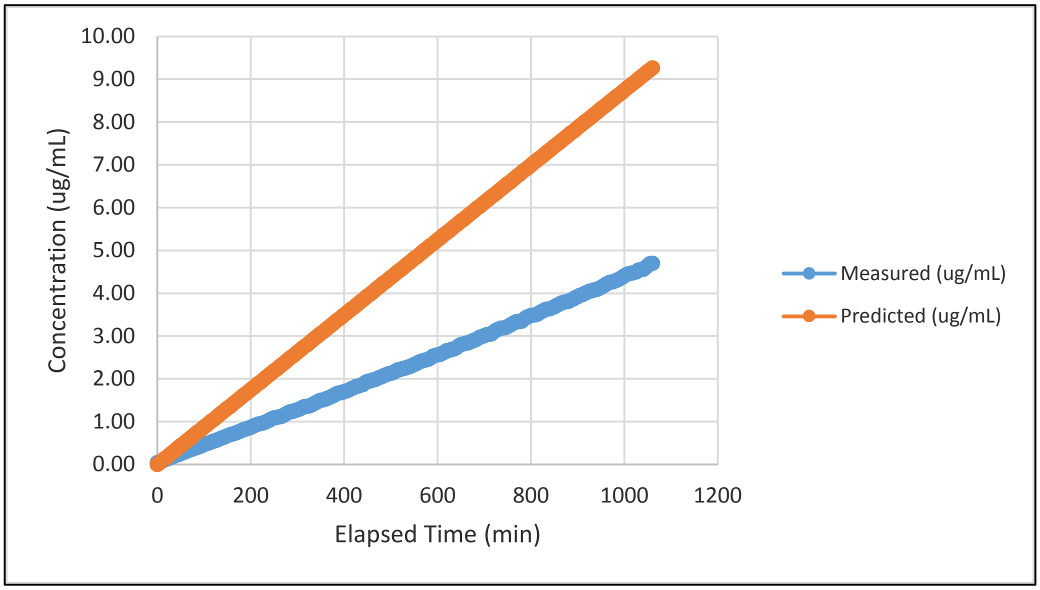
7.2 Warm NH_3 Removal Experimental Procedures

The particle size of the CBV 712 used for this study was reduced to between 95 and 350 µm before testing. Prior to the start of each exposure, nominal 0.075 g of material was loaded in the exposure chamber, which resulted in sorbent bed length of around 0.5 in (L/D = 3.3). Aliquots of CBV 712 were exposed at the desired test conditions using the same procedures described for the warm HCl removal testing in Section 5.5.1 with the exception of using the ammonium ion selective electrode to measure the change in ammonium ion concentration in the impinger solution instead of using the chloride selective electrode to measure the change in chloride ion. At the end of each test, the exposed sorbent was extracted with 100 ml of acidified H_2O and the resulting solution along with the H_2O impinger solution were analyzed for ammonium ion content using ISE and IC to determine total ammonia mass balance.

7.3 Warm NH_3 Removal Experimental Results

The QC check to determine the loss of HCl to system components performed prior to warm HCl removal testing was also perform prior to the start of NH_3 testing. Previous testing with HCl had shown that a heated N_2 makeup flow was needed to keep the temperature of the test gas above the dew point prior to contact with the impinger solution. Because of this observation, the heated N_2 makeup was used in all of the NH_3 testing. The NH_3 QC check involved collecting impinger samples of a test gas stream containing 23.8 ppmv NH_3 in N_2 with 10 percent steam at the outlet of a blank exposure chamber maintained at 392°F and 100 psig for 1060 min. The plot of measured ammonium ion concentration in the acidic H_2O impinger solution and theoretical expected concentrations based on the certified NH_3 concentration in the compressed gas mixture over the same time period is shown in Figure 14. Poor agreement between measured and expected ammonium ion concentrations indicated that either the expected amount of ion was not making it to the impinger solution or the impinger collection system and/or the ammonium ISE probe was not operating as planned. Subsequent analysis of the impinger solution by IC after completion of the QC test agreed with the theoretical amount expected over the 1060-min sampling period, which confirmed that the certified amount of NH_3 in the compressed gas mixture was correct, no loss of ammonium ion to system components was observed, and the acidified H_2O contained in the impinger solution was effective in retaining the ion at the conditions tested. This meant that there was a bias in the ISE measurements. Based on these results, a decision was made to use the ISE impinger measurements only as a guide to ensure complete saturation of ammonium ion on the candidate sorbent during testing and to rely on the analysis of the exposed material using IC to calculate capacities. Because of this finding, all capacities reported for warm NH_3 removal testing represent saturation capacities as opposed to the HCl capacities, which represented the amount of chloride ion retained at 10 percent breakthrough.

Figure 14. Measured and Theoretical Expected Ammonium Ion Concentrations for a Blank Reactor Test in Wet N_2



Exposures of the CBV-712 material to NH_3 test gases under various operating conditions commenced after completion of the QC check sample. Table 15 shows the exposure conditions, calculated capacities at saturation, and overall ammonium mass balances for the warm NH_3 ammonia removal study and Figure 15 shows the corresponding NH_3 breakthrough curves. Note that the slope of the upper region of each of the breakthrough curves depicted in Figure 15 is essentially the same as the slope of the measured concentrations in Figure 14, where no sorbent was presented in the exposure chamber. Equivalency of the slopes derived from the ISE measurements to that obtained for the empty reactor indicated that the materials were completely saturated before stopping the exposure, which was crucial to being able to compare the capacity values to one another across all exposure conditions.

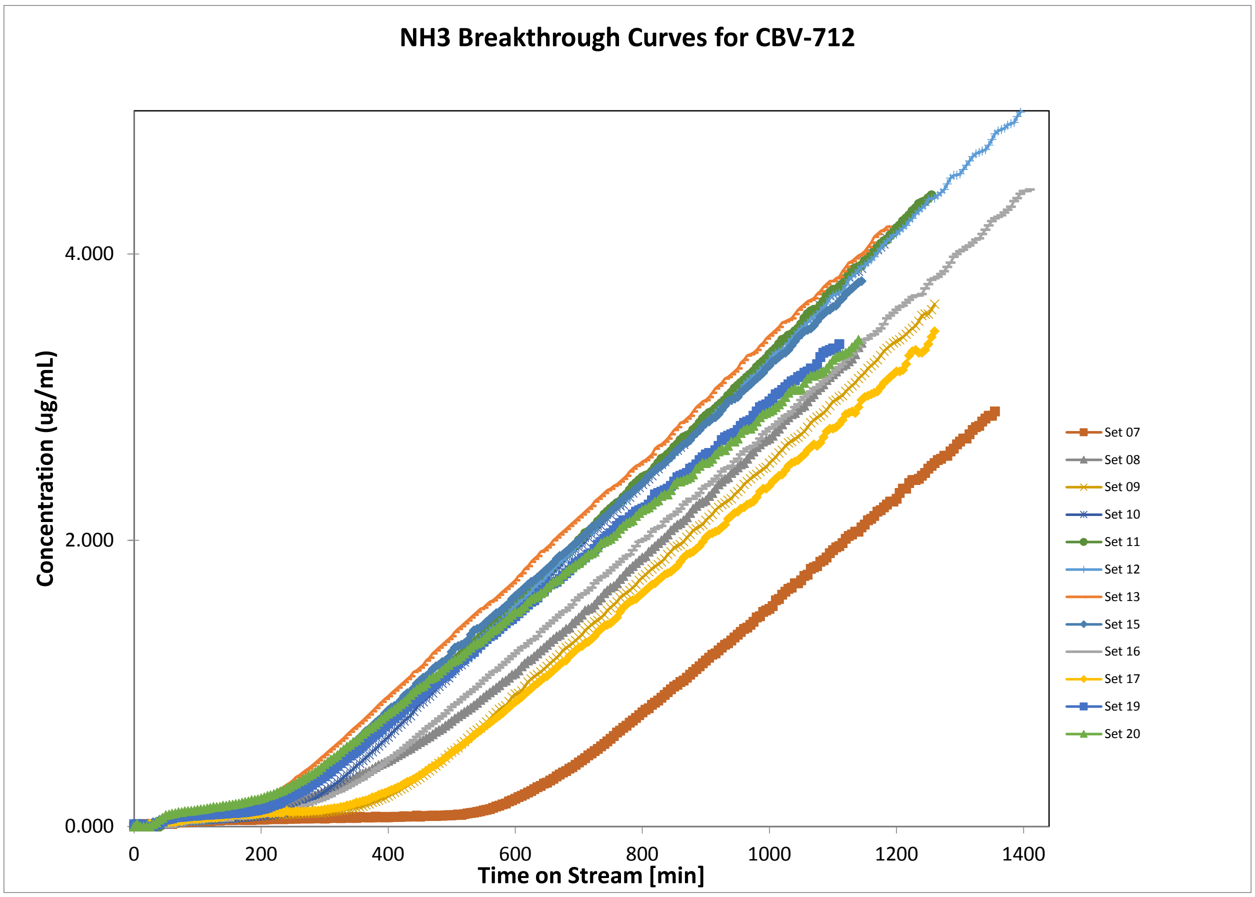
Table 15. Summary of Warm NH_3 Removal Conditions and Test Results

Set #	Temperature (°F)	Test Gas	Pressure (psig)	Capacity (wt. %)[1]	Mass Balance (% Recovery)
7	212	Clean syngas	100	1.17	82.8
8	302	Clean syngas	100	0.85	92.3
9	302	Clean syngas	100	0.84	103
10	392	Clean syngas	100	0.69	117
11	392	Clean syngas	100	0.71	136
12	482	Clean syngas	100	0.55	125

13	572	Clean syngas	100	0.43	105
15	392	Clean syngas	50	0.64	233
16	392	Clean syngas	150	0.77	86.9
17	392	Clean syngas	200	0.77	77.6
19	392	Clean syngas[2]	100	0.70	228
20	392	Clean syngas[3]	100	0.66	263

[1] NH_3 capacity defined at saturation based on IC measurements of exposed CBV-712.
[2] Steam concentration was 20 volume percent.
[3] Steam concentration was 30 volume percent.

Figure 15. Warm NH_3 Removal Retention Isotherms for CBV 712



For Sets 7-13, the CBV 712 material was exposed to NH_3 in clean syngas containing 10 percent steam between 212 and 572°F while maintaining the system pressure constant at 100 psig. The saturated capacities shown in Table 15, which are presented in units of weight percent, were calculated using IC analysis results of the exposed material and the original weight of sorbent exposed. These results, which ranged from 1.17 weight percent for the exposure conducted at 212°C to 0.43 weight percent at 572°F, clearly show that more ammonium ion was retained on the CBV 712 material at lower exposure temperatures compared to the high temperatures. Note that good agreement between saturated capacities was obtained for Set 8 and Set 9 conducted at 302°F and 100 psig, which were duplicate exposures and Set 10 and Set 11 conducted at 392°F and 100 psig, which were also duplicates. For Sets 15-17, the exposure temperature and steam content were held constant at 392°F and 10 volume percent, respectively, and the system pressure was varied between 50 and 200 psig. The saturated capacity of 0.64 weight percent at 50 psig appears to be slightly lower compared to the capacity of 0.77 weight percent obtained for the exposures at 150 and 200 psig. There was only a slight reduction in ammonium ion retention from the exposure that was conducted at 392°F, 100 psig, and 10 volume percent steam compared to when the steam concentration was increased to 20 volume percent in Set 19 and 30 volume percent in Set 20.

Although the saturated capacities determined in this study appear to be somewhat higher (0.71 weight percent at 392°F and 200 psig) compared to the total capacity determined by SRI (0.43 weight percent at 392°F and 300 psig), there were some similar general trends in the data. These trends include a slight reduction in ammonium ion retention with increasing exposure temperature and very little difference in retention as the exposure pressure increases and the steam content increases. For example, the SRI data shows a slight decrease in total capacity when the exposure temperature was 392°F and the system pressure was 300 psig (0.43 weight percent) for single cycle testing and when the exposure temperature was 446°F and system pressure was 200 psig (0.2 to 0.4 weight percent) during multiple cycle testing. This was the same general trend noted in the saturated capacities for Sets 7-13, but the magnitude of change was smaller in the SRI data because the temperature range was smaller. In addition, the small differences in total capacity between 0.19 weight percent to 0.21 weight percent determined by SRI as the steam content increase from 30 percent to 50 percent in multiple cycle testing is consistent with the warm NH_3 removal testing results for Set 19 (20 percent steam) and Set 20 (30 percent steam).

Another QC check incorporated in this study included calculating overall mass balances for each exposure, which was carried out by comparing the total amount of ammonium ion detected in the exposed sample extracts to the total theoretical amount of ammonium ion delivered to the system after compensating for the breakthrough amount detected by IC in the impinger solution. The mass balance results shown in Table 15 ranged from 82.8 to 263 percent recovery. The reason for the extremely high mass balance results obtained for Sets 15, 19, and 20 is not known. But note that the dew point of the test gas was different for these three exposures compared to the other exposures, which may have resulted in the test gas temperature dropping below the dew point even though precautions were taken to avoid this condition. If this is the reason for the high mass balance results, it appears as though any condensation occurred downstream of the sorbent bed because the amount of ammonium ion detected in the material extracts that was used to calculate the saturation capacity values appear to be normal. This means that the mass balance calculation was biased by the amount of ammonium ion detected in the impinger solution that represented breakthrough of the ion during the exposure.

Very much like the warm HCl removal data presented in Section 5.5.3, the warm NH_3 removal data discussed here expands the knowledge base of retention characteristics of this contaminant on CBV 712 that can be used in conjunction with the feasibility data reported by SRI to model and design a commercial-scale system. As with the data for HCl, conditions that define the specific boundaries for operating an NH_3 control system were not defined but general trends in contaminant retention that expanded the range of temperature, system pressure, and steam content in clean simulated syngas were determined. It is important to note that exposures conducted with H_2S contained in the syngas were not performed because of time limitations on this project. Results from the SRI study did address this issue briefly and determined that the presence of 100 ppmv H_2S in the simulated syngas will reduce the total capacity of ammonium ion of CBV 712. Any additional work in this area should focus on parametric testing in the presence of H_2S, but at levels around 10 ppmv instead of 100 ppmv since this technology will more than likely be positioned downstream of RTI's WDP system in most IGCC configurations.

8.0 Conclusions

This report describes activities associated with laboratory testing performed at RTI and field testing performed at Tampa Electric Company's Polk Station Power Plant to advance the commercial development of RTI's warm syngas cleanup technology. Systems were installed at Polk Station to determine the cleanliness of WDP-treated syngas by demonstrating chemical production via microreactor testing using commercial catalysts. A test skid was also installed to demonstrate the efficacy of sorbent materials to remove Hg, As, and Se from Polk Station syngas downstream of WDP. In addition, gas-phase testing was conducted at various points to determine the distribution of NH_3, HCN, Hg, As, and Se upstream and downstream of the WDP and TCRP systems.

The laboratory studies conducted at RTI involved testing the hydrogen chloride tolerance of RTI's desulfurization sorbent, RTI-3, and parametric testing to provide guidance for designing removal systems for HCl and NH_3.

Appendix I

Direct Sulfur Recovery Process (DSRP) Development

Goals and Objectives

In previous work, RTI has developed a new process for the direct recovery of elemental sulfur from the SO_2 in N_2 stream that leaves the regeneration step of RTI's warm syngas desulfurization process (WDP). The goal of this work was to revisit the RTI direct sulfur recovery process (DSRP), focusing primarily on DSRP tail gas treatment, to have a better understanding of the process and to enhance the confidence level of the process design and modeling of a pre-commercial scale unit. A modular approach was used to understand the DSRP operation. The task involved understanding the operation of both the DSRP and the tail gas reactor.

TASK 1: DSRP Reactor Study

The primary goal was to identify the process conditions that provide SO_2 conversion and selectivity to elemental sulfur. Reaction variables to be examined involved SO_2 concentration (2.5, 5.0, 7.5 and 9.5%), temperature (range 300-550°C), RG reducing gas (H_2 and syngas used to reduce residual SO_2 to H_2S in the DSRP tail gas) and RG : SO_2 ratio. The SO_2 stream exiting the sorbent regenerator has a maximum concentration of about 12 vol%. All the previous data has been obtained at lower SO_2 concentrations. Hence, one of the objectives of the work was to obtain the data at the higher SO_2 concentration. Due to vapor pressure limitations, the challenge underlying this effort was to get >9.5% SO_2 balance nitrogen at 350psig. The alternate method was to start from liquid SO_2 in order to achieve higher % of SO_2 at high pressures. One of the key goals was also to be able to analyze an unconditioned product sample consisting of sulfur, hydrogen sulfide and carbonyl sulfide. All the previous data analyzed a conditioned product sample containing hydrogen sulfide and carbonyl sulfide and calculated the sulfur selectivity from the difference. Various analytical schemes were discussed to analyze elemental sulfur to improve the confidence in the sulfur yield and selectivity. To achieve this objective, the reactor system was accordingly designed to avoid the reactor upsets caused by the sulfur condensation and blockage.

TASK 2: Tail Gas Reactor Study

The study on the tail gas reactor was to optimize some of the process parameters involving the RG : SO_2 ratio and temperature. This study was also aimed at studying the activity of our catalyst (T-306 SCI) for the tail gas reactor operation. The goal was to identify the process conditions to completely reduce all the sulfur species, primarily sulfur and unconverted SO_2, into hydrogen sulfide to facilitate the downstream operations. Reaction variables to be examined involved SO_2

concentration (2.5 and lower), temperature (find the lowest temperature where SO_2 gets completely reduced), and RG (H_2 and syngas).

Microreactor System and Analytics

Reactor System

The reactor system was designed keeping in mind a close to complete conversion of SO_2 to elemental sulfur in the DSRP reactor (Reactor 1) followed by the reduction of all the sulfur species using H_2/syngas in the tail gas reactor (Reactor 2). A provision to inject the reductant gas directly into Reactor 2 was also incorporated to provide flexibility with the DSRP reactor operation. The product stream exiting the tail gas reactor was then passed through a sulfur trap, which was maintained at slightly below the melting point of sulfur and above 100ºC to avoid water condensation. An inline regulator was used to sample the product gas into the GC's to analyze the product gases including H_2, CO, CO_2, H_2S, SO_2, and COS. A Dycore Mass Spectrometer was used to analyze the DSRP reactor product stream. The sampling scheme consisted of a critical orifice, which was designed to sample about 5-10cc of the product gas. The mass spectrometer sucked about 1cc/min of the sample and the remaining sample was treated in Reactor 3 using H_2/syngas as the reductant before venting it out. The critical orifice followed by a capillary tube provided for a stepwise drop in pressure to avoid sulfur condensation and blockage. Depending on the vapor pressure of sulfur at various stages, the temperature of the different lines was carefully controlled and monitored.

Figure 1 shows the process flow diagram for the microreactor system that was used. A 1 inch stainless steel (SS316) tube was used as the DSRP reactor. The catalyst bed (T-306 SCI- 48g), positioned at the center of the reactor tube, was sandwiched between inert SiC beds at the top and the bottom. A thermocouple probe located at the center of the sorbent bed was used to measure and control the temperature of the bed to maintain the isothermal conditions. A ½ inch stainless steel (SS316) tube completely packed with T-306 SCI catalyst was used as Reactor 2 and Reactor 3. A thermocouple probe located at the center of the sorbent bed was used to measure the temperature of the bed.

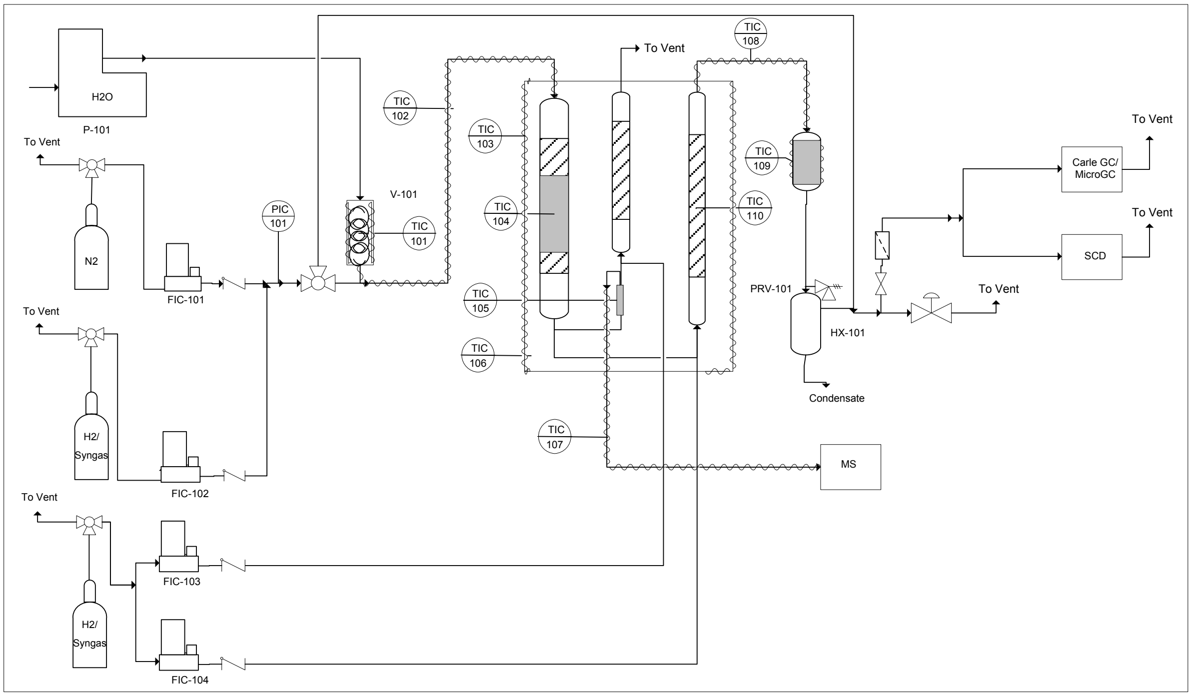


Figure 1. Process Flow Diagram for the Laboratory DSRP Reactor System

Analytics

Due to a series of process limitations and concentration ranges for various species, a variety of analytical techniques were used for this work. Carle GC, with an analysis time of 13 min, was initially used to analyze for H_2, CO, CO_2, N_2 and H_2S. A GC with a specialized SCD detector was used to analyze the ppm level concentrations of SO_2 and COS. To expedite the sample analysis, the Carle GC was replaced with a micro-GC with a shorter analysis time of 4 min. The sample injection volumes on different channels of the micro-GC were optimized to be able to analyze the percent level of typical syngas components and ppm levels of contaminant sulfur gases. A Dycore Mass Spectrometer, with a quadrupole mass analyzer, was used to analyze the DSRP reactor product stream. A 1-meter long capillary tube with an OD and ID of 150 microns and 50 microns, respectively, was used to drop the pressure to the desired level in the ionization chamber. The capillary tube was inserted in 1/8" stainless steel tubing to be able to heat the tubing to the desired temperature to avoid sulfur condensation and blockage.

A series of activities involving the mass spectrometer were undertaken to make possible the quantitation of the sulfur species from the DSRP reactor effluent stream. These activities involved the following:

1. Confirmed the capability to analyze ppm level concentrations of H_2S and SO_2
2. Sensitivity improvement
3. Calibration for H_2S, SO_2 and COS

4. Obtained Reproducible H_2S calibration curves by applying N_2 normalization in heated capillary and injection lines, a strategy devised to tackle the H_2S conditioning issue. Figure 2 shows the calibration curve for H_2S.
5. Attempts to calibrate the mass spectrometer for elemental sulfur analysis
    a. Saturate an inert stream with sulfur vapors
    b. Using H_2, reduce the sulfur vapor stream to determine/verify the sulfur concentration

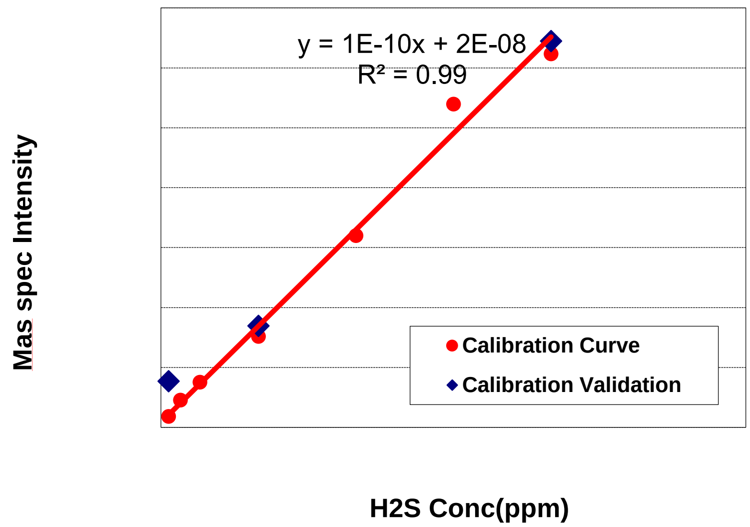


Figure 2. Calibration curve for H_2S on the mass spectrometer

Results and Discussion

TASK 2: Tail Gas Reactor

Two of the important parameters that play a key role in deciding the energy consumption or the economics of the tail gas treatment are the amount of the reductant gas and the temperature of the operation. Stoichiometrically, a RG : SO_2 of 3:1 is required to ensure complete reduction of unconverted SO_2 from the DSRP operation.

$$SO_2 + 3H_2 \longrightarrow H_2S + 2H_2O$$

Table 2 lists the results of the study conducted to understand the operation of the tail gas reactor. The reaction performance was quantified by calculating the SO_2 conversion, H_2S selectivity and COS selectivity. Hydrogen and pre-mixed syngas were used as the reductant in the preliminary studies. Reducing gas composition was varied by mixing hydrogen and syngas. Table 1 mentions the composition of the dry syngas used for the reactions.

Table 1 Composition of the dry syngas used for microreactor testing

Gas	Concentration (vol%)
H_2	32.2
CO	43.0
CO_2	12.9
Ar	11.9

Table 2. SO_2 reduction as a function of reducing gas ratio, temperature and SO_2 concentration (Reducing Gas- H_2/syngas, SO_2 Concentration – 2.5-5 vol%, Reaction Temperature- 375-550ºC, P- 300 psig, GHSV- 3000/hr)

Run #	SO_2 Conc. (vol %)	Overall SO_2 : H_2	SO_2 : H_2 in Reactor #1	SO_2 : H_2 in Reactor #2	SO_2 Conv. (%)	H_2S Selectivity (%)	COS Selectivity (%)	Effluent H_2 Conc. (ppmv)
1	2.5 (450ºC)	1:5	5	0	100.0	103.5	-	-
2		1:4	4	0	100.0	103.5	-	-
3		1:3	3	0	100.0	103.5	-	-
4		1:3	2	1	100.0	103.5	-	-
5	5.0 (550ºC)	1:3	3.0	0	100.0	101.2	-	0
6		1:3.05	3.05	0	100.0	101.4	-	4481
7		1:3.2	3.20	0	100.0	101.4	-	8764
8	2.5 (375ºC)	1:3.2	3.2	0	100.0	102.8	-	3800
9		1:3.2*	3.2	0	100.0	103.4	-	3177
10		1:3.2**	3.2	0	100.0	102.5	0.2345	1916
11		1:3.2#	3.2	0	100.0	102.6	0.1643	248

Value in the parentheses below the SO_2 concentration is the reaction temperature in degrees Celsius

*- H_2 with 15 vol % steam

**- Syngas with 15 vol % steam

#- Combination of H_2 and syngas with steam

A premixed mixture with 2.5% SO_2 in N_2 was used for the preliminary studies. Despite the lower concentration (in ppm level) of sulfur species in the tail gas reactor, a relatively higher concentration of SO_2 (2.5-5%) was used to be able to utilize these results to also understand the operation of the DSRP reactor. Since the aim of the tail gas reactor is to achieve the complete reduction of the residual sulfur species leaving the DSRP reactor, the preliminary studies were begun with an excess of reducing gas at a RG : SO_2 ratio of 5. RG : SO_2 referred to as reducing gas ratio is the ratio of the moles of the reductant, H_2 and/or CO, to the moles of SO_2 in the feed. As can be seen from the results for Runs 1-3, a reducing gas ratio of ≥ 3 achieves complete reduction of SO_2 to H_2S at 450ºC. The aim of Run 4 was two-fold, i.e. to understand the flexibility of our reactor system and also to mimic the actual operation of the DSRP unit followed by the tail gas treatment.

These results at percent level SO_2 concentrations can be safely extrapolated to the ppm level feed concentrations in the tail gas reactor. However to justify the application of the results to higher SO_2 concentrations, Run 5 was carried out at 5 vol% SO_2 feed. Results suggest similar chemistry at the higher concentration. This run was also carried out at typical DSRP temperatures of around 550ºC. To ensure complete reduction of sulfur species, the tail gas reactor will be ideally operated in a reducing environment with an excess of reducing gas feed, i.e. above a reducing gas ratio of 3. We targeted to operate the reactor at about 5,000-10,000 ppm of excess hydrogen or reducing gas. Runs 6 and 7 were carried out by varying the RG : SO_2 ratio to study the excess hydrogen in the effluent. Results suggest that a reducing ratio between 3.05-3.2 was sufficient to achieve the desired excess H_2 concentration. Runs 8-11 were carried out to study the effect of varying reducing gas composition. Results of Run 8 and 9 exhibit that steam had no detrimental effect on the reduction reaction. Runs 9-11 were carried out with different H_2/CO ratios, viz. ∞, 0.74 and 2.33, respectively. Results suggest no noticeable effect of the varying syngas composition on the reduction reaction at the temperatures studied.

Thus, the results of the study above suggested that it just takes a reducing gas ratio of slightly >3 (3.05-3.2) to achieve complete reduction. The next parameter to optimize was the tail gas reactor temperature. The aim was to determine the minimum temperature for the tail gas reactor operation for different syngas compositions. The gas coming out of the sulfur condenser is at ≈110-120ºC and hence needs to be heated for the tail gas treatment. Hence, the tail gas reactor needs to be operated at the minimum possible temperature to reduce the energy consumption. To collect this data over the desired range of temperatures, various schemes, namely iteration method, reactor cooling and reactor heating, were used. The temperature range to be studied was narrowed to 250-375ºC by conducting preliminary studies using 100% hydrogen as the reducing gas.

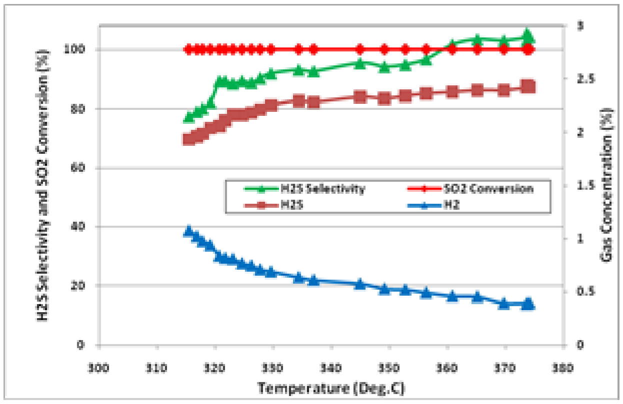


Figure 3a. Using 100% H_2

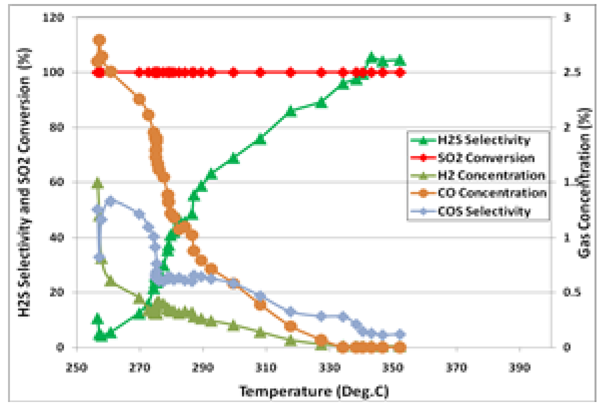


Figure 3b. Using Syngas

Figure 3. SO_2 reduction as a function of reaction temperature (SO_2 Concentration – 2.5 vol%, Reaction Temperature - 250-375°C, P - 300 psig, GHSV - 3000/hr)

Figure 3 shows the results of this study for the tail gas reactor operation. Figure 3a shows the results for the run with 100% H_2 as the reducing gas. SO_2 conversion and H_2S selectivity were used to quantify the reaction performance. The plot also shows the H_2S and H_2 concentration in the effluent gas as a function of temperature. As can be seen, a complete conversion of SO_2 was obtained over the temperature range studied. The H_2S selectivity starts dropping at around 360°C suggesting incomplete reduction below this temperature, leading to the formation of sulfur. The reaction was not continued below 315ºC to avoid reactor blockage due to sulfur condensation. Figure 3b shows the results for the run with syngas as the reducing gas. A complete conversion of SO_2 with a very low H_2S and COS selectivity at 250ºC suggests a very high selectivity for sulfur at this temperature. This result is particularly interesting for the operation of the DSRP reactor, where the aim is to maximize the sulfur selectivity and minimize the H_2S selectivity. A sharp increase in H_2S selectivity at around 280°C suggests the light off for the reduction reaction. Using syngas as the reducing gas, the minimum temperature for the operation of the tail gas reactor to achieve complete reduction seems to be around 350ºC. In order to further study the effect of syngas composition, a similar run using a combination of hydrogen and syngas was carried out. The H_2/CO ratio in the syngas mixture was adjusted to obtain a reductant gas stream containing 70% H_2 and 30% CO. Results of this run suggested a minimum temperature for the complete reduction to be around 340ºC. Thus the minimum acceptable temperatures obtained for a series of different syngas compositions have been over the range of 340-360°C. Considering the experimental variability of these results, it will be safe to conclude that the reducing gas composition has no bearing on the complete reduction temperature. Depending on the results obtained from the two previous studies for reducing gas ratio and minimum temperature, the appropriate conditions to operate the tail gas reactor should be a reducing gas ratio of about 3.2 and a temperature of about 360ºC.

TASK 1: DSRP Reactor

A preliminary run with 100% H_2 as the reductant at a reducing gas ratio of 2, which is generally used for the DSRP operation, suggested a SO_2 conversion of 98% with a H_2S selectivity of 6%. As expected, a yellow suspension was obtained in the condenser and the sulfur condensation in the lines limited the run time to less than 2 hours.

$$SO_2 + 2H_2 \longrightarrow S + 2H_2O$$

Moving forward, a combined reactor operation with the DSRP reactor operating at the conditions required to maximize the sulfur selectivity and minimize H_2S formation, and the tail gas reactor operating at the conditions to ensure complete reduction of the sulfur species was proposed. The results from the studies for the tail gas reactor opened up a new scope of studies for the DSRP reactor in terms of reaction temperature. DSRP reaction attempts using a reducing gas ratio of 3 at 250ºC yielded a 100% SO_2 conversion along with a H_2S and COS selectivity of 2% and 1%, suggesting a SO_2 selectivity of 97%. One of the goals going forward should be verifying the results at these conditions by analyzing elemental sulfur or the unconditioned sample of SO_2, H_2S and COS in the mass spectrometer.

Conclusions

The testing conducted during this work effort helped confirm and define the conditions needed for full reduction of residual sulfur in the tail gas from the DSRP process. It also defined the minimum temperature needed for such reduction to occur which helps design the process with minimum overall energy requirements for tail gas treatment. Learnings from the tail gas treatment task also provided new insight into improvements for the DSRP reaction. The light-off behavior observed for the SO_2 reduction helped to design the feed temperatures for the sour gas entering the DSRP reactor. Additionally, product selectivities observed while using syngas as a reductant indicated potential for formation of byproducts such as COS. This information will be helpful for designing the DSRP process. Use of higher reducing gas ratio and adjusted temperature resulted in improved SO_2 conversion and SO_2 selectivity. Because of other higher priorities of the overall warm syngas cleanup pre-commercial scale-up program and a decision not to pursue further scale-up testing of the DSRP technology as part of the project, further DSRP testing work was discontinued. However, the learnings from this testing will be useful for any future DSRP development effort.

Appendix J

Novel Carbon Dioxide Sorbent Development

(Development of a Solid Sorbent-based Process for CO_2 Removal from Warm Syngas)

1.0 Introduction

Removal of contaminants and diluents from syngas at high temperature to produce power, hydrogen or CO_2 sans/lean syngas leads to higher energy efficiency of the overall process. One of the major components to be removed or regulated from syngas is CO_2. To date, no feasible warm-temperature CO_2 removal process from syngas has been conceptualized. Solid sorbents are quite promising for pre-combustion CO_2 capture due to easy recovery and regeneration, high CO_2 loading over wide temperature range, high thermal and mechanical stability, low heat capacities, low cost and low toxicity compared to liquid solvent and membrane systems. RTI has identified a series of solid sorbent materials based on magnesium–alkali mixed salts that have very promising CO_2 capture properties for CO_2 removal from warm syngas. RTI has proposed a warm, sorbent-based CO_2 capture process based on this novel sorbent. A preliminary technical assessment of this proposed process was performed by Noblis prior to the start of this project and the results from this study showed that RTI's proposed sorbent-based CO_2 capture process could improve the net electrical efficiency of an IGCC facility by approximately 1.9 efficiency points compared to a baseline case using Selexol™ as the CO_2 capture process. The objective of this development effort was to further develop the sorbent material and process such that efficiency gains revealed by the model effort can be realized at pilot-scale.

2.0 Process Development

Typical commercial chemisorption processes incorporate temperature-swing or pressure-swing processes. Temperature-swing processes adsorb molecules at the process conditions and, while keeping the pressure constant, raise the temperature until the molecules desorb from the surface. Conversely, pressure-swing processes keep the temperature constant and lower the pressure to conditions that are favorable for the molecules to desorb from the surface. Contrary to typical applications of these technologies, the novel process design investigated in this research includes a multi-stage, reverse-temperature swing fluidized-bed process. Upon adsorption at a certain temperature and pressure, regeneration is operated at a slightly lower temperature to enable utilizing the heat of adsorption and water-gas-shift to sustain the heat required during sorbent regeneration. As a result, no additional heat is required to be supplied to the regenerator and the main energy penalties associated with regeneration are low-pressure steam for stripping and the subsequent CO_2 compression to pipeline pressures. In order to achieve this heat utilization, regeneration will have to operate at a much lower CO_2 partial pressure than the adsorber and hence at a lower operating pressure than the adsorption step. As a result, the reverse-temperature swing process is also complimented with a pressure swing process. Due to the high heat exchange requirements and need to control the bed temperature precisely, use of fluidized beds for the adsorption and regeneration step was proposed. Multiple stages may be required, due to the well-mixed characteristic of the fluidized bed, to ensure that a fluidized particle fully loaded with CO_2 in one section of the adsorber does not move to an area with a low CO_2 partial pressure and begin regenerating. In addition, due to the high CO content in the syngas, the process must be combined with a high-temperature WGS. The incoming syngas has a CO concentration approximately twice that of CO_2, so shifting the gas before entering the adsorber is imperative. In addition, as the CO_2 concentration is lowered through the adsorption process, the gas may be shifted again to convert more CO to CO_2. This may be accomplished by incorporating fixed-bed sections of WGS catalyst between fluidized bed stages.

Multiple possible designs have been conceived that could be used to accomplish the process described above. Figure 1 depicts one possible arrangement with separate adsorber and regenerator columns. Desulfurized warm syngas enters the bottom of the adsorber column and the gas exits as CO_2-depleted syngas. Mostly unloaded solid sorbent enters the top of the adsorption column and exits mostly loaded with CO_2, operating in a counter-current process with syngas. The entire sorbent loading capacity is not fully utilized to speed the process, operating with high driving potential and fast kinetics, and to reduce attenuation of the effective capacity. The loaded sorbent is depressurized in a restricted pipe discharge system (RPDS), detailed in later section, and passes through the regenerator, with superheated, low-pressure steam injected at the bottom to effectively strip the CO_2 from the sorbent. The offgas contains humid CO_2, which after condensing the water vapor, can be pressurized to pipeline conditions. The regenerated sorbent is repressurized in lock-hopper and is recycled through the adsorber column. Each column is depicted with five stages for conceptual visualization; however, they could employ any number of stages. The adsorption stages are separated by a fixed-bed section of WGS catalyst. Each stage also includes heat transfer coils to demonstrate one possible way to accomplish heat integration between the two columns. As noted in the diagram, the adsorber column operates near the inlet conditions of the warm syngas, at approximately 800 psig and 460°C; while the regenerator operates near 50 psig and 430°C. A possible profile of CO_2 partial pressure through the columns is denoted between each stage. Instead of distinct WGS catalyst fixed beds, if WGS catalyst can be incorporated with the solid sorbent process, then the process could be altered to that shown in Figure 2. One last version of this set of designs could include an annular design, as depicted in Figure 3. This could allow for effective heat transfer between the adsorber and regenerator through the wall separating them and not require a heat transfer fluid, reducing thermal losses.

The designs outlined above may operate well with the roughly constant temperatures throughout each column; however, the efficacy may be improved by allowing a temperature gradient throughout the columns. Since the driving force for adsorption is greater at lower temperatures in the range of interest, it may be desirable to have the final adsorption stage operate at lower temperature than the previous stages to accomplish deeper scrubbing of the syngas. Meanwhile, the partial pressure is so high in the first stages that higher temperatures will not affect the capture potential greatly. For similar reasons, the reverse temperature profile is desired in the regenerator column. Higher temperatures in the final stage will aid in driving CO_2 from the sorbent, while colder temperatures in the first stage will still allow effective stripping with the low CO_2 partial pressure. Figure 4 displays one possible design that could incorporate such an arrangement. The adsorber is comprised of multiple transport reactors that allow the sorbent to effectively travel upwards and conversely for the syngas. Gas is injected to transport the sorbent up to the next stage and eventually to the regenerator. Since the sorbent will be hot entering the top of the regenerator, heat may not need to be transferred to the top stages to allow the sorbent to cool by the endothermic desorption process. This arrangement places the two hotter ends of the processes at the top and the colder ends at the bottom, allowing for a roughly constant temperature difference between the two columns even though they each have a temperature profile within them. Thus, they can maintain a driving potential to more easily transfer heat from the adsorber to the regenerator.

Exploration of the feasibility of such a concept was undertaken through various tests in the HP-TGA and HP Microreactor. Investigation of the percent of loading achievable at various partial pressures and temperatures was undertaken in both systems. The goal of the experiments was to simulate the environments that the particle would see in the actual process as it entered the top of the adsorber and passed through the stages to the bottom of the adsorber and then similarly in the regenerator. In the HP-TGA, a sorbent sample was loaded in the reactor and brought to the desired temperature in an inert atmosphere. The partial pressure of CO_2 was then increased to the level present in the top stage of the adsorber. After a 30 minute loading period, the partial pressure was increased again and the process was repeated until the conditions at the bottom stage of the adsorber were reached. The temperature was dropped to the desired regeneration temperature and the sample was exposed to a similar progression through CO_2 partial pressures from the top of the regenerator to the bottom. The resulting weight changes represent the sorbent loading available in each stage of the process. A similar program was executed in the HP Microreactor that confirmed the results from the HP-TGA. In order to establish feasibility of the process, the sorbent must demonstrate suitable weight gain at low enough partial pressures to achieve 90% carbon capture in the adsorber and regenerate at a lower temperature with a partial pressure high enough to minimize the subsequent CO_2 compression.

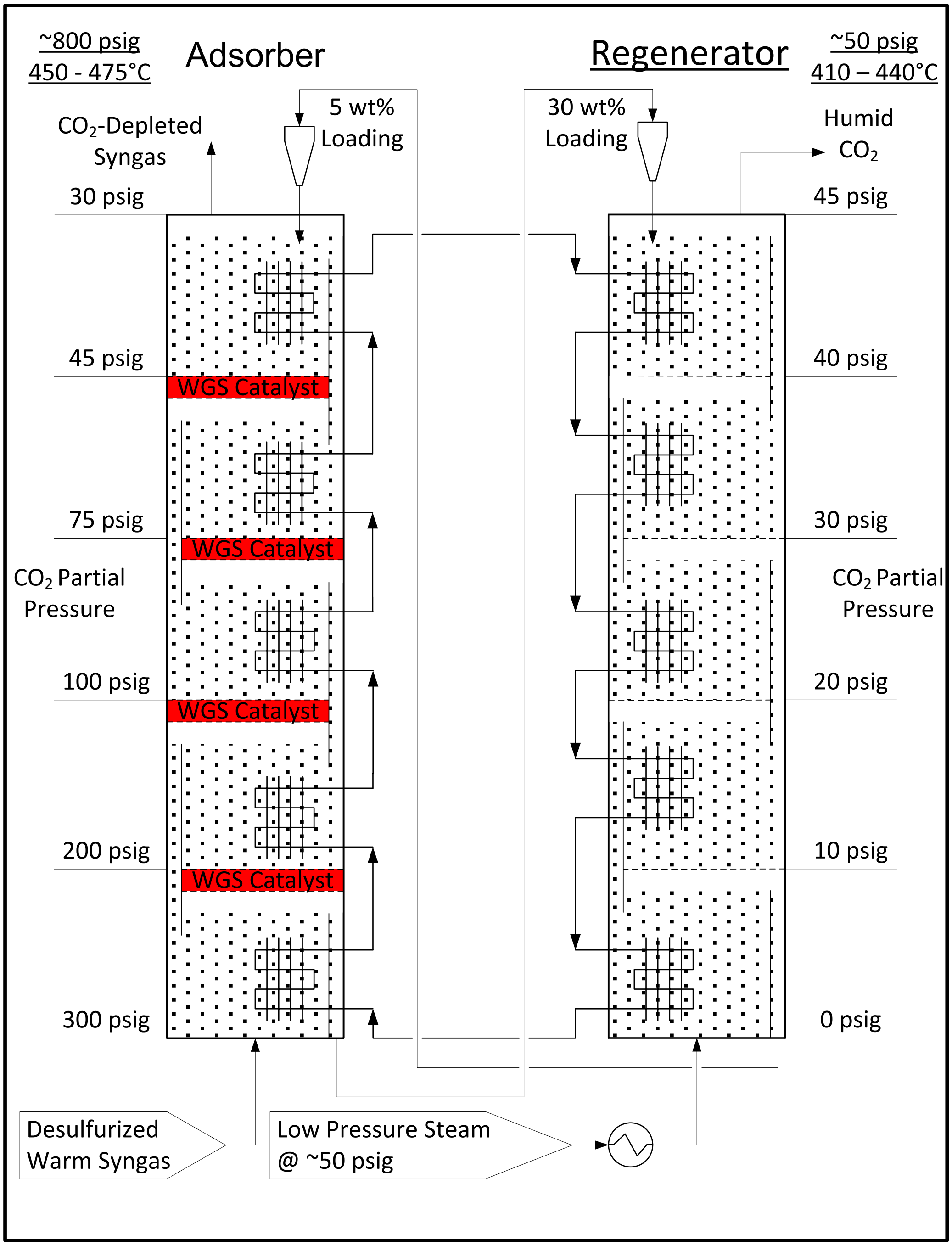


Figure 1. Conceptual Multi-stage Adsorber and Regenerator Column Design with Integrated WGS Catalyst Sections

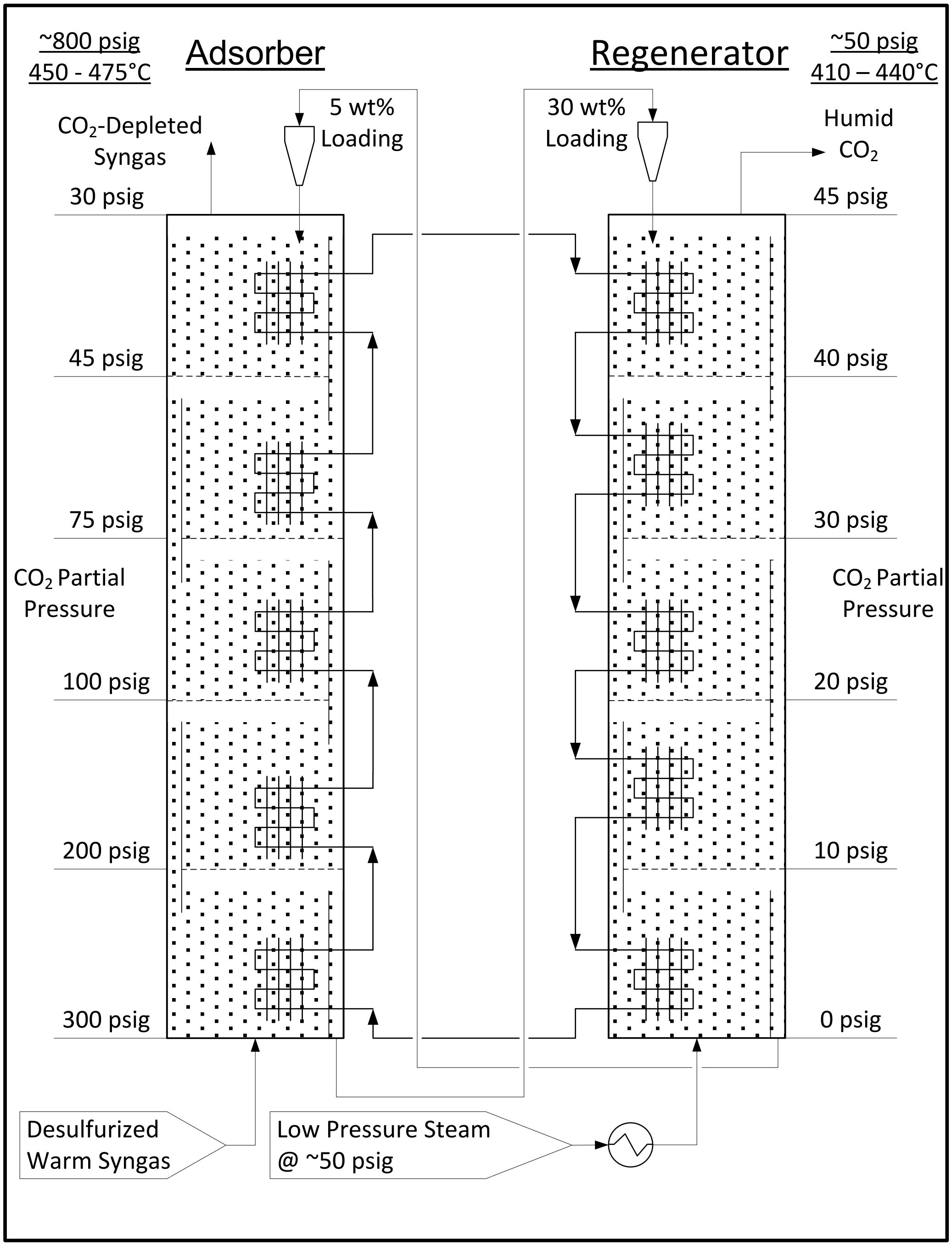


Figure 2. Conceptual Multi-stage Adsorber and Regenerator Column Design with Dual-function WGS and CO_2 Capture Particles

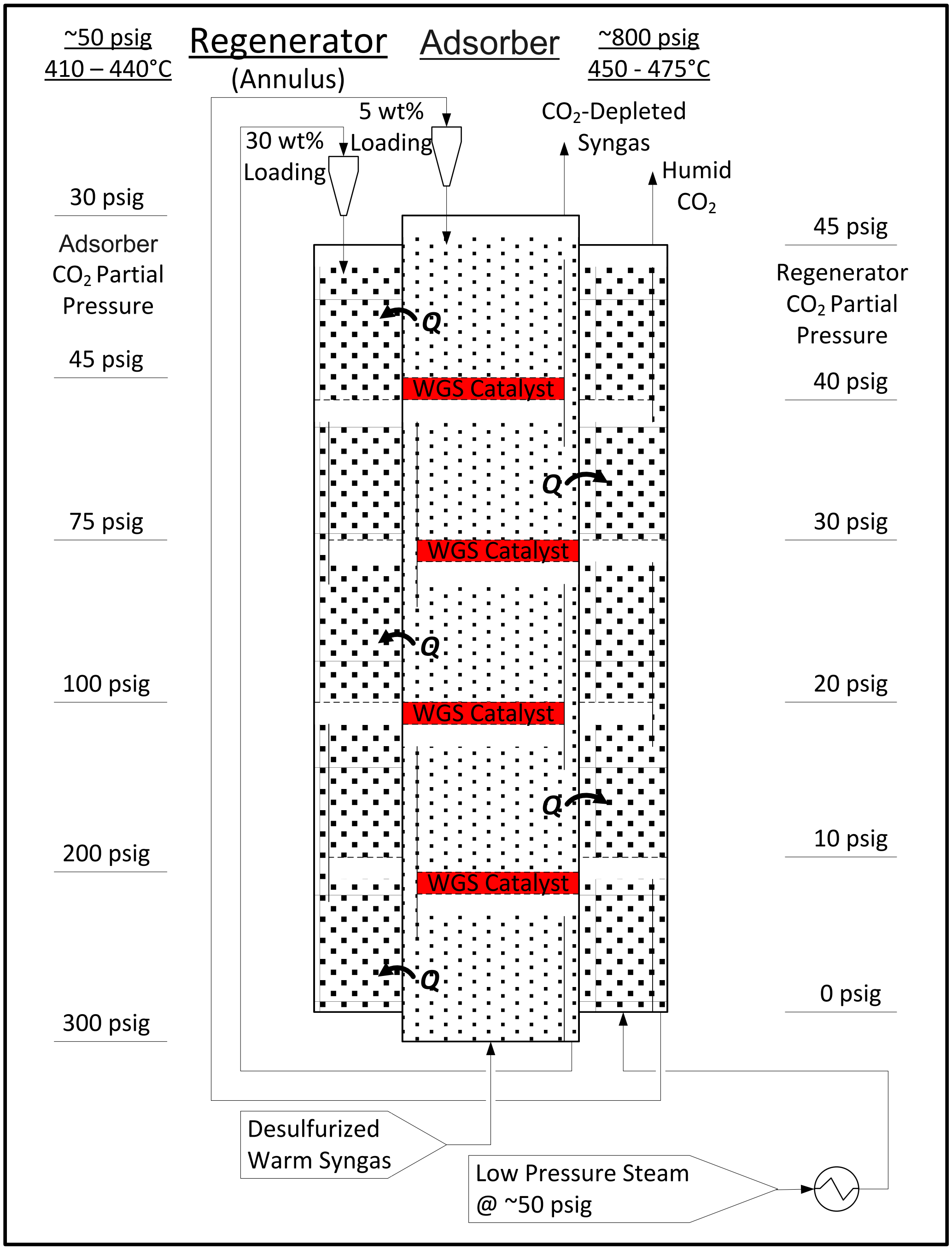


Figure 3. Conceptual Multi-stage Adsorber and Annular Regenerator Column Design with Integrated WGS Catalyst Sections

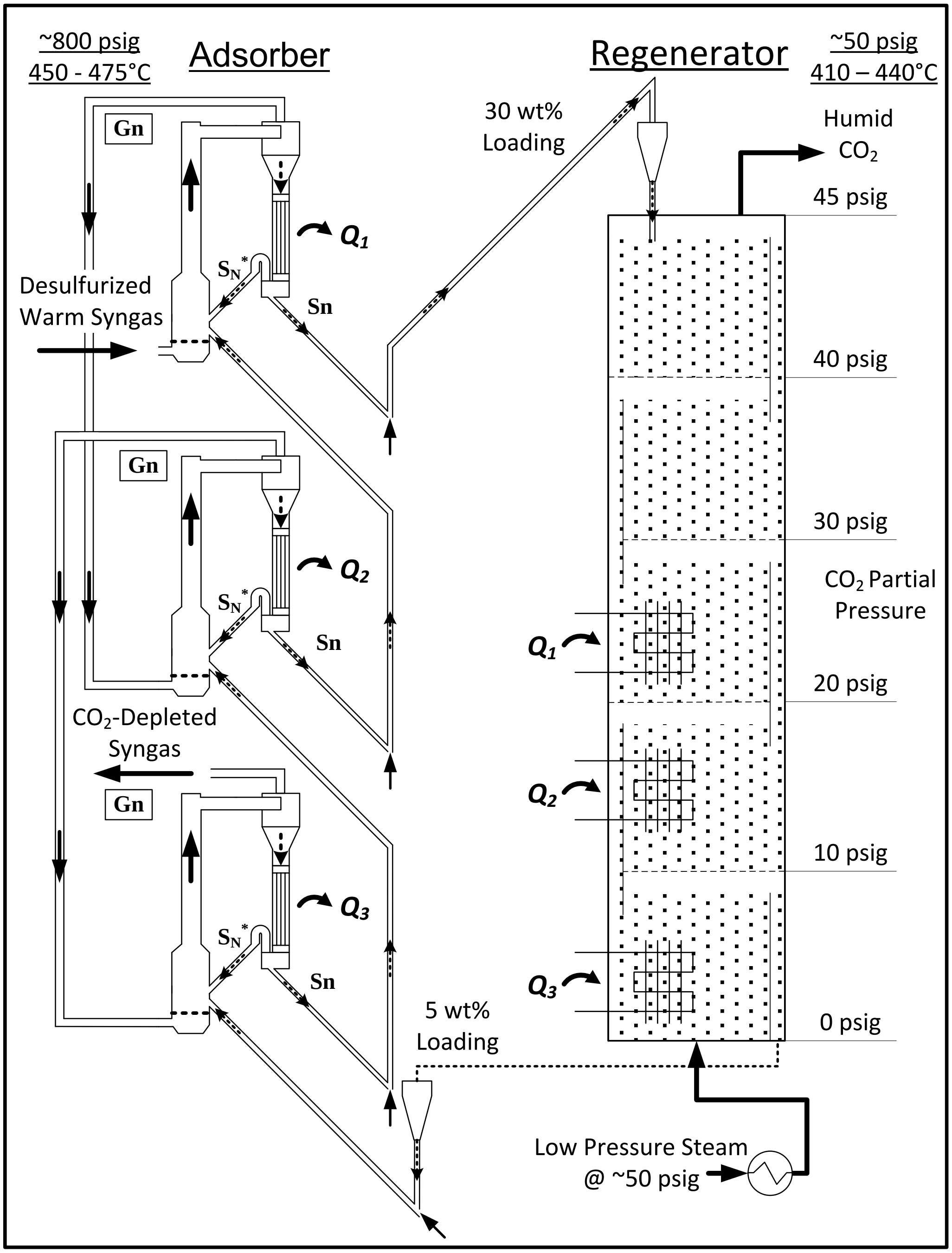


Figure 4. Conceptual Multi-stage Transport Reactor Adsorber and Staged Regenerator Column Design with Dual-function WGS and CO_2 Capture Particles

A mass and energy balance based model of the adsorber and regenerator was built to analyze the efficacy of different designs of the reverse-temperature swing fluidized-bed process and integrate with data from the feasibility experiments. Mass and energy balances of the various inputs and outputs of the system were used to model the actual process. In the adsorber column, a variable number of stages could be incorporated, with an option of incorporating a water gas shift section between each stage and before the first stage. The number of stages in the column only refers to the number of CO_2 capture stages, with the WGS sections occurring before each one. A continuous water gas shift could also be incorporated along with the CO_2 capture. To increase the conversion of CO to CO_2, steam injection was also an option before each WGS section. The flows into the adsorber include the possible steam injection at various points, the syngas entering the adsorber at the first stage, and the regenerated sorbent entering at the last stage. Similarly, output streams from the adsorber are the CO_2-depleted syngas exiting the last stage, and loaded sorbent exiting the first stage. Each stage is modeled as a CSTR at a single, specified temperature. An energy balance on each stage determines the cooling load required to maintain the stage at the specified temperature.

The regenerator column is also built to incorporate a variable number of stages, with inputs of steam at the first stage and loaded sorbent at the last stage. The steam injection dilutes the CO_2 in the gas phase to allow for deeper stripping of the sorbent. The only outlets from the modeled regenerator are the regenerated sorbent from the first stage and the wet CO_2 gas from the last stage.

While many system parameters were varied throughout the analysis, the basis for many of them was based on Case 2 of the Cost and Performance Baseline for Fossil Energy Plants by NETL. That case models a GEE IGCC power plant with CO_2 capture. For our purposes, the syngas composition and flow rate from the 555 MWe plant (stream 9) were utilized in this model, because this process could easily integrate into that plant design. The relative amount of steam introduced for the WGS process in their system was also used as a guideline in this analysis. A percentage pressure drop was incorporated in each stage of the columns as well as the WGS sections. A linear temperature profile throughout the stages was assumed, with the inlet and outlet temperatures of each column specified.

The model was constructed in Matlab 2012b, using the Cantera 2.0 thermodynamic database. Gases were treated as ideal gases and common species in gasification processes were included. A constrained Newton-Rhapson solver was incorporated to determine the required percent of capture in each stage to reach the desired level of overall carbon capture from the process. The percent of capture in each stage could be varied by specifying a profile of capture in each stage relative to each other, and the profile was scaled to meet the required amount of capture. The combination of carbon in CO and CO_2 were used to determine the amount of carbon capture, and a total amount of 90% of carbon was captured in all cases that follow.

Each stage was solved individually, beginning with the first stage and progressing through to the last stage. The first stage was solved using the feed syngas conditions, any injected steam, and assumed inlet conditions from the sorbent from stage 2. The incoming sorbent temperature and CO_2 loading were already known based on the defined temperature profile throughout the column and the adsorption profile previously specified. Information from the outlet gas of each stage was passed as the inlet gas to the subsequent stages, and the incoming sorbent from later stages was similarly known a priori. A check was performed at the top of the columns to ensure that the assumed sorbent loading profile matched the amount from solving explicitly. Any deviations in the values were used by the Newton-Rhapson solver to generate a new adsorption profile guess and the entire column was resolved until the results converged.

From the adsorber model results, it is clear that including integrated WGS sections is imperative to achieving 90% capture. The syngas composition entering the columns has a CO concentration more than double that of CO_2, and even after a WGS section, over 25% of the carbon is still in the form of CO. As a result, there is a minimum of two capture stages required along with two WGS sections before each section. Still, the level of CO_2 capture required in each of those two stages to reach 90% carbon capture is nearly 100 percent. Figure 5 displays percentage of CO_2 capture that would be necessary in each stage to reach 90% total carbon capture. As the number of stages increases from 2-, 3-, 4-, the percentage of CO_2 capture required in each stage decreases from 97% to 80% to 65%, respectively. These results indicate that with a staged WGS and CO_2 capture process scheme, a significant number of stages will have to be used to alleviate the per-stage CO_2 capture requirement.

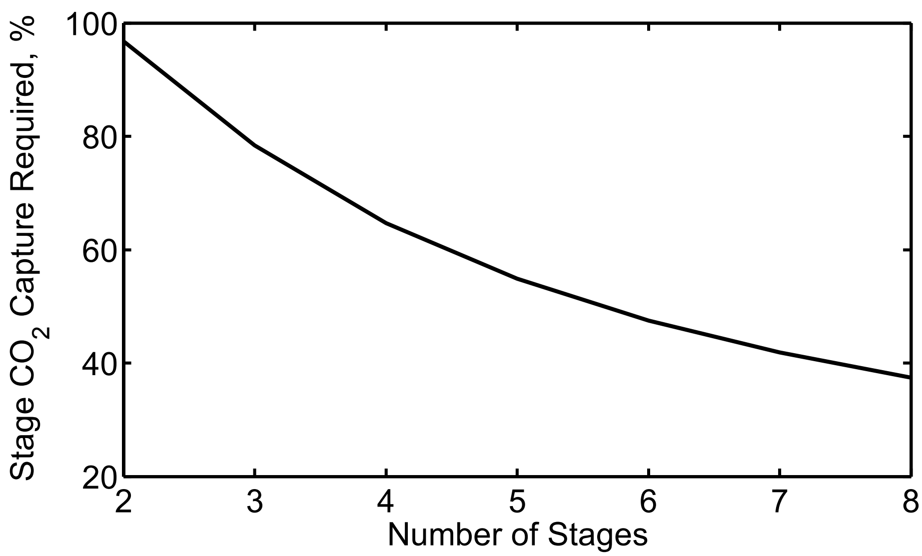


Figure 5. Percentage of CO_2 Capture Required in each Stage to Attain 90% Total Carbon Capture vs. the Total Number of Stages

The sorbent loading data from the feasibility experiments conducted in the HP-TGA were incorporated with the results from the computer model. To establish that the process was feasible, the data from the HP-TGA loading experiments was matched to the CO_2 partial pressures of the adsorption process with continuous WGS. The comparison between the experimental data and the modeled sorbent loading is depicted on the left of Figure 6. The experimental equilibrium loading data remains above the adsorber loading from the model, indicating that the sorbent would never need to be loaded beyond its capabilities at those conditions. The right side of Figure 6 displays the same profiles if the adsorber were to contain five adsorption stages with fixed-bed WGS steps inbetween. The necessary sorbent loading indicated by the model does not remain below the experimental loading and, as a result, would not be able to achieve the necessary loading in the first stage to reach 90% total carbon capture. The partial pressure profiles in the case of five adsorption stages are displayed in Figure 7. The CO_2 partial pressure increases in each WGS section and decreases across each of the adsorber stages. The exiting CO_2 partial pressure from the first stage is approximately 125 psi. As a result, the equilibrium loading of the sorbent is much lower than when continuous WGS is possible. These results indicate that continuous WGS is necessary, at least in the first stage, in the adsorber column to fully utilize the capture potential of the sorbent. It is possible that the adsorber design could include one or two stages with WGS catalyst coated on rods throughout the stage, followed by a top stage just captures the remaining CO_2.

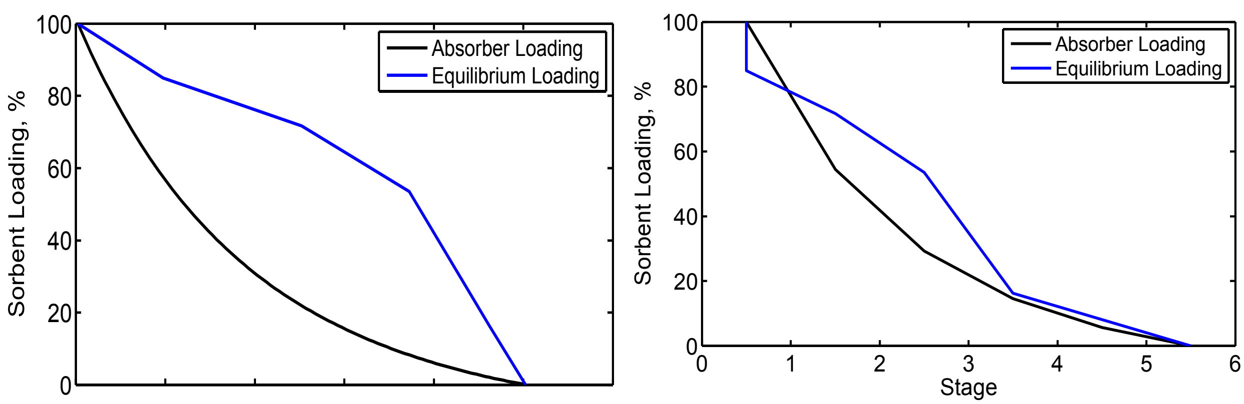


Figure 6. Sorbent Loading Profiles through the Adsorber from Experimental Equilibrium Data and the Model for Continuous WGS (left), and WGS Between Stages (right)

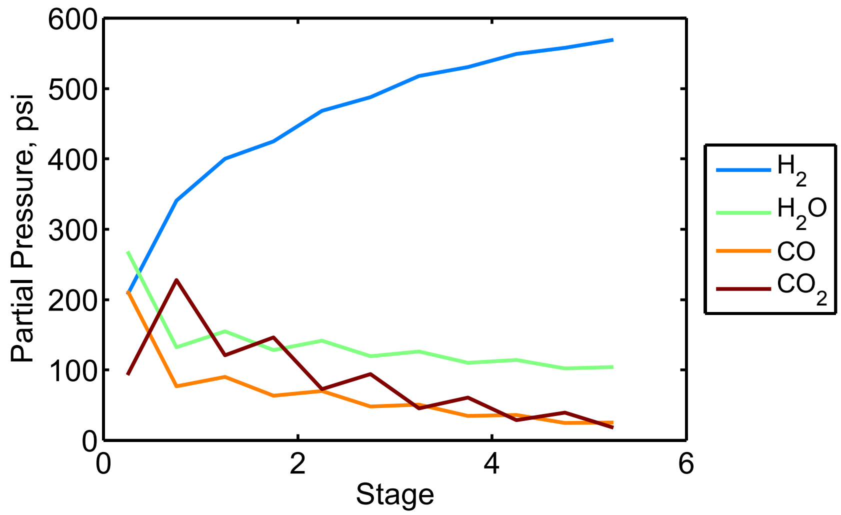


Figure 7. Partial Pressure Profile of the Major Syngas Constituents through a Five-stage Adsorber with WGS Sections Between each Stage

The partial pressures through a modeled regenerator with five stages is shown in Figure 8. The flow rate of steam injected in the bottom of the regenerator was set equal to the amount of CO_2 that enters on the sorbent particles. Consequently, the partial pressure profiles essentially mirror each other throughout the column.

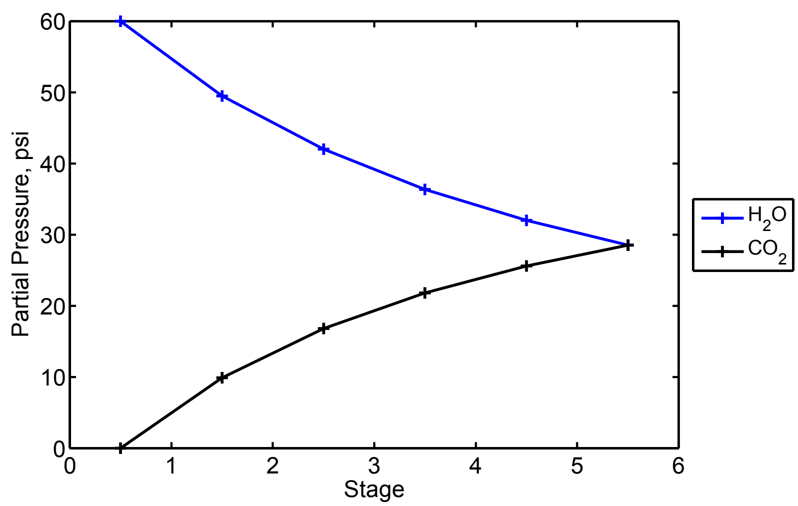


Figure 8. Partial Pressure Profile of the Gas through a five-stage Regenerator

The energy balance performed on each stage of the adsorber and regenerator can determine if the amount of heat generated in the adsorber is enough to counter the heat input required in the regenerator. It was expected that the sorbent would become hotter from the heat of adsorption in the adsorber and the opposite in the regenerator. In addition, the slightly exothermic WGS reaction would generate additional heat that would need to be transferred from the adsorber column. In each column, the sensible energy change of both the gases and the sorbent were taken into account. The change in specific heat of each as they changed composition was also considered. The resulting analysis revealed that there was roughly 20% excess heat generated in the adsorber column than was required in the regenerator, regardless of the configuration. The necessary heat transfers required into and out of each stage are displayed in Figure 9. While the regenerator heating loads are relatively constant for each stage, the stage cooling loads in the adsorber and WGS sections vary greatly. This variability must be considered in the implementation of a practical design.

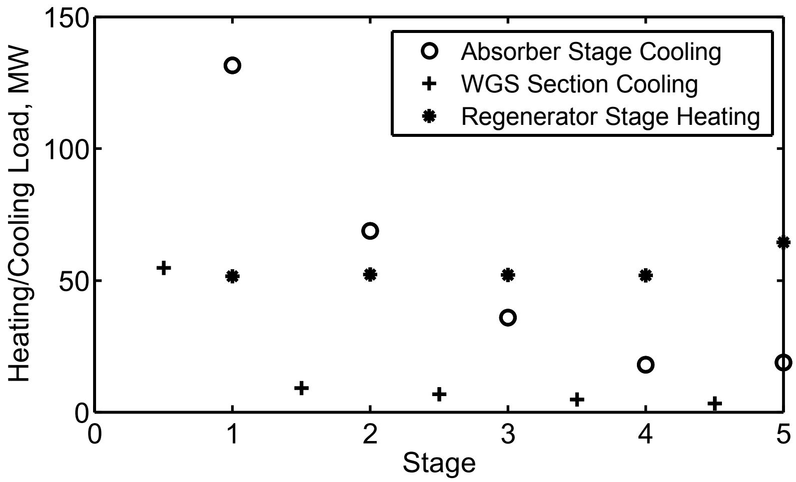


Figure 9. Heat Transfer Amounts Necessary to be Transferred from each Section of the Adsorber and into the Regenerator

While the process has been shown to be technically feasible, numerous challenges remain. It was shown that continuous WGS was necessary in the first stages of the adsorber, and either a dual-function WGS or sorbent particle must be developed or other means to accomplish the continuous WGS must be determined. In addition, detailed modeling of the fluidized bed design is required to optimize the implementation of heat management in the adsorber and regenerator, including the design of heat transfer tubes and balancing the heat loads between different stages of the two vessels. In addition, the movement of the sorbent material through these columns will be a major challenge. The mass balance on the system reveals that the necessary mass flow rate of sorbent throughout the system to achieve 90% capture is over 1600 kg/s. Not just moving these particles, but pressurization of them will be a large operational challenge.

3.0 Sorbent Development

Sorbent development efforts in this project were focused around MgO based sorbents and built upon previous work where MgO sorbents were developed for CO_2 capture from exhaust gas at mild temperatures. The MgO sorbents of special interest are promoted using alkali salt metals to enahance sorbent activity and regenerability under warm conditions. Sorbents evaluated in this study used a basic magnesium carbonate precursor as an MgO source. The alkali metal promoters and their source were selected based on our experience and know how.

3.1 Sorbent Screening Methodology

Although the importance of the development of sorbents for CO_2 capture at elevated pressure and temperature has been widely recognized and reported with the increasing numbers of the publications in recent years, the majority of the sorbent characterization and performance testing reported in the literature were performed at relatively mild conditions (i.e., ambient pressure with less than 200^{o}C) and were not conducted at conditions relevant to CO_2 capture from syngas. Performance and adsorption/regeneration dynamics of these sorbents could change dramatically under high partial pressures of CO_2 and H_2O in the syngas stream. Thus, one of the major development efforts in this project was to upgrade/build testing apparatuses to accommodate the screening of sorbents under the relevant syngas conditions with high throughput and reproducible results. High pressure microreactor and high pressure thermogravimetric analyzer (HP-TGA) were the two experimental apparatuses that were utilized throughout the project. All of the sorbents developed under this project were subjected to sorbent screening using the high pressure microreactor. The high pressure microreactor was used to determine the CO_2 loading capacity and the performance stability of the sorbents under multi-cycle operation. Sorbent characterization was performed on selected fresh and aged samples after the multi-cycle tests.

In addition to studying the sorbent activity and stability in the high pressure microreactor system, a thorough understanding of the CO_2 adsorption/desorption at different temperatures and CO_2 partial pressures was pivotal to determine the viability of the reverse temperature-swing process. Hence, a parallel effort was instituted, using the HP-TGA system to gain a more fundamental understanding of the adsorption and desorption dynamics of the baseline material. HP-TGA was utilized extensively to produce adsorption-desorption isotherm and adsorption-desorption isobar of the baseline material. The influence of steam in the syngas on the CO_2 loading was also studied in the HP-TGA system.

3.2 Process Description

High Pressure Microreactor System

The P&ID of the high pressure microreactor system is presented in Figure 10. The system consists of three main sections: (i) simulated syngas generation, (ii) packed-bed reactor, and (iii) gas analytics. Gases are supplied to the unit by the central gas supply network that is capable of supplying N_2, CO_2, H_2, and CO to the system at a maximum of 500 psig. In-line regulators are used to regulate the delivery pressure to the gas mass flow controllers at 350 psig. The simulated syngas was generated by blending N_2 and CO_2 at the desired ratio. The gas flow rates are controlled by mass flow controllers. Water is introduced to the system by an ISCO Teledyne I syringe pump and blended with the gas stream inside the temperature-controlled hot box, which is maintained at 160-170^{o}C throughout the testing period. Both of these streams are preheated separately by flowing through 1/16 in. tubing wrapped around a cartridge heater. The temperature of the cartridge heater is controlled at a set point that is between 160-170°C, which is above the dew point of the water in the mixed stream but below the boiling point of water at the operating pressure. Upon preheating, the dry gas mixture and steam are mixed to produce wet syngas. The wet syngas mixture is then routed to a 6-port gas-switching valve. The packed-bed reactor has been designed as a conventional, down-flow packed bed consisting of sorbent material sandwiched between two layers of quartz wool and SiC particles used as diluent. The packed-bed reactor is constructed from a ½ in. OD by 11 in. long high pressure stainless steel tube. The packed-bed reactor can accommodate about 2-3 g of sorbent per inch of the reactor length, depending on the density of the material. The reactor is heated using three 200 W clamp heaters, which are mounted on a 1 in. OD aluminum sleeve wrapped around the reactor tube. The gas leaving the reactor is introduced into a Peltier cooler located outside the temperature controlled box to condense out water from the gas stream. The H_2O-lean stream is then sent back into the temperature controlled box again, before entering a back pressure regulator, V-102, which controls the system pressure. N_2 is then introduced into the exit gas stream, prior to being sent to the CO_2 analyzer, as a makeup gas for the condensed H_2O to accurately represent the volumetric CO_2 content of the reactor outlet stream.

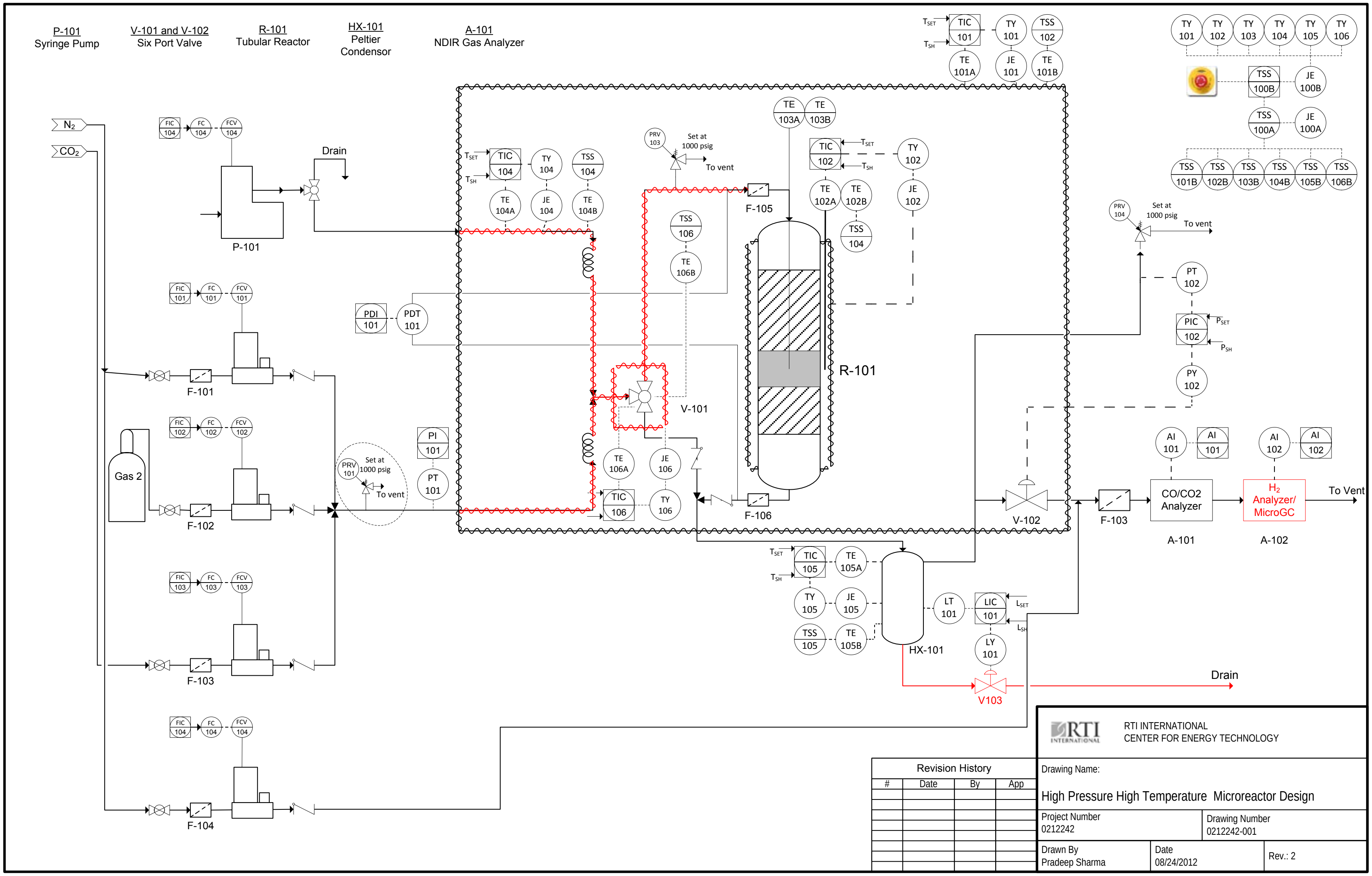


Figure 10. P&ID of High Pressure Microreactor System

A typical CO_2 adsorption/regeneration experiment consists of 6 steps:

(i) Preheating: After loading the reactor with sorbent and checking the system for leaks, N_2 flow through the reactor is initiated. The desired temperature set points are provided to the hot box, preheater, packed-bed reactor, and condenser. Once the temperature process values reach the set points, the system is pressurized to the desired set point using nitrogen flow.

(ii) Feed test: When the system temperature and pressure reach the experimental operating conditions, the feed gas is switched from nitrogen to a wet syngas mixture that bypasses the system. This ensures that the system plumbing downstream of the reactor (including the condenser and knockout pot) are purged and contain a steady syngas composition, which is recorded by the NDIR analyzer.

(iii) Analytical purge step: The $H_2O/CO_2/N_2$ mixture is purged from the bypass lines by switching to a H_2O/N_2 gas mixture.

(iv) Adsorption step: The $H_2O/CO_2/N_2$ mixture is fed to the packed-bed reactor.

(v) Regeneration: The sorbent is regenerated by changing the composition of the feed gas mixture. The regeneration of the sorbent can be performed under a broad range of CO_2 partial pressures with and without the presence of H_2O.

High Pressure Thermogravimetic Analyzer (HP-TGA)

The Process and Instrumentation Diagram (P&ID) of the HP-TGA system is shown below in Figure 11. The HP-TGA was utilized to generate adsorption-desorption isotherms and adsorption-desorption isobars of the materials. Accurate analysis of weight change of a sample in a reactive or non-reactive gas flow at high temperatures and pressures could be done using the Cahn HP-TGA. There are three sections in HP-TGA consisting of feed gas generation, Cahn HP-TGA, and gas cooling and depressurization. Two gas streams (CO_2 and Ar) and one vaporized water stream were mixed to create a gas bath for the sample in each experiment. The gas streams were regulated by mass flow controllers and the water stream was controlled by a Teledyne ISCO pump at the desired flow rate. Water entered as a liquid and was heated by a rope heater until it became a gas and mixed with the two other test gases (CO_2 and Ar). Another rope heater preheated the gas bath streams before mixing with the steam and continued heating the mixture until it enters the reactor vessel. A third gas stream (He) maintains an inert flow of gas over the Cahn balance head. All input gas streams can be pressurized to pressures of 900 psi and the gas bath stream can be heated to 600°C. These gases flowed over the sample while the weight of the sample was measured in the balance head of the Cahn HP-TGA section. A 1600 W furnace heated the reactor and sample during experiments. A thermoelectric cooler maintained a low temperature at the reactor joint to maintain an O-ring seal. In the gas cooling and depressurization section, the gas was cooled in a counter-flow heat exchanger with process cooling water. Liquid condensate was knocked out in a liquid accumulator. A back-pressure regulator (BPR) maintained the desired pressure in the system. Gases are vented after the BPR near atmospheric pressure.

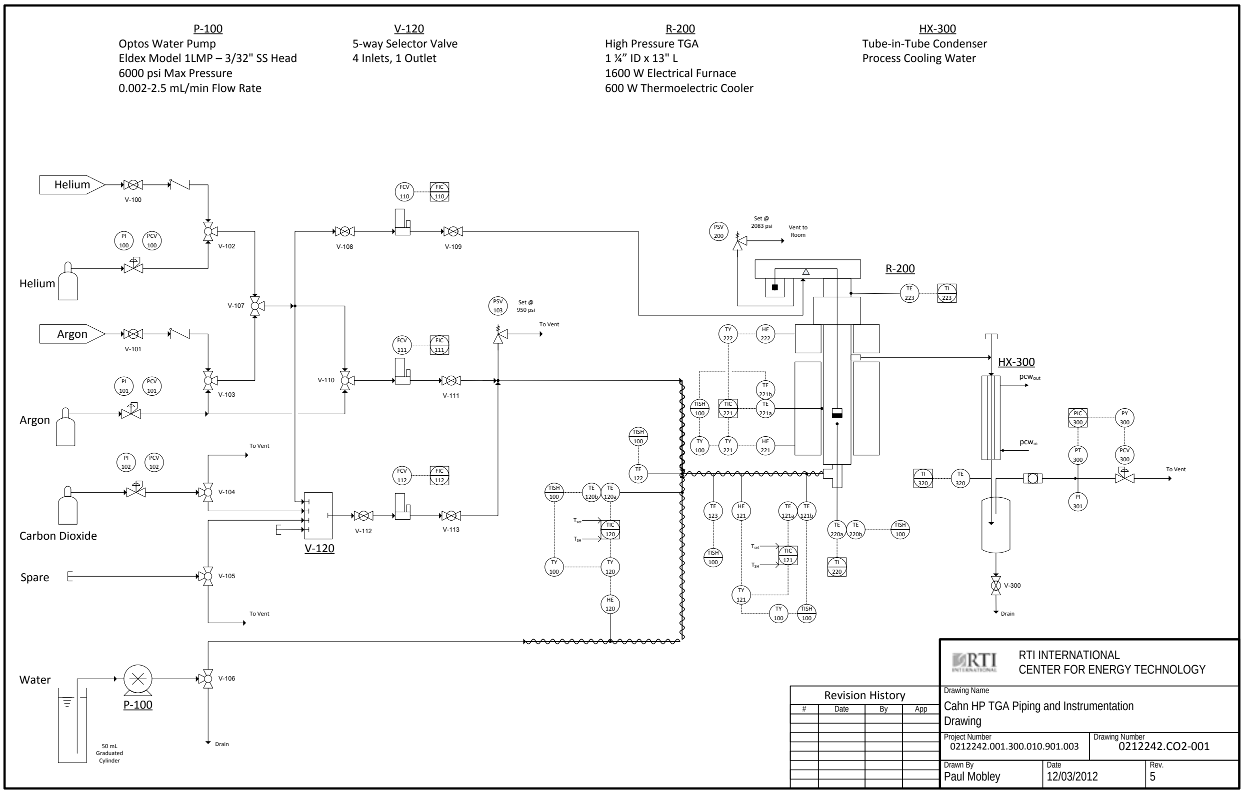


Figure 11. P&ID of High Pressure Thermogravimetric Analyzer System

3.3 Results and Discussion

For the preliminary sorbent screening in the microreactor system, each adsorption-regeneration cycle included exposing the sorbent to a CO_2/N_2 mixture for CO_2 adsorption, followed by the regeneration of the sorbent in N_2 at the same reaction temperature and pressure. Besides evaluating the sorbent in terms of its sorption capacity, each sorbent was also tested for multiple adsorption-regeneration cycles to understand the sorbent stability. Steam forms a significant portion of the syngas entering the CO_2 and is also an important component of syngas due to its participation in the water gas shift reaction. Considering our process design wherein the water gas shift reaction and CO_2 capture processes might occur in stages or simultaneously, the extent of water gas shift reaction and therefore the CO_2 capture extent will be dictated by the concentration of steam. Steam also participates significantly in the CO_2 capture process through formation of an important intermediate species. Thus, the presence of steam affects the chemistry of the CO_2 capture process and the CO_2 capture mechanism. Hence, it was critically important to involve steam in the feed gas to closely mimic the CO_2 capture process. A set of experiments were completed with and without steam in the feed gas to be able to study the effect of steam on the sorbent performance (capacity and stability).

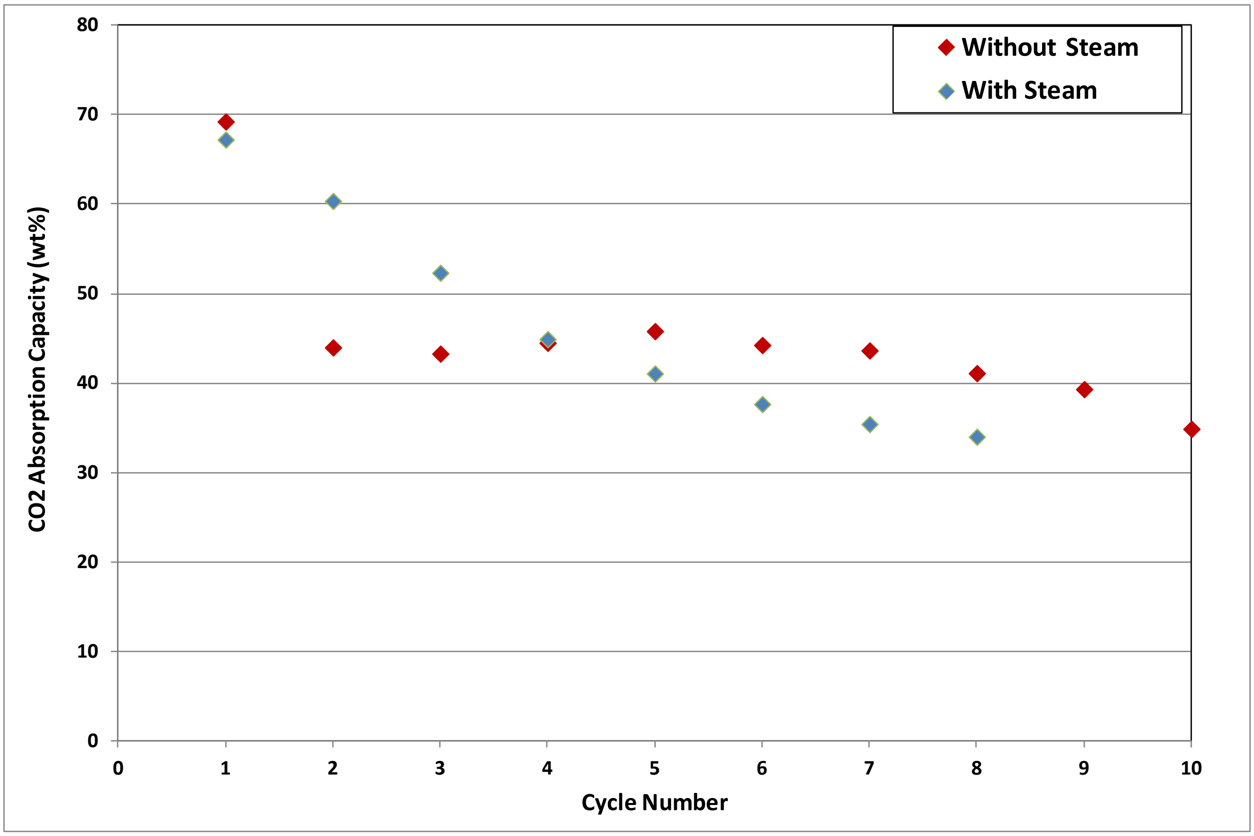


Figure 12. MgO/Pro-A Sorbent Performance for Dry and Wet Syngas (T- 450°C, P_T- 300 psig, P_{CO2}- 150 psia, P_{H2O}- 15-45 psia)

Figure 12 presents the results for a multi-adsorption/regeneration cycle experiment performed on the baseline MgO/Pro-A (promoter A) based material. It presents the CO_2 adsorption capacity, defined as the weight of the CO_2 adsorbed per gram of the fresh sorbent and expressed in percentage, as a function of cycle number. It compares the sorption capacities of the sorbent on exposure to dry gas (without steam) and to wet gas (with steam). CO_2 adsorption was carried out using a 150 psia CO_2 stream in N_2, containing 0-45 psia H_2O, and was followed by a regeneration in a N_2 stream without any CO_2. Both the adsorption and regeneration were carried out at a reactor temperature and pressure of 450°C and 300 psig, respectively. Each data point on the plot represents one adsorption/regeneration cycle. As can be seen in Figure 12, the CO_2 sorption capacities for the dry and wet gas are very identical at the beginning of the experiment. However, a relatively faster rate of decay was observed with the presence of steam. This result establishes the importance of the steam in the CO_2 capture process. Hence moving forward, all the sorbent development work was performed with the presence of steam in the feed gas.

As stated earlier, detailed characterization of the sorbent sample at various stages along the CO_2 capture process was performed to improve sorbent properties by understanding the role of various sorbent components. Also, it was crucial to understand effect of steam on sorbent performance, especially material integrity, as the proposed CO_2 capture process involves 10-20% steam in feed gases. Significant efforts were devoted to understand CO_2 capture and deactivation mechanism of the material. For this purpose, below mentioned controlled samples were generated and analyzed using XRD, ICP, TGA and BET techniques. .

Saturated Sample

CO_2 capture testing was performed in high pressure microreactor and high pressure TGA systems. CO_2 capture process involved adsorption of CO_2 on the sorbent followed by desorption of CO_2, which was also referred to as the regeneration of the sorbent. This sorbent adsorption-regeneration cycle involved several steps to carefully evaluate the sorbent performance. A sample that was removed from the reactor after the completion of the adsorption step, which involved complete saturation of sorbent with CO_2 at the required experimental conditions, was referred to as the Saturated Sample. Different saturated samples were generated using both dry and wet CO_2 i.e. feed gas with the presence/absence of steam. These samples were analyzed using XRD and TGA techniques. Amount of $MgCO_3$ and promoter from XRD analysis revealed information on active sites for CO_2 adsorption. Weight loss in TGA indicates extent of regeneration. Samples saturated using wet CO_2 provided valuable information on the role of steam in CO_2 capture mechanism. Some partially-saturated sample were also generated to gain a deep understanding of the CO_2 capture mechanism. These partially-saturated samples were generated by intermittently terminating the adsorption step. XRD analysis of these samples provided the information about the intermediate species formed during the course of the CO_2 capture mechanism.

Deactivated/Steady-state Sample

A sample was recovered after multiple adsorption-regeneration cycles and after reaching steady state capacity or significant decrease in initial activity. This sample was characterized by XRD and elemental analysis. These results were compared with fresh samples for the determination of structural and compositional changes during adsorption and regeneration. For example, if there is promoter substrate loss is the deactivation mechanism, we can observe a major intensity change in the XRD pattern. Similarly, a decrease in promoter amount can be seen in ICP results. Any changes to MgO phase also could be identified in the XRD analysis of aged sample.

All fresh samples predominantly consisted of peaks realted to MgO and promoter. The aged sample (saturated and regenerated) was tested for 10 adsorption-regeneration cycles in the microreactor and was removed after completing the adsorption step for the 10^{th}cycle, making sure that it stays in the saturated $MgCO_3$ form. This sample was referred to as the "saturated sample " and was submitted for the XRD analysis. The "regenerated sample" was generated by exposing the "saturated sample" to higher temperatures in the furnace. Exposure to higher temperatures reverses the CO_2 adsorption reaction, causing desorption of CO_2 and regeneration of the sorbent. In addition to the expected peaks for MgO and $MgCO_3$, the XRD pattern of the saturated sample also contains the peaks for a desirable (from our previous experience) MgO-promoter complex suggesting that both Mg and promoter participate in the CO_2 capture process. The absence of this complex in the regenerated sorbent suggests its reversible formation during the adsorption process and also confirms its contribution in CO_2 sorption.

The next step was to better understand the reaction mechanism and to better identify the role of various species during the course of the reaction. To achieve this objective, the aged sample was generated in the partially saturated form to identify the intermediates. The partial saturation implied incomplete adsorption. Typical CO_2 adsorption capacity of the sorbent under study was about 40-60 wt%. The concerned partially saturated sample was generated after stopping the CO_2 adsorption capacity at 12 wt%.

The XRD patterns conclud that all three samples contain the desired MgO-promoter complex. This established that reaction initiates through the formation of this complex, which may be acting as CO_2 carrier. The intensity of the peak did not change much during the course of one to ten cycles. This suggests that the reaction leading to the formation of the complex does not decay during the course of the adsorption-regeneration cycles. Addition, the partially saturated sample shows a peak for brucite [$Mg(OH)_2$], suggesting that CO_2 adsorption is occurring though the formation of brucite as an intermediate, which in turn lead to $MgCO_3$ formation. Steam reacts with MgO forming $Mg(OH)_2$ (brucite) species, which affects the CO_2 capture process. This intermediate formation also establishes the importance of steam concentration in the feed gas during the CO_2 capture process. The above sorbent characterization not only establish formation of the MgO-promoter complex during the CO_2 capture process but also emphasize the importance of sorbent composition with respect to the Mg and promoter, which would establish the extent of the complex formation, leading to CO_2 adsorption. Hence, the next step was to study the effect of sorbent composition on the sorbent properties including the sorbent capacity and stability and surface properties. In addition to the XRD analyses to understand the reaction chemistry, sorbents (fresh and aged) were also subjected to other analyses, including BET and ICP analysis. Table 1 below presents the results of the BET and ICP analysis for $MgO/Na_2CO_3/NaNO_3$ based sorbents.

Table 1. ICP Analysis for the MgO based Sorbent					
Sample	**BET Surface Area (m^2/g)**	**ICP, CHN analysis (wt.%)**			
		Mg	**Promoter**	**C**	**N**
13146-174 (As prepared SCI extrudate)	37	47.98	9.33	2.19	0.76
13580-13 (Regenerated after 10 cycles)		47.89	7.36	2.54	< 0.1

Effect of Sorbent Composition on the CO_2 Capture Process (Effect of Mg:Promoter Ratio)

Characterization of the aged sorbent samples established the formation of the desirable MgO-promoter complex during the CO_2 capture process which suggests the participation of both Mg and promoter in the CO_2 capture process. The chemical formula of the complex suggests it's formation should be a function of relative composition of Mg and promoter species. To derive further insights into the CO_2 capture mechanism, five different sorbents with different Mg:promoter ratio were synthesized. Table 2 presents the composition of these sorbents.

To study the effect of Mg:promoter ratio on the sorbent performance, prepared samples were saturated with CO_2. For this purpose, five ½" OD, 10" long stainless steel tubular reactors were connected in series. About 4 gms of fresh sorbent material was packed in these reactors and placed in muffle furnace. These materials were then exposed to pure CO_2 under continuous flow at 450°C and 300 psig pressure for one hour. This ensures complete saturation of the sorbents at the reaction conditions. The saturated samples were then characterized using XRD and TGA analysis to extract important information about role of Mg:promoter ratio in determining sorbent performance and stability.

The XRD analyses revealed that the intensity of peak associated with the complex is directly proportional to promoter concentration. Saturated sorbents did not contain any significant peaks for free MgO or promoter phases, suggesting complete conversion of both the species to $MgCO_3$ or the complex. Additionally, $MgCO_3$ peak intensity is proportional to Mg content in the sorbent. Also, the presence of a specific type of promoter precursor in the saturated samples suggests it doesn't seem to be directly participating in formation of the complex or CO_2 capture. Additionally, regeneration of saturated samples was carried out in ambient pressure TGA over the temperature range of 25-600°C under Ar flow. TGA experiments were designed to study the effect of sorbent composition on its activity and also gain insights into the regeneration behavior of the sorbents. Figure 13 shows the results of the TGA experiments.

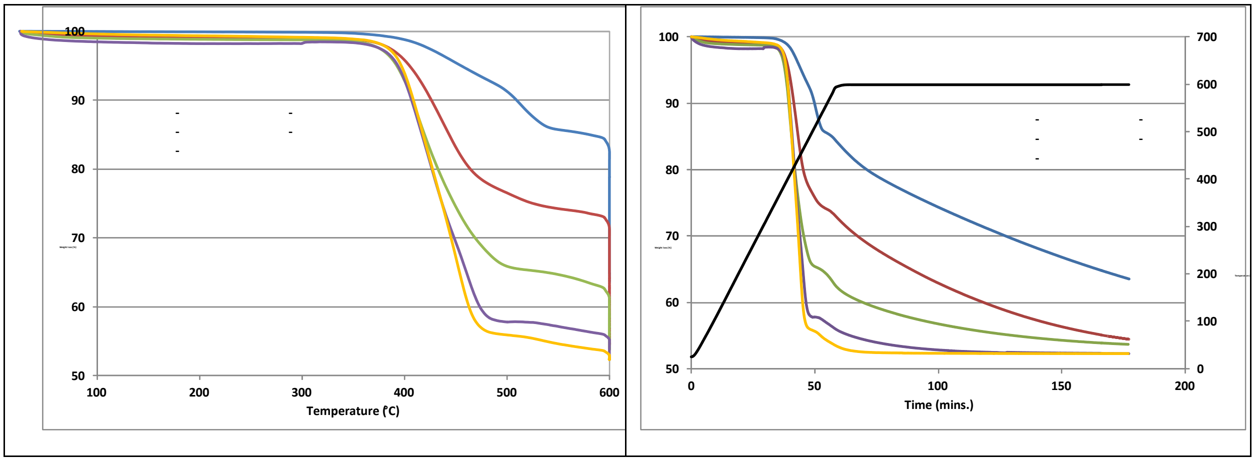


Figure 13. TGA Analysis of Sorbents with Different Mg:Promoter Ratios

The above graphs show the plot of weight of the sorbent as a function of time/temperature. The exposure of the sorbent to higher temperature causes the reversible conversion of the complex to MgO and promoter carbonate with liberation of CO_2, leading to decrease in the weight of the sorbent. The decrease in the weight of the sample with time/temperature refers to the capacity of the sorbent. Table 2 also enlists the experimental adsorption capacity of these sorbents. $MgCO_3$ and Eitelite are the two carbonated products formed as a result of CO_2 chemisorption reaction. Thus, the theoretical sorbent capacity is expected to be proportional to the concentration of MgO in the sorbent. As expected, the capacity increases with the increase in the Mg:promoter ratio and was found to be proportional with MgO content.

Table 2. Composition of $MgO/Na_2CO_3/NaNO_3$ based Sorbent

Mg/Na ratio	Sorbent Capacity (wt%)
A	57.4
B	83.7
C	86.1
D	91.2
E	91.1

One of the key observations was that materials with lower Mg:promoter ratio produced higher concentration of the complex and required higher regeneration temperatures. Additionally, the regeneration curve suggests two different regeneration steps with a faster step and a slower one.

The extent of regeneration in the first step seems to be proportional with MgO content of the sorbent suggesting that it is the $MgCO_3$ regeneration, while the second step is due to the CO_2 released from the complex. Also, CO_2 release from the complex is found to be slower for the species with the lower Mg:promoter ratio suggesting that higher promoter content promoted stronger bond formation and faster kinetics for the adsorption reaction and adversely, slower kinetics for the regeneration reaction. In addition to the testing in the TGA system, sorbents with different Mg:promoter ratios were also tested in the high pressure microreactor system to study their stability. Figure 14 presents the results of the experiments in the high pressure microreactor system. As expected capacity increases with increase in Mg:promoter ratio.

In an attempt to identify other promoters, we conducted a small test to compare the activity and stability of the sorbent with a different promoter precursor (P2). These sorbents were tested in the high pressure microreactor system to study the stability of the sorbents over multiple cycles.

As can be seen from the plot on the left in Figure 15, P2 promoted sorbent exhibited higher activity in the beginning, but the deactivation with the number of cycles was faster, with both exhibiting similar capacity at the end of the five cycles. The plot on the right in Figure 15 shows the breakthrough curves for the two samples, indicating that the P2 promoted sample exhibited slower adsorption kinetics.

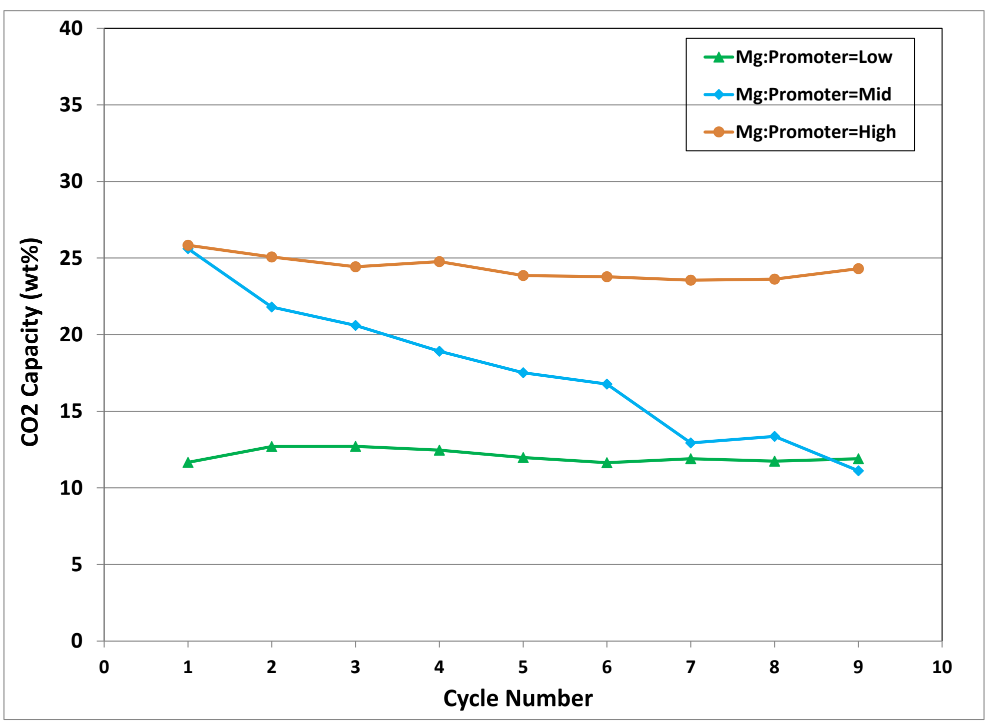


Figure 14. Effect of Mg:Promoter Ratio on Sorbent Activity and Stability

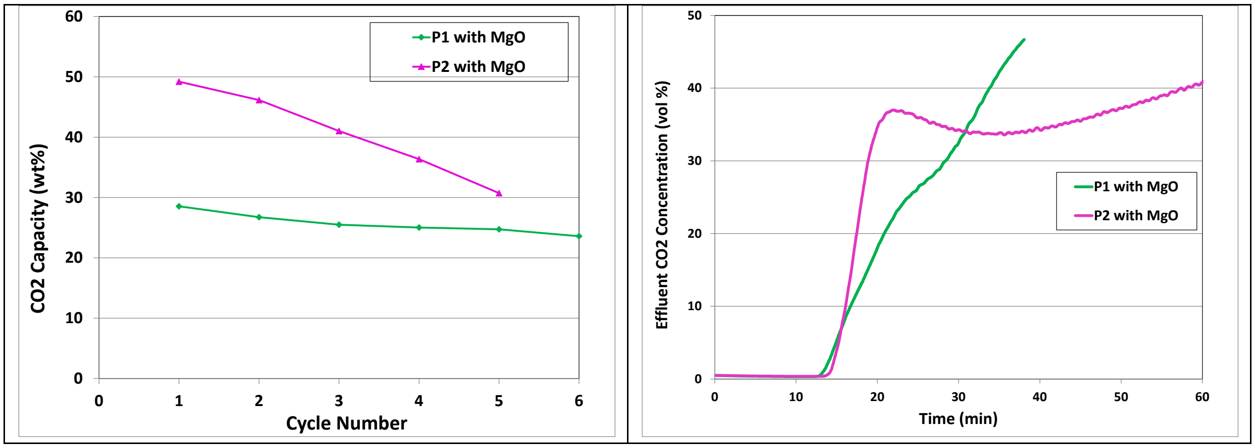


Figure 15. Effect of Promoter on Sorbent Activity and Stability

Investigation of Long Term Stability and Deactivation Mechanism

The understanding gained from the Mg:promoter ratio study was utilized to optimize the sorbent composition. The next task was aimed at testing the long term stability of the sorbent in a continuous process to determine the dynamic capacity of the sorbent in the CO_2 capture process. Each sorbent was tested for more than 50 adsorption-desorption cycles to determine the long term stability of the sorbent.

Figure 16 shows the result of this study. Each data point on the plot refers to an adsorption-desorption cycle. Adsorption was carried using a CO_2-N_2 feed with 150 psia of CO_2, followed by regeneration in the nitrogen feed. The reaction temperature and pressure was held constant at 450°C and 300 psig for both the adsorption and desorption steps. In the first set of experiments, three different sorbents with varied Mg:promoter ratio were tested. These sorbents exhibited the best performance in the previous study while studying the effect of Mg:Na ratio on the sorbent performance.

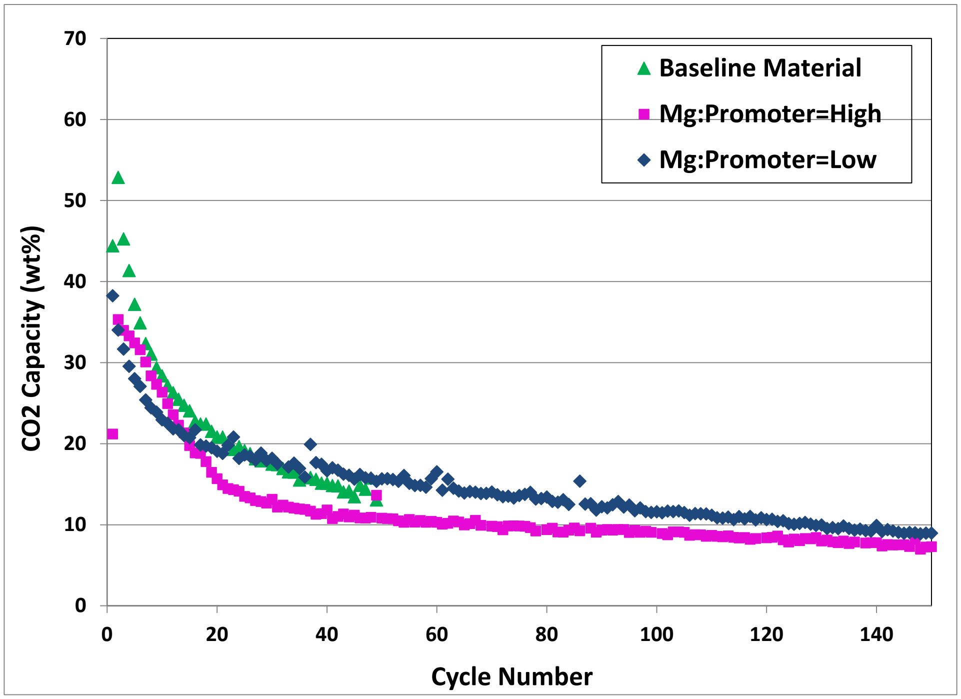


Figure 16. Long-term Stability of MgO based Sorbents

As can be seen from the plot, decrease in sorbent adsorption capacity, indicating sorbent deactivation, was observed as a function of cycle number. The deactivation was very fast in the first 20 cycles and slowed down later. One of the key observation was that all the sorbents exhibited similar initial capacity (40-50 wt%) and deactivated to about 10 wt% at the end of 150 cycles. The sorbents continued to deactivate throughout the course of 150 cycles. Additionally, each sorbent seems to follow a similar deactivation pattern. The above plot shows that sorbent capacity continued to decrease below 10 wt%. Hence, sorbent physicochemical properties need to be adjusted so as to improve its stability.

Various sorbent characterization techniques, including XRD, SEM/TEM, EDS and BET were utilized to study the change in the compositional and morphological properties of the sorbent to understand the cause for the loss in the sorbent capacity. The XRD patterns revelaed that with the increase in the number of cycles, the intensity of the promoter decreased, suggesting leaching during the long term adsorption-desorption cycling. Also, the intensity of MgO peak increased and $MgCO_3$ decreased in deactivated sample. This could be attributed to larger MgO crystallites segregated from the complex formed with the promoter.

The MgO crystallite size in fresh and deactivated samples was determined from XRD patterns applying the Scherrer equation. Table 3 shows the results of these analyses. Table 3 also enlists the BET surface area and the pore volume of the fresh and deactivated sorbent samples. As can be seen from the table, there is significant increase in the particle size and decrease in the surface area, suggesting that MgO particle growth could be the source of deactivation. MgO particle size has more than doubled over the course of 150 adsorption-desorption cycles, and BET surface area and cumulative pore volume have significantly decreased thereby decreasing the total number of active sites for CO_2 adsorption.

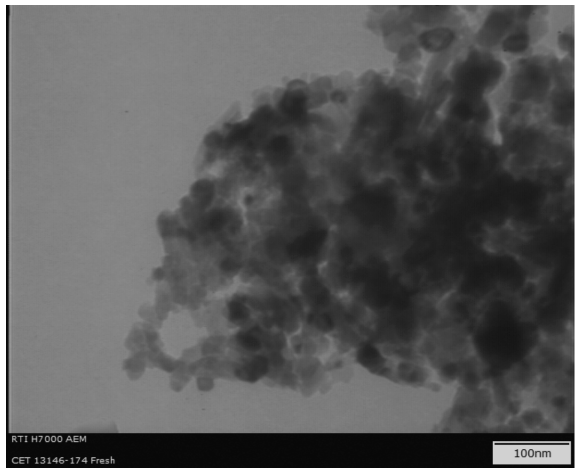


Figure 17. TEM and EDS Analysis of the Fresh Sample

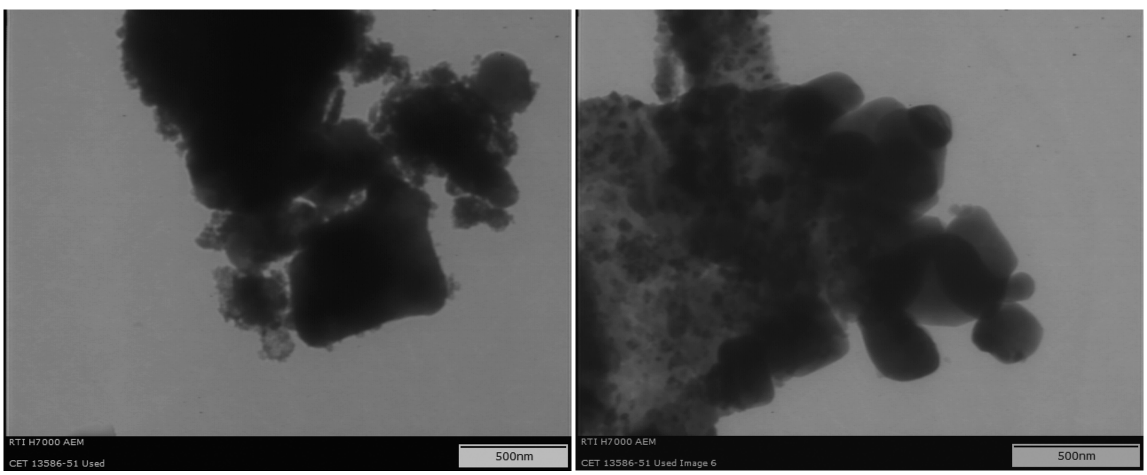


Figure 18. TEM and EDS Analysis of the Aged Sample

TEM images and corresponding EDS patterns of fresh and deactivated and regenerated sorbents are presented in Figure 17 and Figure 18 respectively. These figures reveal that the fresh sample is fairly homogeneous and contains well dispersed particles with diameters less than 50 nm. The small, equigranular particles contain primarily Mg and O and seem to make up most of the sample as observed by TEM-EDS.

The deactivated sample primarily consist two types of particles: large, high contrast single particles, and small particles that appear to contain the remains of the equigranular particles from the fresh sample. The high contrast single particles contain Mg, O and varying amounts of promoter. The promoter peak heights varied within one large particle. The small particles have a similar elemental composition to the particles in the fresh sample. These particles might be contributing to remaining activity in the deactivated samples.

As can be seen from the TEM images for the fresh and the aged sorbent, the adsorption and desorption cycling led to MgO grain growth and segregation of MgO and alkali salts. This was confirmed by EDS peak intensity of Mg and promoter species on fresh and deactivated samples. These results are in line with XRD and BET data, where significant increase in MgO crystallite size and decrease in surface area was observed.

Table 3. BET and Particle Size Analyses of MgO based Sorbent

	Fresh	**Aged (deactivated)**
MgO Particle Size (Å)	179	396
BET Surface Area (m^2/g)	40	5
Pore volume (cc/g)	0.02	0.002

Above characterization results revealed following three primary reasons for sorbent deactivation:

1. MgO crystal growth
2. Segregation of MgO and alkali salts
3. Loss in surface area

The above results indicate that the key to develop an active and stable sorbent is to avoid the sorbent sintering to control MgO particle growth and to improve homogeneity of MgO and alkali salts. The approach that was followed to counteract the particle growth during the testing process was to pre-sinter the sorbent material, prior to CO_2 capture testing. In essence, we tried to mimic the particle growth occurring during the CO_2 capture process, prior to the sorbent performance testing. RTI developed best practices were used to achieve this Figure 19 presents the results of this test. As can be seen from the plot, the optimized sorbent exhibited a similar initial activity as the previous sorbent. However, the deactivation was observed for only the first 15-20 cycles followed by a stable performance with a sorption capacity of about 15 wt% for the next 130 adsorption-desorption cycles. Thus, the presintering process helped achieve a stable performance for the sorbent.

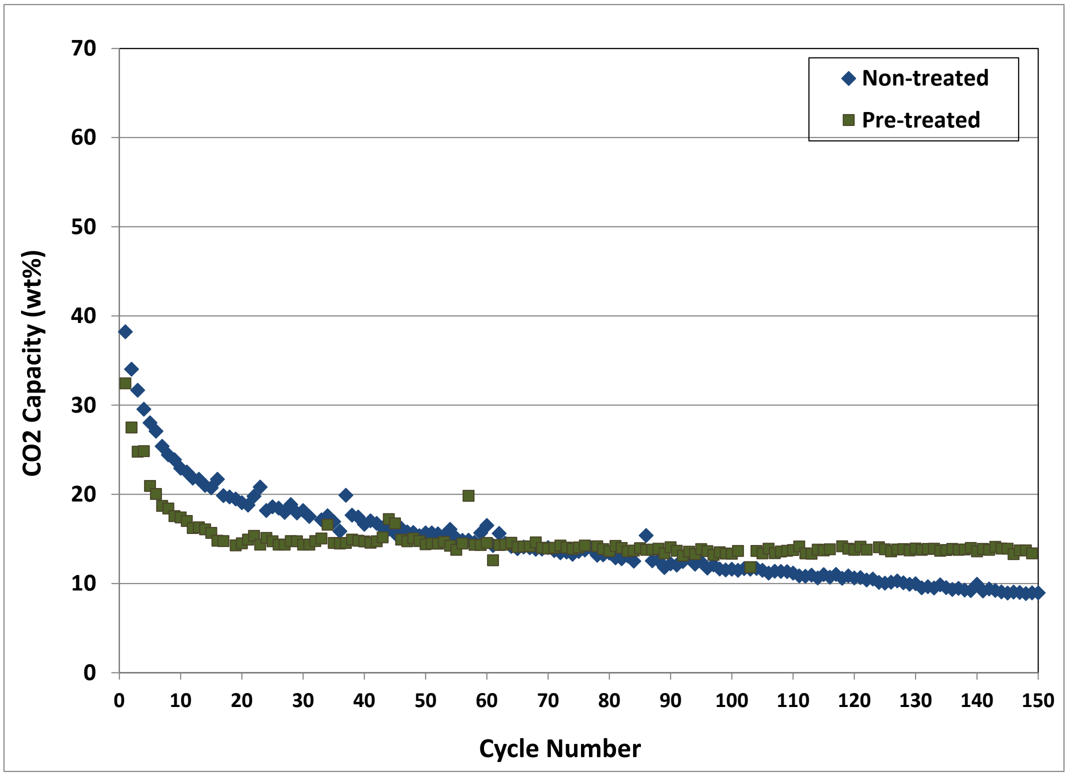


Figure 19. Performance Testing of $MgO/Na_2CO_3/NaNO_3$ based Sorbent with Mg:Na-3.75:1

4.0 Technical Assessment of IGCC with Warm CO_2 Capture

4.1 Baseline IGCC Power Plant with CO_2 Capture

A GEE gasifier based IGCC power plant using a dual stage Selexol™ process to capture sulfur and CO_2 and with a net electricity production capacity of 550 MWe was used as the baseline. A detailed description, analysis and economic assessment of the baseline case is available in the "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity" report prepared by DOE (DOE/NETL-2010/1397). This specific IGCC with CO_2 capture plant is Case 2 in this report and henceforth is referred to as "DOE Case 2".

4.1.1 Process Description

Gasification

The DOE Case 2 utilizes two GE gasification trains operating at a total coal feed rate of 5,302 tonnes/day. The largest operating GEE gasifier is at Polk Power Station. However, that unit operates at about 2.8 MPa (400 psia). The gasifier in this study, which operates at 5.6 MPa (815 psia), will be able to process more coal and maintain the same gas residence time. The slurry feed pump takes suction from the slurry run tank, and the discharge is sent to the feed injector of the GEE gasifier. An air separation plant supplies 4,171 tonnes/day of 95 mol% oxygen to the gasifiers and the Claus plant. Carbon conversion in the gasifier is assumed to be 98 percent including a fines recycle stream. The coal slurry and the oxygen react in the gasifier at 5.6 MPa (815 psia) and 1,316°C (2,400°F) to produce syngas.

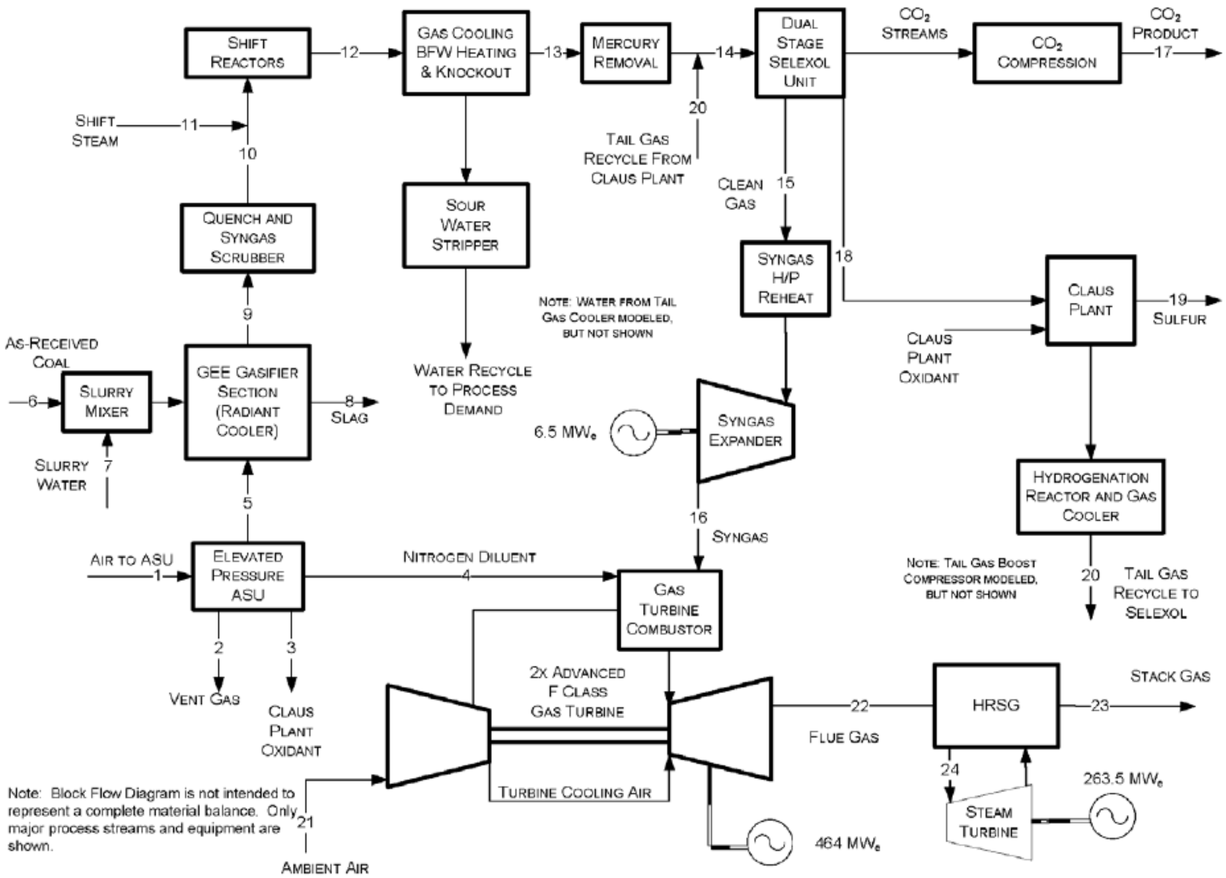


Figure 20. Block Flow Diagram of the GEE Gasifier based IGCC Power Plant with CO_2 Capture, Referred to as DOE Case 2

Syngas Conditioning

The syngas consists primarily of hydrogen and carbon monoxide, with lesser amounts of water vapor and carbon dioxide, and small amounts of hydrogen sulfide, COS, methane, argon, and nitrogen. The heat in the gasifier liquefies coal ash. Hot syngas and molten solids from the reactor flow downward into a radiant heat exchanger where the syngas is cooled. The syngas exiting the radiant cooler is directed through water in the quench chamber and exits at 232°C saturated with water. The remaining chlorides, NH_3, SO_2, and PM are removed by a water quench in a scrubber and the gas exits saturated with water at 206°C. Steam is added to the syngas exiting the scrubber to adjust the H_2O:CO molar ratio to 2:1 prior to the first sour gas shift reactor (SGS). The hot syngas exiting the first stage of SGS is used to generate the steam that is added to the syngas in the first place. A second stage of SGS results in 97% overall conversion of the CO to CO_2. The warm syngas from the second stage of SGS is cooled to 236°C by preheating the unshifted syngas prior to the SGS. The SGS catalyst also serves to hydrolyze COS thus eliminating the need for a separate COS hydrolysis reactor. Following the second SGS cooler the syngas is further cooled to 35°C and then passes through a carbon bed to remove 95% of Hg.

Acid Gas Removal

The acid gas removal (AGR) process in DOE Case 2 is a two-stage Selexol™ process where H_2S is removed in the first stage and CO_2 in the second stage of adsorption. The process results in three product streams, the clean syngas, a CO_2-rich stream and an acid gas feed to the Claus plant. The acid gas contains 35% H_2S and 52% CO_2 with the balance primarily N_2 and is routed to the Claus unit where H_2S in the acid gas is partially oxidized to elemental sulfur. The CO_2-rich stream is sent to the CO_2 compression and dehydration section. The CO_2 from the AGR process is flashed at three pressure levels to separate CO_2 and decrease H_2 losses to the CO_2 product pipeline. The HP CO_2 stream is flashed at 20 bar, compressed and recycled back to the CO_2 adsorber. The MP CO_2 stream is flashed at 10 bar and the LP CO_2 stream is flashed at 1 bar, compressed to 10 bar and combined with the MP CO_2 stream. The combined stream is compressed from 10 bar to a supercritical condition at 153 bar using a multiple-stage, intercooled compressor. During compression, the CO_2 stream is dehydrated to a dewpoint of -40°C with triethylene glycol (TEG). The raw CO_2 stream from the Selexol™ process contains over 99% CO_2. The CO_2 stream is transported to the plant fence line and is deemed sequestration ready.

Power Block

The clean syngas from the AGR plant is heated to 241°C using HP BFW before passing through an expansion turbine. The clean syngas is diluted with nitrogen and then enters the CT burner. There is no integration between the CT and the gasifier ASU in this case. The exhaust gas exits the CT at 562°C and enters the HRSG where additional heat is recovered. The FG exits the HRSG at 132°C and is discharged through the plant stack. The steam raised in the HRSG is used to power an advanced commercially available steam turbine using a 124 bar/534°C/534°C steam cycle.

4.1.2 Performance Results

The plant produces a net output of 543 MW at a net plant efficiency of 32.6% (HHV basis). Overall performance for the entire plant is summarized in Table 4, which includes auxiliary power requirements. The ASU accounts for nearly 60% of the auxiliary load between the main air compressor, the nitrogen compressor, the oxygen compressor, and ASU auxiliaries. The two-stage Selexol™ process and CO_2 compression account for an additional 26% of the auxiliary power load. The BFW pumps and cooling water system (CWPs and cooling tower fan) comprise over 6% of the load, leaving 8 percent of the auxiliary load for all other systems.

Table 4. DOE Case 2 Power Plant Performance Summary

Power Summary (Gross Power and Generator Terminals, kWe)	
Gas Turbine Power	464,000
Sweet Gas Expander Power	6,500
Steam Turbine Power	263,500
Total Power, kWe	**734,000**
Auxiliary Load Summary, kWe	
Air Separation Unit	114,610
Power Plant Auxiliaries	17,960
Acid Gas Removal	19,230
CO_2 Compressor	31,160
Claus Plant Auxiliaries	2,030
Miscellaneous Balance of Plant	3,000
Transformer Losses	2,760
Total Auxiliaries, kWe	**190,750**
Net Power, kWe	**543,250**
Net Plant Efficiency, % (HHV)	**32.6**

4.1.3 Capital Cost

The total plant cost of the various plant sections of the GEE gasifier with CO_2 capture are shown in Table 5 along with the owner's costs, total overnight cost (TOC), and total as-spent cost (TASC). The total plant cost comprises of the bare-erected cost plus the cost of services provided by the engineering, procurement and construction (EPC) contractor and project and process contingencies. TPC is an overnight cost expressed in base-year (2007) dollars. The total installed plant cost was reported to be $1,472,845,000, while the total overnight cost was $1,811,411,000 and the total as-spent cost was $2,065,009,000.

Table 5. Summary of Capital Cost Estimation of DOE Case 2

Item	
Total Plant Cost	
Coal and Sorbent Handling	$36,660,000
Coal and Sorbent Preparation and Feed	$58,826,000
Feedwater and Misc. BOP Systems	$38,146,000

Gasifier and Accessories	$250,109,000
Gas Cleanup and Piping	$273,174,000
CO_2 Compression	$38,739,000
Combustion Turbine/Accessories	$129,600,000
HRSG, Ducting and Stack	$46,257,000
Steam Turbine Generator	$39,699,000
Cooling Water System	$37,477,000
Ash/Spent Sorbent Handling System	$46,038,000
Accessory Electric Plant	$89,451,000
Instrumentation and Control	$27,743,000
Improvements to Site	$20,196,000
Buildings and Structures	$18,684,000
Total Plant Cost	**$1,472,845,000**
Owners Costs	
Preproduction Costs	
6 Months All Labor	13,488,000
1 Month Maintenance Material	2,998,000
1 Month Non-Fuel Consumables	384,000
1 Month Waste Disposal	318,000
25% of 1 Month Fuel Cost at 100% CF	1,697,000
2% of Total Plant Cost	29,457,000
Total	**48,341,000**
Inventory Capital	
60 Day Supply of Fuel and Consumables at 100% CF	14,068,000
0.5% of TPC for Spare Parts	7,364,000
Total	**21,432,000**
Initial Catalyst and Chemicals	**7,199,000**
Land	**900,000**
Other Owners Costs	**220,927,000**
Financing Costs	**39,767,000**
Total Overnight Costs (TOC)	**1,811,411,000**
Total As-Spent Cost (TASC)	**2,065,009,000**

4.1.4 Cost of Electricity

The cost metric used in the DOE report is the cost of electricity (COE), which is the revenue received by the generator per net megawatt-hour during the power plant's first year of operation, assuming that the COE escalates thereafter at a nominal annual rate equal to the general inflation rate, i.e., that it remains constant in real terms over the operational period of the power plant. To calculate the COE, the Power Systems Financial Model (PSFM) was used in the report to determine a “base-year” (2007) COE that, when escalated at an assumed nominal annual general inflation rate of 3% provided the stipulated internal rate of return on equity over the entire economic analysis period (capital expenditure period plus thirty years of operation). The resulting cost of electricity for DOE Case 2 and its breakdown is given in Table 6. For comparison, the cost of electricity for DOE Case 1 which represents a GEE Gasifier based IGCC power plant without CO_2 capture and a net output of 550 MWe is 76.3 \$/MWh. The COE increases by 38.4% when the two-stage Selexol™ process is used to remove sulfur and CO_2.

Table 6. Comparison of Cost of Electricity and its Contributors for DOE Case 1 and Case 2

Cost of Electricity	DOE Case 1	DOE Case 2
Capital Cost, \$/MWh	43.4	59.1
Fixed Cost, \$/MWh	11.3	14.8
Variable Cost, \$/MWh	7.3	9.3
Fuel Cost, \$/MWh	14.3	17.1
CO_2 TS&M Cost, \$/MWh	0.0	5.3
Cost of Electricity, \$/MWh	**76.3**	**105.6**
Increase in COE, %	**-**	**38.4%**

4.2 RTI's Warm Gas Clean-up Technology Package (RTI WGCU)

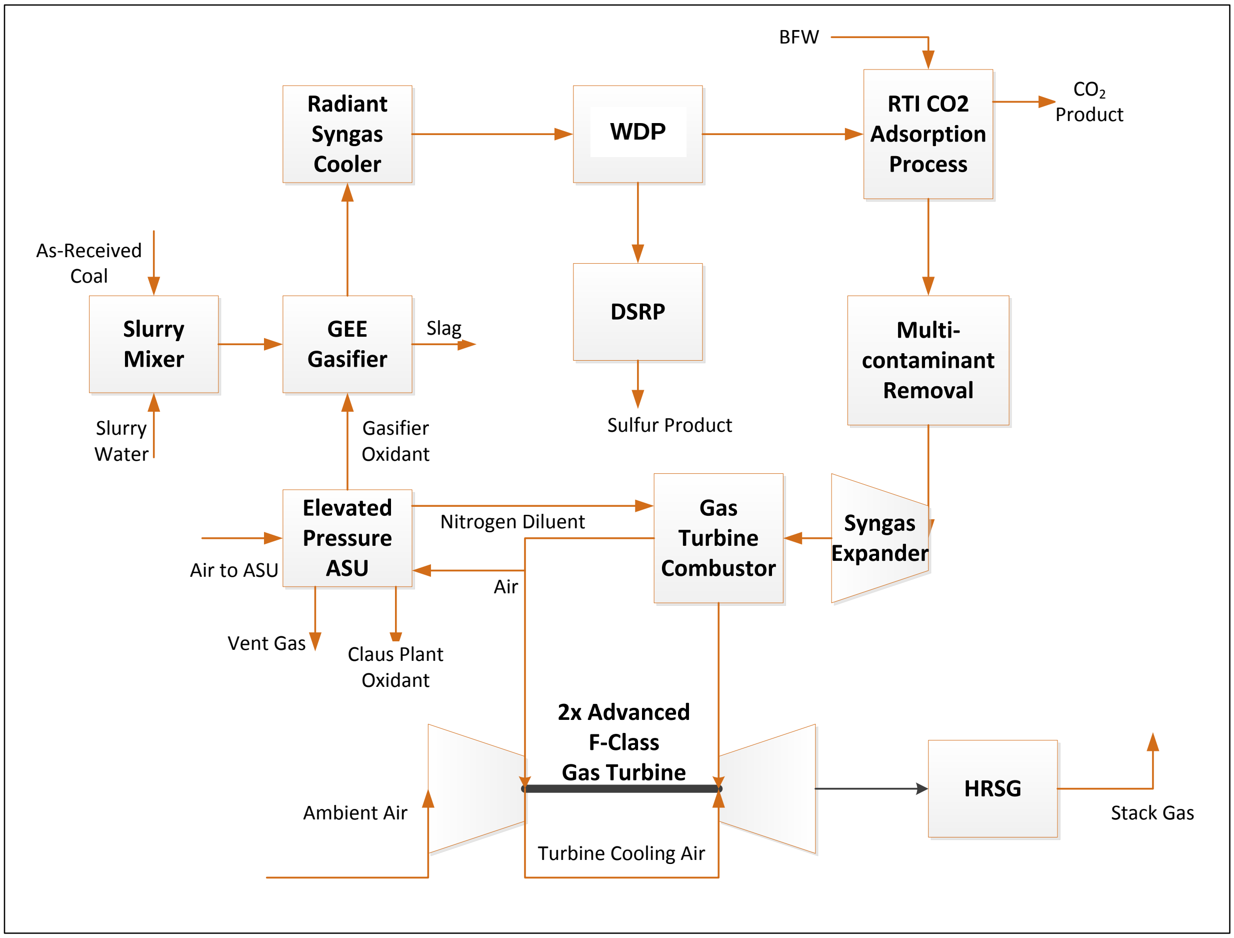


Figure 21. Block Flow Diagram of a GE IGCC Power Plant with RTI WGCU Warm-temperature Sulfur Removal and CO_2 Capture Process

The use of a conventional syngas desulfurization and CO_2 capture process such as the dual stage Selexol™ process requires cooling the raw syngas leaving the gasifier to a much lower temperature. For an IGCC process, the low temperature cleaned syngas then needs to be reheated before being sent to the combustion turbine. This cooling and reheating cycle introduces an efficiency penalty to an IGCC plant. With a warm temperature syngas desulfurization and carbon capture process such as RTI's warm temperature desulfurization process (WDP) with direct sulfur recovery process (DSRP) and warm-temperature CO_2 adsorption process, together referred to as RTI's warm gas cleanup (RTI WGCU) process, syngas can be cleaned at an elevated temperature and sent to the combustion turbine without the need for reheat. Thus it offers potential improvement in overall thermal efficiency. A block flow diagram of a conceptual GE gasifier based IGCC power plant with RTI WGCU process for warm-temperature sulfur and CO_2 removal is shown in Figure 21. In this process, syngas from the gasifier is cooled down to 482°C in a radiant syngas cooler while producing high pressure steam. The cooled syngas enters the WDP unit where H_2S and COS are scrubbed and the desulfurized syngas is sent to the CO_2 capture process placed downstream of the sulfur scrubber. The hot desulfurized syngas enters the adsorber where it is mixed with steam to achieve a H_2O:CO ratio of 1.5 in the resulting wet syngas. The adsorber is designed to achieve 98% conversion of CO to CO_2 and the capture of 90% of carbon (CO, CO_2, CH_4) present in the syngas. In order to maintain warm syngas temperature throughout the process, RTI has also developed guard beds for the removal of chlorides and mercury at warm temperature >200°C.

4.2.1 Warm Temperature Desulfurization and Direct Sulfur Recovery Process (WDP/DSRP)

4.2.1.1 Process Description

In the WDP/DSRP process hot syngas from the gasifier radiant boiler is first sent to a fired tube convection boiler which generates high pressure saturated steam. Cooled syngas leaves the waste heat boiler and is mixed with the recycled H_2S from the tail gas portion of the sulfur production step. The combined stream is then sent to a cyclone to remove ash and char carried over from the gasifier. The solids captured in the cyclone are sent to a quench drum where the solids are cooled in a water pool and slurried back to the gasifier feed drum to be recycled back to the gasifier. The cyclone vapor is then sent to the WDP adsorber which is a transport reactor. Here feed gas is contacted with hot sorbent solids from the regenerator and a recycle stream from the adsorber cyclone.

Table 7. Properties of Sour Syngas Feed to WDP Adsorber and the Exiting Sweet Syngas

	WDP Feed		WDP Effluent	
Mass Flow Rate	465,448 kg/hr		459,707 kg/hr	
Pressure	55 bar		53 bar	
Composition	**Vol. Fraction [-]**	**Mass flow [kg/h]**	**Vol. Fraction [-]**	**Mass flow [kg/h]**
Ar	0.009	7,944	0.008	7,944
CH_4	0.001	408	0.001	408
CO	0.358	231,602	0.331	220,022
CO_2	0.138	140,428	0.155	158,623
H_2	0.341	15,876	0.354	16,709
H_2O	0.137	57,026	0.115	49,578
H_2S	0.007	5,753	0.008	11
N_2	0.010	6,412	0.028	6,412

In the adsorber the H_2S and COS are reacted with the active compound in the ZnO sorbent to form ZnS according to the following reactions:

(1) $COS + ZnS \rightarrow ZnS + CO_2$
(2) $H_2S + ZnO \rightarrow ZnS + H_2O$

The vapor leaving the adsorber top has sulfur removed to less than 10 ppmv. The desulfurized syngas with entrained ZnS leaves the top of the adsorber and are fed to a cyclone where the solid sorbent containing ZnS is separated from the desulfurized vapor. The solids from the cyclone enter a standpipe where a diverter valve takes part of these solids and feeds them to a regenerator and the remaining solids are recycled back to the bottom of the adsorber. The other solids stream is fed to the bottom of a fluidized bed regenerator where it is contacted with a mixture of oxygen and nitrogen in a fixed ratio. The oxygen reacts with the ZnS and forms SO_2 according to the following reactions:

(3) $ZnS + 1.5\ O_2 \rightarrow ZnO + SO_2$

This exothermic reaction heats up the solids resulting in the vapors and solids leaving the reactor at elevated temperature. The vapor leaving the fluidized bed is sent to a cyclone where any entrained solids are captured and returned to the bed. The regenerator off-gas containing SO_2 is then exchanged with the incoming oxygen and nitrogen stream to preheat oxygen and nitrogen and cool the regenerator off-gas. The regenerator off-gas is then mixed with a slipstream of the treated syngas containing the reducing components CO and H_2. The amount of treated syngas required for this step is ~4% of the total treated syngas. This combined stream is then sent to a candle type filter to remove any remaining entrained solids from the regenerator and adsorber. The filtered gas is then sent to a fixed bed direct sulfur recovery process (DSRP) reactor where SO_2 is reduced to elemental sulfur according to the following reactions:

(4) $SO_2 + 2\ CO \rightarrow 2\ CO_2 + S$
(5) $SO_2 + 2\ H_2 \rightarrow 2H_2O + S$

Approximately 98% of the SO_2 is converted to sulfur in the DSRP reactor. This is an exothermic reaction which raises the reaction outlet temperature. The catalyst is on the tube side of this reactor with the gases flowing through the tubes. The reaction is cooled by exchange with saturated high pressure steam on the shell side that is superheated. The hot gases leaving the reactor are sent to a two-stage sulfur condenser. In the first stage, the gas is cooled by regenerating low pressure steam. In the second stage the gas is further cooled by exchange with boiler feed water (BFW). The condensed sulfur after being depressurized drops into a sulfur pit. The cooled gas containing residual SO_2 is then heated by exchange with superheated medium pressure steam and is sent to a hydrogenation reduction reaction:

(6) $SO_2 + 3 H_2 \rightarrow H_2S + 2 H_2O$

The hydrogenated stream is then cooled in two stages. In the first stage, the gas is cooled by generating low pressure steam. In the second stage the gas is further cooled to 157°C by exchange with boiler feed water (BFW). The cooled stream is then compressed in a recycle compressor and mixed with the syngas following the syngas cooler.

The adsorber off-gas following the cyclone is split into two streams, a slip stream described earlier is taken off as a source of reducing gas for the DSRP and hydrogenation reactors. The remaining desulfurized syngas stream requires further cleaning to remove CO_2, chlorides, mercury and solids before being fed to the gas turbine.

4.2.1.2 Technical and Economic Assessment of WDP/DSRP Process

As part of a previous project, RTI worked with Nexant, Inc to perform a high-level techno-economic assessment of the WDP/DSRP technology for integrated gasification combined cycle (IGCC) applications. Nexant developed a conceptual IGCC plant design with which the feasibility of WDP/DSRP for high temperature H_2S removal was evaluated in comparison with a conventional acid gas removal (AGR) technology. This study did not include the capture of CO_2 and only assessed the impact of using the WDP/DSRP technology as a replacement for conventional sulfur removal processes. A 600 MW_e IGCC conceptual plant design based on GE gasifier for coal conversion and Selexol™ AGR for sulfur removal was chosen as the reference plant, using two different Illinois No. 6 coal feeds.

Performance difference between the reference IGCC design with a conventional low temperature AGR process and that of WDP/DSRP IGCC design are quite significant with average increase in overall thermal efficiency of ~2.8% (HHV). This increase in overall thermal efficiency is a combined attribute of WDP technology for removing sulfur from hot raw syngas at high temperature and its companion technology of DSRP of high temperature sulfur recovery, and the design of a convective cooler to cool hot raw syngas exiting the gasifier, upstream of the WDP process for maximum waste heat recovery.

The equipment cost for the Selexol™-based AGR process (including COS hydrolysis & LTGC, sulfur recovery, and tail gas treating unit) was estimated to be 10% higher than the equipment cost for the combined WDP/DSRP process. On a total plant cost per installed capacity, the WDP/DSRP plants cost about 14% less due to the higher thermal efficiency.

Performance Highlights

Based on overall thermal efficiency, capital cost and cost of electricity, the WDP/DSRP IGCC design appears to be an attractive alternative to the single-stage Selexol™-based Reference IGCC design.

- Approximately 4% of treated syngas was mixed with regeneration off-gas to reduce SO_2. This drops the gas turbine power production by 4%, respectively.
- The design of a convective cooler to cool hot raw syngas exiting the gasifier, recovery of heat from exothermic SO_2 reduction, and cooling of treated syngas enables raising high pressure steam equivalent to 20,425 kW_e
- The total power consumed by the WGCU/DSRP process is 500 kW_e for recycle compressors
- The total installed plant cost for the combined WDP/DSRP process cleanup block was estimated as $193,750,000.

4.2.2 RTI's Warm Temperature CO_2 Capture Process

Development or RTI's warm contaminant removal processes including the warm temperature desulfurization process (WDP) for H_2S and COS removal from syngas at elevated temperatures and the trace contaminant removal process (TCRP) for removal of numerous heavy metals from syngas at temperatures greater than 200°C has been a great success. However, in a carbon-constrained economy, the key element enabling the benefit of warm syngas clean-up is a process that removes carbon from the fuel gas under warm syngas conditions. To this end, RTI is developing a solid sorbent-based CO_2 removal process that integrates directly into and complements RTI's overall warm syngas clean-up technology package. RTI has identified a series of solid sorbent materials based on magnesium – alkali mixed salts that have very promising CO_2 capture properties for CO_2 removal from warm syngas. Some of these materials can capture CO_2 at temperatures as high as 450°C with a capacity close to 50 wt% CO_2. Such capture at warm temperature is achieved by a strong chemisorption bond between CO_2 and sorbent resulting in a high heat of adsorption of 115 kJ/mol-CO_2 as measured using differential scanning calorimetry tests performed in an inert environment.

Typical sorbent-based chemisorption processes utilize either temperature-swing or pressure-swing to capture and release adsorbates. A typical temperature-swing process relies on operating the regeneration step at a higher temperature compared to the adsorption step to help desorb the adsorbates. The difference in equilibrium CO_2 loading at these temperatures (adsorption and desorption) sets the maximum possible CO_2 working capacity. Additionally, in a temperature swing process the operating pressure for adsorption and desorption are typically quite similar, however, it is not uncommon for the operating pressure to be different. Alternatively to the temperature swing process, the desorption step in a pressure-swing process is operated at a lower pressure (lower CO_2 partial pressure) to desorb adsorbates from the surface.

For the IGCC case, the CO_2 capture takes place downstream of the WDP step at 450°C. The heat of adsorption will be released at this warm temperature and can be used efficiently. However, following a temperature swing process the desorption step will be carried out at temperature >450°C. Thus, the heat of desorption needs to be supplied at such high temperature. Since the heat of adsorption is ~115 kJ/mol-CO_2, supplying such a quantity of heat at such high temperature could be economically prohibitive. For this reason, RTI has proposed implementing a reverse temperature swing process in which the desorption step is carried out at temperature <450°C to enable the transfer of heat from the adsorber to the desorber. Various process configurations of enabling this heat transfer are discussed in the Process Development section. In the reverse-temperature swing adsorption process envisioned by RTI the adsorption step is operated at 450°C and the desorption step is operated at 410°C. As a result, the CO_2 partial pressure during desorption is going to be much lower than the CO_2 partial pressure during adsorption. This can be achieved by operating the process as pressure swing with the desorber operating at a much lower total pressure compared to the adsorber.

4.2.2.1 Reverse-Temperature Swing Adsorption Process (RTI-RTSA)

The reverse-temperature swing adsorption process, henceforth referred to as RTI-RTSA, is designed and sized to capture 90% of carbon from the syngas produced in the GEE gasifier of Case 2 in the DOE report. The CO_2 capture plant receives sweet syngas from the WDP/DSRP process having the mass flow rate, composition, and process conditions provided in Table 7. The high temperature CO_2 capture process is required to remove greater than 447,981 kg/hr of CO_2 from the syngas.

4.2.2.1.1 Process Description

CO_2 Capture Sorbent

The CO_2 capture sorbent used in our evaluations is a fluidizable MgO-based sorbent. Initial work with MgO-based sorbets synthesized in powder form has demonstrated fresh sorbent CO_2 capacity of 50 wt%. Synthesis of these powders need to be scaled up and converted to a fluidizable form. For the purpose of techno-economic evaluation, working capacity in a continuous adsorption-desorption process using regenerated sorbent for CO_2 capture was assumed to be 15 wt%. As a result, the rate at which the sorbent enters the adsorber is 3.0×10^6 kg/hr. The regenerator will be designed to desorb 65% of CO_2 deposited on the sorbent, thus, to maintain 15 wt% capacity and 65% regeneration, the regenerated sorbent will consist of 8 wt% CO_2. This means that the sorbent will achieve an overall capacity of 23 wt% CO_2 during continuous operation. The average sorbent circulation rate is 3.2×10^6 kg/hr.

The proposed high-temperature, continuous adsorption-regeneration process is similar in concept to an FCC reactor where catalyst is continuously circulated between the reactors. In FCC systems, however, pneumatic conveying is used for solids transport and is achieved using high superficial gas velocities (>20 ft/s). Additionally, catalyst is subjected to high gas velocities at the gas distributor and cyclone inlet and outlet. In such systems, catalyst make-up rates of ~100 kg/million-kg-circulated (kg/MMkg-circ) are generally observed [i]. This make-up rate also includes addition of fresh catalyst to compensate for deactivation. Since our advanced sorbent process does not include a pneumatic conveying step, losses due to attrition in the riser (a dominant factor in the FCC process) are completely eliminated. Based on discussions with Ted Knowlton of PSRI [i], a leading solids flow and handling research company, it is anticipated that sorbent loss rates in our advanced sorbent process could be 8 to 10 times lower than losses experienced in a FCC process. As a conservative measure, we have assumed an attrition rate of 50 kg/MMkg-circ (1/2 that typically experienced in FCC systems) which may be much higher than what will be experienced in real-life, large-scale operations. Thus an attrition rate of 25 kg/MMkg-circ is assumed for the adsorber and desorber section respectively. With the average adsorbent circulation rate of 3.2×10^6 kg/hr, the total sorbent-only loss due to attrition is compensated by fresh make-up sorbent at a rate of 122 kg/hr to the hot, regenerated sorbent to maintain sorbent inventory.

CO_2 Adsorber

A detailed process flow diagram of the RTI-RTSA CO_2 capture process is shown in Figure 22. The sweet syngas from the WDP adsorber unit (Stream 101) consists of 47,735 kg/hr of H_2O and 214,371 kg/hr of CO representing a H_2O:CO molar ratio of 0.35. Water at 69 bar and 284°C is added to this stream to raise the H_2O:CO ratio to 1.5 which is desirable for the water gas shift reaction. The wet syngas is then fed to the CO_2 adsorber (R-101). The adsorber section R-101 represents a combined water-gas-shift and CO_2 capture unit that can achieve 95% CO conversion and capture of 95% CO_2 resulting in a total carbon capture of 90%. It is understood that single-step 95% conversion of WGS reaction without simultaneous CO_2 removal is thermodynamically not possible at R-101 process conditions and multiple WGS steps with either simultaneous or intermittent, stage-wise CO_2 removal will need to be employed. A detailed look at the various adsorber design configurations integrating the WGS and CO_2 capture steps along with adsorber-desorber integration schemes is discussed in detail in the Process Development section. For the techno-economic analysis step, a single block that can simultaneously convert 95% of CO and further capture 95% of CO_2 to meet the 90% carbon capture target is assumed. In order to maintain the high-temperature-profile before and in-between adsorption stages the water gas shift reaction will also be carried out at high temperature of ≤450°C.

The CO_2 adsorber functions to allow intimate mixing of the syngas with the CO_2 capture sorbent and provide sufficient management of the exothermic heat of CO_2 adsorption and water gas shift reaction. The wet syngas enters the bottom of the CO_2 adsorber (R-101) and the regenerated sorbent (Stream 109) from the sorbent regenerator (R-107) enters at the top. The CO_2 capture process is operated with a sorbent CO_2 working capacity of 15 wt% and a carbon capture efficiency of 90%. This necessitates a sorbent flow rate of 3.0 x10^6 kg/hr (Stream 109). A sorbent injection system, detailed below, is used to transfer regenerated sorbent at 410°C to the top of the CO_2 adsorber. In the CO_2 adsorber 95% of CO in the syngas is shifted and 90% of the carbon, representing 447,981 kg/hr of CO_2, is captured by the sorbent at 450°C. The total heat released during the process is 1,352 GJ/hr. This heat is removed from the adsorber and is transferred to the desorber to meet the heat of desorption demanded at a lower temperature. Various process schemes enabling the heat integration between the adsorber and the desorber were looked at and are detailed in the Process Development section.

Sorbent Injection System

The regenerated sorbent (Stream 113), from the regenerator operating at 410°C and 3.5 bara needs to be pressurized up to 53 bara. Regenerated sorbent is collected in surge hopper to which makeup sorbent at ambient temperature (Stream 117) is added and fed through a pressurized dual lock hopper system at 410°C to a dense phase pneumatic conveyor which uses nitrogen to convey the regenerated sorbent to the top of the adsorber. Similar systems are employed for dry coal feeding by Shell and Siemens gasifier, although without the high operating temperature requirement. Lock hopper feed system operate in batch mode, intermittently charging and discharging sorbent into the pressurized dense-phase pneumatic conveying line. In order to make sorbent feeding continuous and to meet the size requirement of the sorbent circulation rate, multiple lock hopper systems will be used in parallel. Such a sorbent pressurization and feed system can be expensive and challenging to operate reliably., especially above 600 psia. Demonstration of the reliability and safety of the sorbent feeding system at ≥750 psia and high temperature is essential for the successful development of the reverse temperature swing adsorption process. The power consumption requirement of the sorbent injection system for RTI-RTSA process circulating 3.0x10^6 kg/hr of sorbent was estimated at 3500 kW_e.

Return of H_2-rich Syngas

The CO_2-scrubbed syngas rich in H_2 exits at the top of the adsorber section carrying entrained fines. The H_2-rich syngas passes through a cyclone (CY-102) where larger entrained sorbent is separated and returned to the adsorber. Finally, a high temperature dual candle filter (F-103) is used to remove fines. Since the mercury removal vessel, placed downstream of the CO_2 adsorber, must operate at 290°C maximum temperature the filtered syngas is first cooled from 450 to 247°C by raising 50,443 kg/hr of steam at 4.8 bara (70 psia). The cooled stream is then sent to a mercury guard bed where sulfur-impregnated carbon is used to remove any residual mercury in the stream. This is a two vessel system with one unit in series with the other. This enables one vessel to be taken offline to replace the beds. Following the mercury guard bed the mercury free gas is sent to a chloride guard bed where HCl is removed by reaction with sodium bicarbonate in the following reaction:

(1) $HCl + NaHCO_3 \rightarrow NaCl + CO_2 + H_2O$

Again two vessels are required that operate in series. When the first vessel is spent, it is taken out of service while the sodium bicarbonate is replaced. The second vessel can handle the chloride removal until the first vessel returns back online and is placed in series following the other vessel.

The cooled high-pressure syngas is then expanded from 53 bar to 32 bar in a gas expansion turbine assumed to be operating at an isentropic efficiency of 80% and a mechanical efficiency of 98% to produce 8,900 kWe. As shown in Table 8, the H_2-rich syngas from the expansion turbine is similar to the gas turbine combustor feed in Case 2 of the DOE report. One main difference is the lower H_2O content in the base case syngas as the gas was cooled down to 35°C for contaminant removal. Syngas in RTI case is never cooled below its dew point temperature and hence retains all the moisture from the gasifier plus excess water added for water gas shift reaction. This additional moisture in gas turbine feed syngas lowers the requirement of dilution nitrogen injection to the gas turbine. This in turn lowers the nitrogen compressor power requirement by 3,600 kWe. No ammonia removal system has been provided and any NOx produced in the gas turbine will be removed by an SCR on the gas turbine exhaust gas.

Table 8. Comparison of H_2-rich Syngas Stream from the DOE Case 2 and RTI-RTSA Process

	RTI-RTSA		DOE Case 2	
Mass Flow Rate	144,336 kg/hr		90,179 kg/hr	
Temperature	188 °C		196 °C	
Pressure	32 bar		32 bar	
Composition	**Vol. Fraction [-]**	**Mass flow [kg/h]**	**Vol. Fraction [-]**	**Mass flow [kg/h]**
Ar	0.010	7,944	0.011	8,004
CH_4	0.001	408	0.001	419
CO	0.008	4,400	0.012	6,051
CO_2	0.045	40,588	0.050	38,492
H_2	0.783	32,227	0.914	32,097
H_2O	0.142	52,344	0.001	31
H_2S	0.000	11	0.000	0
N_2 (Balance)	0.011	6,412	0.011	5,125

Sorbent Depressurization

The CO_2-loaded sorbent leaves the bottom of the adsorber and is directed to the top of the desorber for regeneration. Since the desorber is operated at 4.8 bara (70 psia) while the adsorber is operating at 53 bara (768 psia) the CO_2-rich sorbent needs to be depressurized. For this purpose, the use of a novel Restricted Pipe Discharge System (RPDS) developed by PSRI is envisioned. In an RPDS, solids are simply discharged in moving packed-bed flow from system pressure to as low as atmospheric pressure through a pipe restricted at the outlet. The pressure drop in the pipe is produced by the gas flowing faster than the solids. Initially developed to depressurize 224- to 621- micron oil shale from 600 psig to atmospheric pressure, this technology can now also be used for Group A type material. The RPDS was found to smoothly and reliably depressurize the solids and has an advantage over lock hopper systems as solids discharge is continuous, valve maintenance costs are lower, solids can be simultaneously transferred and depressurized, and capital costs are low.

Sorbent Regeneration

In the reverse temperature swing process the sorbent regeneration will be performed at 410°C, which is 40°C below the adsorption temperature of 450°C, to enable the integration of heat between the adsorber and the desorber which is one of the most vital advantages of this process. Since the regeneration is carried out at a lower temperature than the adsorber, lab experiments have shown that the CO_2 doesn't start to desorb until CO_2 partial pressure drops below 2.8 bara (40 psia). Partial pressure of CO_2 can be lowered either by adding stripping steam or lowering the absolute pressure or a combination of both. In the existing design, the desorber is designed to operate at 4.8 bara (70 psia) with a stripping steam feed of 108,092 kg/hr to release 456,818 kg/hr of CO_2 with a CO_2 partial pressure of 36 psia at the top of the desorber. The stripping steam is raised by cooling the H_2-rich syngas from 450 to 247 °C and by cooling the capture stream at the desorber outlet from 410 to 170 °C.

The CO_2 loaded sorbent from the adsorber is first depressurized, as detailed in the Sorbent Depressurization section, and then fed to the top of the desorber. The sorbent in the desorber is fluidized by feeding 108,092 kg/hr steam at 4.8 bara (70 psia) at the bottom of the desorber.

Capture Stream Recovery and Processing

The CO_2 capture stream consisting of desorbed CO_2 and stripping steam exits at the top of the desorber section carrying entrained fines. The capture stream passes through cyclone (CY-108) where larger entrained sorbent is separated and returned to the desorber. Finally, high temperature dual candle filter (F-109) is used to remove the fines. The filtered syngas is then cooled from 410 to 170 °C by raising 57,649 kg/hr of steam at 4.8 bara (70 psia). The capture stream is further cooled to 49°C using cooling water and then sent to the CO_2 compression and dehydration section. In the compression section, CO_2 is compressed to 153 bara (2215 psia) in a four-stage centrifugal compressor. Power consumption for this large compressor was estimated assuming an isentropic efficiency of 86 percent and a mechanical efficiency of 98 percent for all stages. The total power consumed during CO_2 compression is 28,000 kWe. During compression to 153 bara (2215 psia) in the multiple-stage, intercooled compressor, the CO_2 stream is dehydrated to a dewpoint of -40ºC (-40°F) with triethylene glycol. The virtually moisture-free supercritical CO_2 stream is delivered to the plant battery limit as sequestration ready CO_2.

4.2.2.1.2 Process Simulation

The RTI-RTSA CO_2 capture process was designed and simulated using Aspen Plus v7.3 chemical process simulation software. Aspen Plus is an ideal choice due to its distinct simulation and properties environments and streamlined engineering workflows for the simulation of conceptual design to model deployment. Aspen Process Economic Analyzer (Aspen PEA) was used to estimate the equipment and bare-erected cost of the CO_2 capture plant. Aspen PEA can seamlessly interface with Aspen Plus to assimilate process flow diagram and stream tables from Aspen Plus to enable sizing and costing of the project. Several equipment types were limited in size for use as individual pieces in CO_2 capture. However, the primary objective was to select the most appropriate equipment type and use of multiple equipment in parallel to meet the equipment size requirement of the process.

4.2.2.1.3 Power Summary

The total electricity consumption of RTI's WGCU processes is 32,000 kW_e. The CO_2 compression step itself consumes 28,000 kW_e which represents 87.5% of the total electricity demand. The electrical power requirement of the lock hopper system was estimated to be 3,500 kW_e while the power consumed by the recycle compressors used by the WDP/DSRP process is 500 kW_e.

Table 9. Summary of the Electrical Power Requirement of RTI-RTSA based WGCU Process

Equipment Name	Electricity Consumption, kW_e
WDP/DSRP	500
Regenerator Lock Hopper	3,500
CO_2 Compression	28,000
Total	**32,000**

The overall power summary of the power plant is shown in Table 10. Compared to DOE Case 2, the gas turbine power drops by ~4% as a small fraction of the syngas is used in the warm gas desulfurization process for the reduction of regeneration off-gases. On the other hand, the warm gas desulfurization process generates high pressure steam that is used to generate ~20 MW_e in a steam turbine. As a result, the net power produced by the power plant increases to 569,858 kW_e which is 26,608 kW_e higher than DOE Case 2 resulting in the net plan efficiency to increase from 32.6% to 34.2%.

Table 10. Overall Power Summary of IGCC Power Plant with RTI Warm-temperature Acid Gas Removal Processes

Power Summary (Gross Power and Generator Terminals, kW_e)	
Gas Turbine Power	445,793
Sweet Gas Expander Power	8,900
Steam Turbine Power	283,925
Total Power, kW_e	**738,618**
Auxiliary Load Summary, kW_e	
Air Separation Unit	114,610
Power Plant Auxiliaries	17,960
Acid Gas Removal	4,000
CO_2 Compressor	28,000
Miscellaneous Balance of Plant	3,000
Transformer Losses	2,760
Total Auxiliaries, kW_e	**168,760**
Net Power, kW_e	**569,858**
Net Plant Efficiency, % (HHV)	**34.2**

4.2.2.1.4 Capital Cost

The total plant cost for RTI's WGCU process is shown in Table 11. Similar to the DOE case, the total plant cost comprises of the bare-erected cost (BEC) as estimated using Aspen Process Economic Analyzer plus the cost of services provided by the engineering, procurement and construction (EPC) contractor and project and process contingencies. The contribution of EPC was assumed to be 10% of BEC while process and project contingencies were assumed to be 20% and 25% respectively. The total installed plant cost for RTI's WGCU process block was estimated to be $549,686,435. The TPC for RTI process is twice that for the dual-stage Selexol™ process.

Table 11. Summary of Major Contributors to the Capital Cost of RTI's Warm-temperature Acid Gas Removal Processes

RTI WGCU/DSRP	$193,750,000
Sorbent Injection System	$126,522,582
CO_2 Adsorber	$73,082,500
CO_2 Compression and Dehydration	$46,500,000

CO_2 Desorber	$34,758,750
Heat Recovery and Quench	$10,573,945
Sweet Gas Expander	$7,190,605
Balance of Plant	$57,308,053
TPC of the Capture Plant	$549,686,435

The WDP/ DSRP unit accounts for 35% of the total RTI WGCU TPC followed by the sorbent injection system contributing 23%. This suggests that although pressure swing adsorption enables CO_2 desorption to take place at a lower temperature than adsorption to allow for the integration of heat, the capital cost associated with the repressurization of the sorbent is economically detrimental.

TPC for the GEE gasifier based IGCC power plant with RTI's WGCU technology package was estimated by substituting the TPC for the "Gas Cleanup and Piping" and "CO_2 Compression" in Table 11 with the TPC estimated for RTI's WGCU process. The TPC for the combined plant is estimated as $1,710,618,435. Using the methodology detailed in the DOE report, the TOC and TASC were estimated to be $2,120,713,150 and $2,417,612,991, respectively.

Table 12. Summary of RTI Warm-temperature Acid Gas Removal Process TOC and TASC

Item	
Total Plant Cost	
Power Plant	$1,160,932,000
Acid Gas Removal Plant	$549,686,435
Total Plant Cost	**$1,710,618,435**
Total Overnight Costs (TOC)	**$2,120,713,150**
Total As-Spent Cost (TASC)	**$2,417,612,991**

4.2.2.1.5 Cost of Electricity

Cost of Electricity was estimated following similar methodology outlined in the DOE report. The resulting cost of electricity for RTI WGCU and its breakdown is given in Table 13. For comparison, the cost of electricity for DOE Case 2 is also shown.

Table 13. Comparison of Cost of Electricity and its Contributors for DOE Case 2 and RTI's Warm Temperature Acid Gas Removal Processes

Cost of Electricity	RTI	DOE Case 2
Capital Cost, $/MWh	65.8	59.1
Fixed Cost, $/MWh	15.3	14.8

Variable Cost, $/MWh	10.9	9.3
Fuel Cost, $/MWh	16.3	17.1
CO_2 TS&M Cost, $/MWh	5.3	5.3
Cost of Electricity, $/MWh	**113.7**	**105.6**
Increase in COE, %	**49.0%**	**38.4%**

The COE for the RTI case is 113.7 $/MWh which represents an increase in COE of 49.0% compared to DOE Case 1. Comparatively, the COE for DOE Case 2 is 105.6 $/MWh representing an increase in COE of 38.4%. Even though the net power plant efficiency is better by 1.6% points for the RTI case the capital cost was twice that for the dual-stage Selexol™ process. The higher capital cost significantly drives up the contribution of the capital cost towards COE and overshadows the benefit of improved plant energy efficiency rendering RTI-RTSA CO_2 capture technology economically unviable.

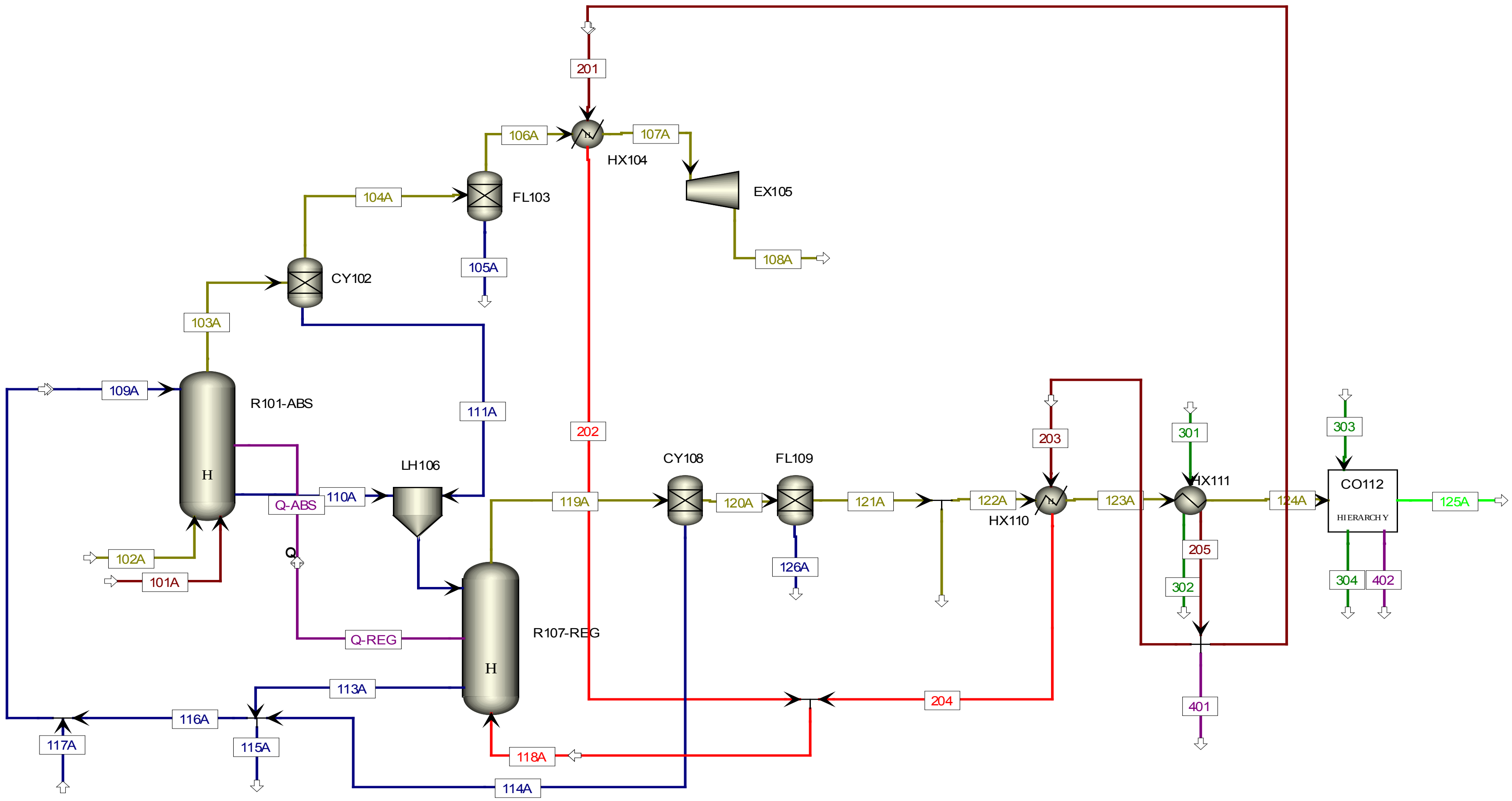


Figure 22. Process Flow Diagram of the High-temperature Reverse-temperature Swing CO_2 Capture Process

4.2.2.2 Temperature Swing Adsorption (TSA) Process

An alternate process arrangement utilizing the RTI's MgO-based sorbent – a classical temperature swing adsorption (TSA) process was also explored as part of this techno-economic analysis. Such a process is conceptually similar to conventional gas-liquid adsorption processes where the adsorber and regenerator operate at approximately the same pressure while the regenerator operates at a higher temperature. Since the adsorption in this proposed process takes place at a temperature of 450°C, the heat of adsorption and reaction heat generated by the water-gas-shift reaction can be recovered as medium- to high-pressure steam and converted to electricity. On the other hand, the heat of desorption (endothermic) can be supplied in the regenerator by firing natural gas. Such a process arrangement is equivalent to burning natural gas to raise medium- to high-pressure steam to in turn produce electricity. Firing of natural gas in the regenerator can be carried out either a) direct firing using enriched oxygen (95 vol%) which allows for the capture of combustion product CO_2 at a high purity, or b) indirect heating using air in which case the combustion product stream will not be mixed with the capture stream to avoid dilution with nitrogen from air. Although economics and process operation may favor the use of air for indirect natural gas firing, the issue of CO_2 emissions associated with natural gas combustion may demand the use of enriched oxygen for direct natural gas firing. Also, the combusted gas stream from NG reformer presents an attractive alternative for stripping steam in the regenerator. However, one of the advantages associated with using air as oxidant is that nitrogen in the air helps limit the high temperatures (< 2200°C) in the NG reformer. Using enriched oxygen as oxidant instead of air posed a problem with controlling the high temperatures in the NG reformer. Hence, a portion of pure CO_2 stream exiting the regenerator was recycled to serve as heat sink. A

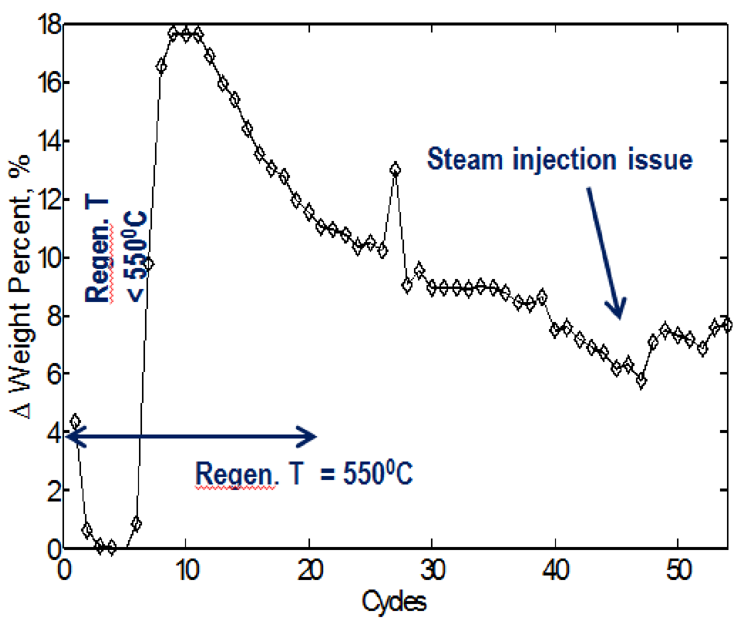


Figure 23. Experimental Results of Temperature Swing Adsorption Tests Performed in High-pressure, High-temperature TGA

significant effort was dedicated to optimize the regenerator design and extents of CO_2 recycle flow rates.

Experiments representing a classical TSA process were performed in a high pressure, high-temperature TGA. The cyclic adsorption-desorption experimental data is plotted in Figure 23. The sorbent was loaded with CO_2 at 450°C and 400 psig total pressure. The partial pressure of CO_2 was 350 psig and steam made up the remaining 50 psig. Upon loading with CO_2,the sorbent was heated to 550°C under the same gas conditions - 350 psig CO_2 and 50 psig. The sorbent was fully regenerated under these conditions. The initial CO_2 loading under temperature swing adsorption process conditions was 18 wt%. However after 20 cycles, CO_2 capacity dropped to 8 wt%. Since the sorbent used for these experiments was optimized for reverse temperature swing adsorption, for process simulation purposes, it is assumed that upon sorbent optimization CO_2 working capacity of 15 wt% will be achieved.

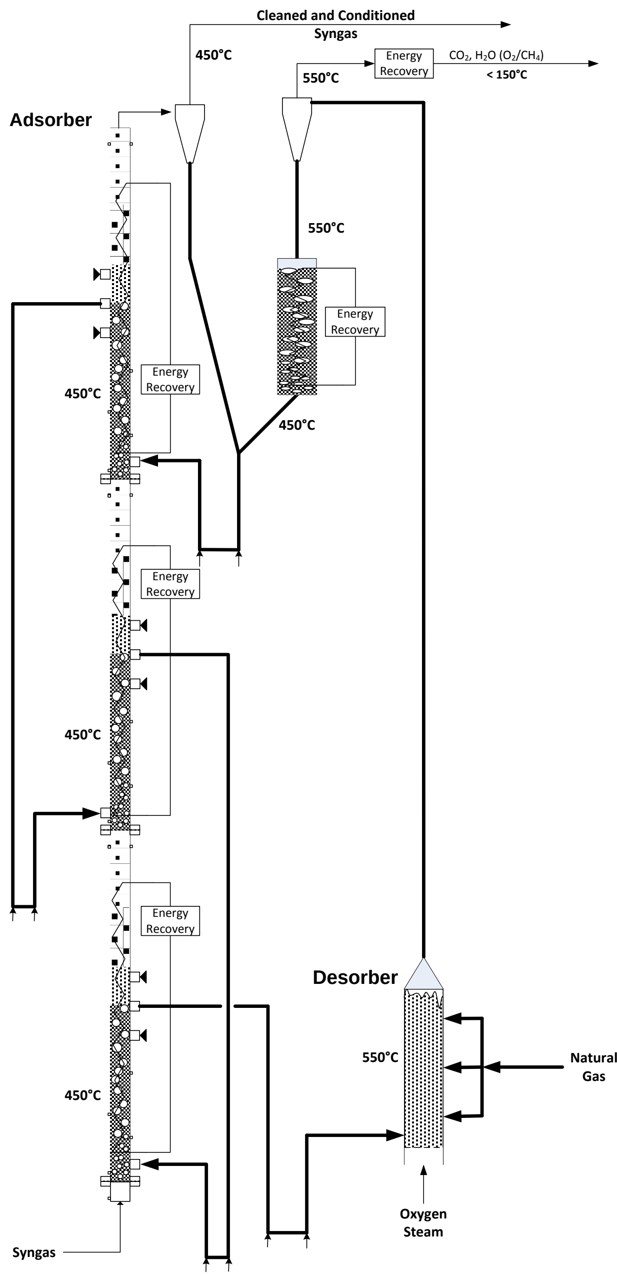


Figure 24. Adsorber-desorber TSA Process Scheme for CO_2 Capture

4.2.2.2.1 Process Description

A conceptual adsorber-desorber process scheme for temperature swing adsorption is shown in Figure 24 and a detailed process flow diagram of the high-temperature CO_2 capture process from Aspen Plus simulations is shown in Figure 26.

The adsorber is envisioned to be a staged fluidized bed allowing intimate mixing of syngas and sorbent on each stage while overall maintaining a counter-current flow of syngas and sorbent. The syngas enters the bottom-most adsorber stage and rises upwards through consecutive stages while regenerated sorbent enters the top-most adsorber stage and moves downward through the loop seal arrangement. The adsorber is maintained at an operating temperature of 450°C. Each stage is fitted with heat transfer internals that allow recovery of heat of adsorption by raising medium- to high- pressure steam. The staged adsorber design also allows for high-temperature water-gas-shift catalyst beds to be integrated between stages. Sorbent rich in CO_2 exits the bottommost adsorber stage and flows to the desorber via loop seal.

The adsorber and desorber are operated at approximately the same pressure of ~ 42 bara. Natural gas fed to the desorber burns in the presence of O_2 and supplies the heat of CO_2 desorption. The desorber is maintained at 550°C and is fluidized with combustion products. The desorbed CO_2 along with the combustion products, CO_2 and H_2O, convey the regenerated sorbent out of the desorber to the top of the adsorber where a cyclone separates the sorbent from captured CO_2 stream. The hot capture stream is cooled to 150°C and the heat is recovered by generating steam. A portion of this cooled CO_2 stream is then recycled at the entry of the NG reformer to serve as heat sink to control the reformer temperature to below 2200°C. Similarly, hot regenerated sorbent from the cyclone drops in a bubbling bed reservoir where it is cooled to 450°C and the sensible heat is recovered as steam. The regenerated sorbent at 450°C is then sent to the top-most adsorber stage to complete the sorbent circulation path.

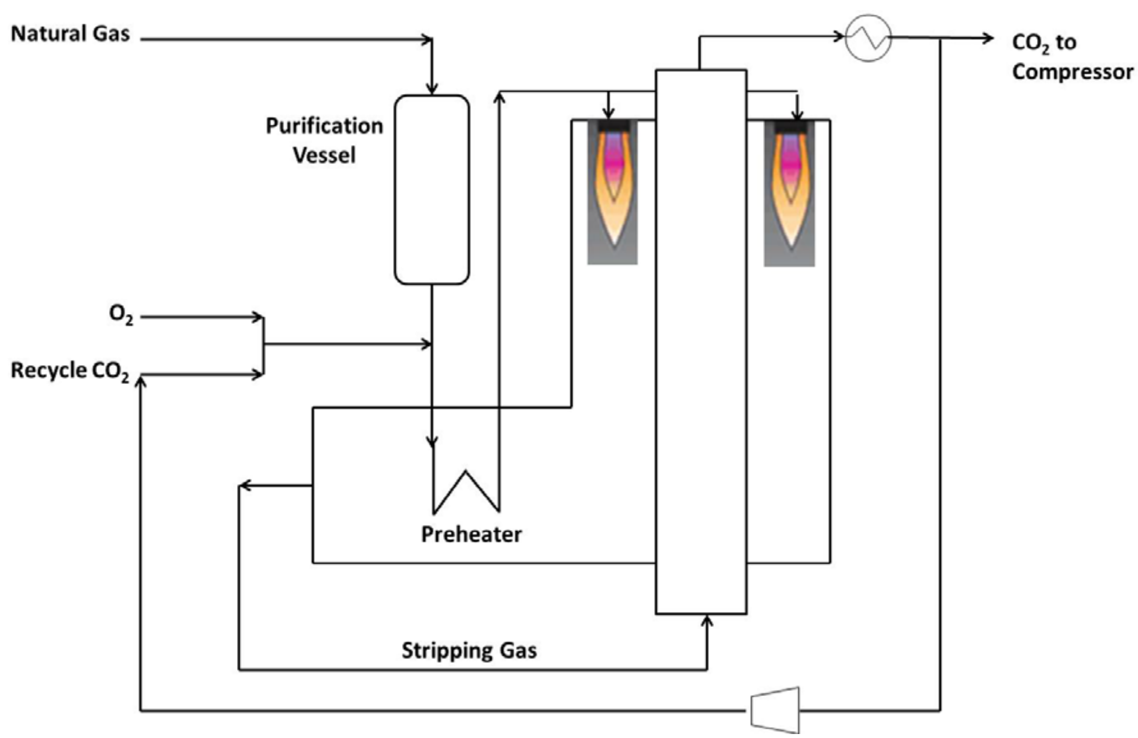


Figure 25. Process Design of the Sorbent Regenerator using Natural Gas Combustion as Fuel

Figure 25 above shows the sorbent regenerator design, which used natural gas reformer to provide the sorbent regeneration heat. As shown in the figure, natural gas, oxygen and recycled CO_2 mixture is preheated to 1200°C in the reformer. Using recycled CO_2 as heat sink, the flame temperature in the reformer is limited to 2200°C. A part of the heat in the reformer is also used to superheat heat steam for the desired steam turbine temperatures (1050°F)

The table below presents the comparison of H_2-rich syngas stream entering the combustion turbine n the DOE and TSA case.

Table 14. Comparison of H_2-rich Syngas Stream from the DOE Case and TSA Process

	TSA		DOE Case	
Mass Flow Rate	218,840 kg/hr		111,279 kg/hr	
Temperature	196 °C		196 °C	
Pressure	32 bar		32 bar	
Composition	**Vol. Fraction [-]**	**Mass flow [kg/h]**	**Vol. Fraction [-]**	**Mass flow [kg/h]**
Ar	0.008	7,249	0.011	7,226
CH_4	0.000	0	0.000	0
CO	0.007	4,410	0.015	7,313
CO_2	0.038	39,122	0.049	36,798
H_2	0.642	30,043	0.862	29,641
H_2O	0.260	108,494	0.000	31
H_2S	0.000	0	0.000	0
N_2 (Balance)	0.045	29,522	0.063	30,210

The adsorber is sized to capture 440,216 kg/hr of CO_2. Assuming a sorbent working capacity of 15 wt%, the sorbent feed rate to the adsorber is 2.9 x 10^6 kg/hr. The CO_2-rich sorbent is transferred to the desorber where it is heated to 550°C. The sensible heat and the heat of desorption is supplied by burning 55,269 kg/hr of natural gas. An air separation unit plant supplies 21,862 kg/hr of 95 mol% O_2 to the desorber. The capture stream exiting the desorber consists of 601,885 kg/hr of CO_2, 27% of which comes from the natural gas. In the TSA process, the total heat recovered as steam is ~1431 GJ/hr. Using steam cycles similar to those used in the DOE report, the recovered thermal heat is converted to 397 MW_e.

4.2.2.2.2 Power Summary

The total electricity consumption of TSA based WGCU process is 117,002 kW_e. Table 15 summarizes the electricity consumption of different blocks in the WGCU process. The air separation unit and oxygen compressor require 96,900 kW_e accounting to 83% of the total electricity consumption. The CO_2 compressor consumes 11,158 kW_e which represents 9% of the total electricity demand. The cooling tower fan and cooling water circulation pumps consume 5612 kW_e.

Table 15. Summary of the Electrical Power Requirement of TSA based WGCU Process

Equipment Name	Electricity Consumption, kW_e
RTI WGCU/DSRP	2,594
Natural Gas Compressor	738
Cooling Tower Fan and Pump	5,612
Air Separation Unit	96,900
CO_2 Compression	11,158
Total	117,002

The overall power summary of the power plant is shown in Table 16. The gas turbine power production is the same as the DOE case. However, the steam turbine power production has increased significantly. The additional power generation comes from the CO_2 capture plant by raising high pressure steam. The total power production for TSA case is 1,065,272 kW_e and the total auxiliary load is 257,052 kW_e resulting in a net power production of 808,220 kW_e which is 71% higher than DOE Case. The thermal input to the plant is the coal fed to the gasifier and natural gas fed to the CO_2 desorber. Based on these inputs, the net plant energy efficiency is 35.7% which is a 3.6% point improvement over DOE Case.

Table 16. Overall Power Summary of IGCC Power Plant with RTI Warm-temperature Acid Gas Removal Processes

Power Summary (Gross Power and Generator Terminals, kW_e)	
Gas Turbine Power	430,900
Sweet Gas Expander Power	4,503
Steam Turbine Power	629,869
Total Power, kW_e	**1,065,272**
Auxiliary Load Summary, kW_e	
Air Separation Unit	64,550

Power Plant Auxiliaries	75,500
Acid Gas Removal	105,844
CO_2 Compressor	11,158
Total Auxiliaries, kW_e	**257,052**
Net Power, kW_e	**808,220**
Net Plant Efficiency, % (HHV)	**35.7**

4.2.2.2.3 Capital Cost

The total installed plant cost for some of the major items of the TSA case are shown in Table 17. The cost of the ASU/Oxidant compressor package is priced at $209,847,810. The cost of steam generation, ducting and turbine was calculated as $219,012,539. Additional cooling water capacity was required to meet the cooling requirement low pressure steam condenser from the steam turbine. The capital cost of cooling tower and cooling water circulation pump was estimated to be $5,095,647. The high-pressure, warm-temperature desorber capable of direct firing of natural gas with purified oxygen is estimated to cost $34,758,750. The total installed plant cost for TSA process was estimated to be $672,697,278.

Table 17. Summary of Major Contributors to the Capital Cost of RTI's Warm-temperature Acid Gas Removal Processes

RTI WGCU/DSRP	$113,202,754
CO_2 Adsorber	$73,082,500
CO_2 Desorber	$34,758,750
Natural Gas Compressor	$1,741,297
ASU/Oxidant Compressor	$209,847,810
Heat Recovery and Quench	$2,841,797
CO_2 Compression and Dehydration	$6,073,646
Sweet Gas Expander	$5,962,203
Steam Generation and Turbine	$219,012,539
Cooling Water System	$5,095,647
Balance of Plant	$1,078,335
TPC of the AGR Plant	$672,697,278

TPC for the GEE gasifier based IGCC power plant with TSA based WGCU process was estimated by substituting the TPC for the "Gas Cleanup and Piping" and "CO_2 Compression" with the TPC estimated for RTI WGCU process using TSA for CO_2 capture. The TPC for the combined plant is estimated as $1,844,823,287. The TOC and TASC were estimated using the methodology detailed in the DOE report and was estimated as $2,246,033,465 and $2,560,487,150, respectively.

Table 18. Summary of RTI Warm-temperature Acid Gas Removal Process TOC and TASC

Item	
Total Plant Cost	
Power Plant	$1,363,422,000
Acid Gas Removal Plant	$672,697,278
Total Plant Cost	**$2,036,119,278**
Total Overnight Costs (TOC)	**$2,530,889,945**
Total As-Spent Cost (TASC)	**$2,885,214,538**

4.2.2.2.4 Cost of Electricity (COE)

Cost of electricity was estimated following similar methodology outlined in the DOE report. The resulting cost of electricity for TSA CO_2 capture process and its breakdown is given in Table 19. For comparison, the cost of electricity for the DOE Case are also shown.

Table 19. Comparison of Cost of Electricity and its Contributors for DOE Case and RTI's Warm Temperature Acid Gas Removal Processes

Cost of Electricity, %	RTI	DOE Case 2
Capital Cost	48.3	62.9
Fixed Cost	11.4	15.3
Variable Cost	12.7	8.8
Fuel Cost	23.0	7.9
CO_2 TS&M Cost	4.6	5.0

The COE for the TSA case was 5.0 $/MWh lower than the DOE which represents a reduction of about 4%.

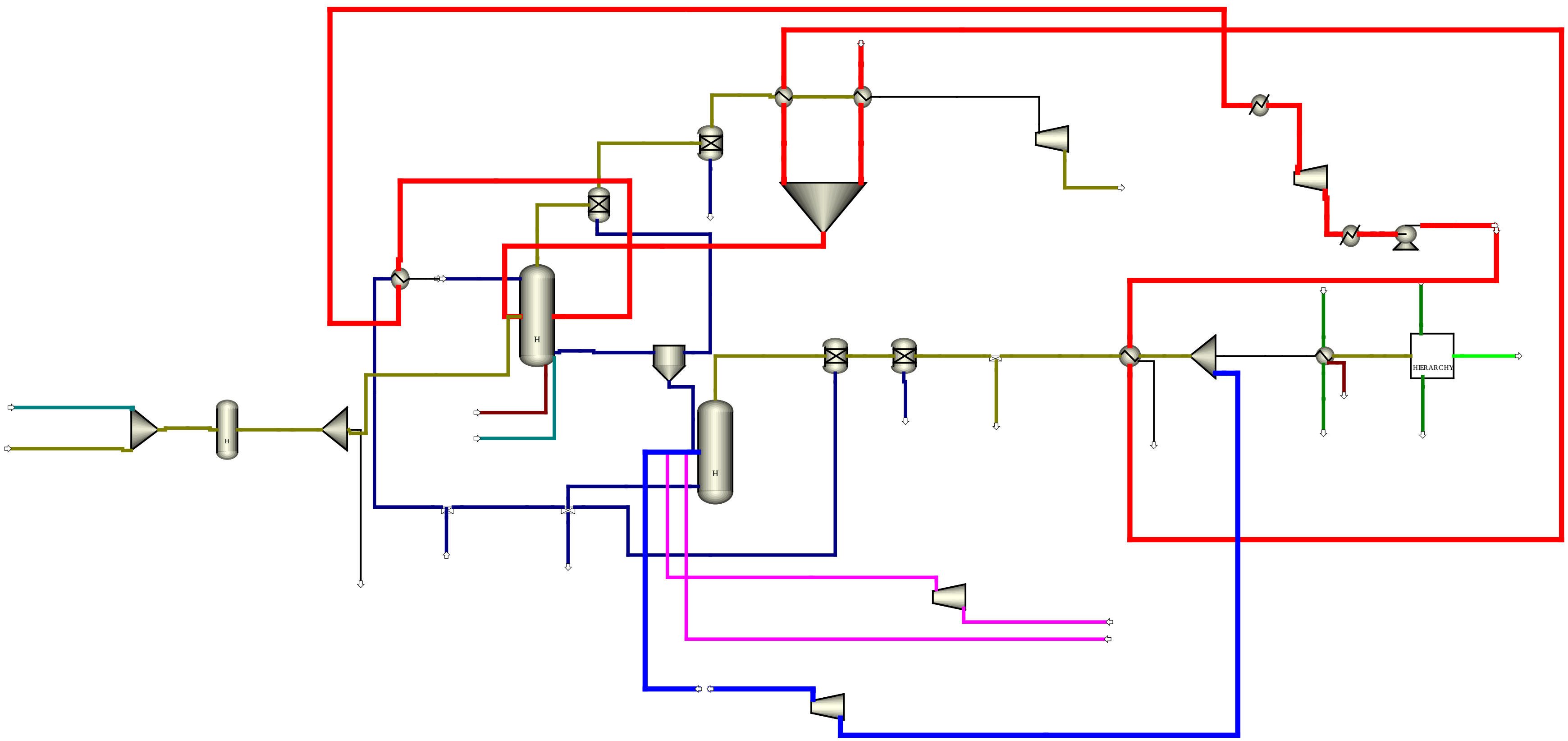


Figure 26. Process Flow Diagram of the High-temperature Temperature Swing CO_2 Capture Process

4.2.2.2.5 Cost of CO_2 Avoided

Cost of CO_2 avoided was used as the parameter to optimize the operating window for the TSA solid sorbent CO_2 capture technology and also to study the cost sensitivity. Experimental results have indicated versatility of the MgO based sold sorbent with respect to the adsorption-regeneration temperatures. MgO sorbent has exhibited good adsorption capacities over the temperature range of 300-450°C. TSA case discussed in the previous section was modeled and costed for an adsorption temperature of 450°C and a regeneration temperature of 550°C. We modeled three cases in total:

Case 1: Adsorption Temperature-450°C, Regeneration Temperature- 550°C

Case 2: Adsorption Temperature-400°C, Regeneration Temperature- 500°C

Case 3: Adsorption Temperature-375°C, Regeneration Temperature- 550°C

Case 2 was designed with the same temperature difference between the adsorption and regeneration step, while the Case 3 was designed with a larger adsorption-regeneration window. An adsorption capacity of 15 wt% was assumed for all the three cases. Figure below presents the results of the study.

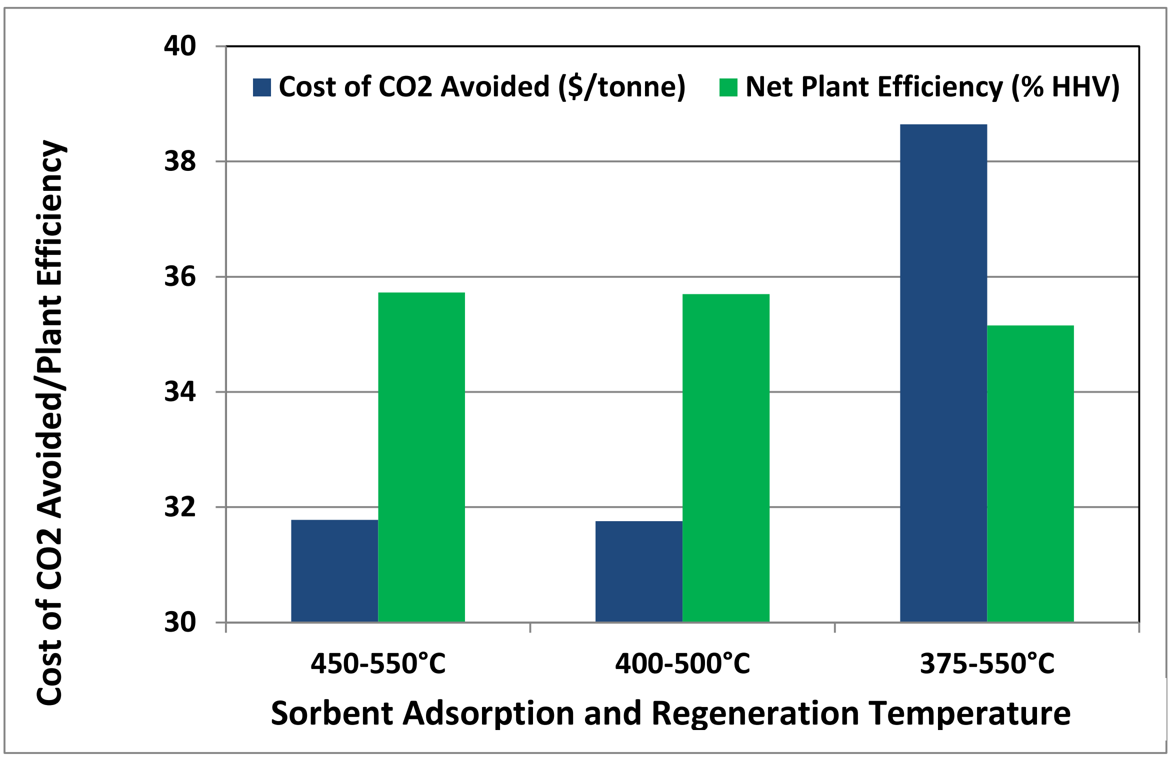


Figure 27. Effect of Adsorption-Regeneration Temperature on the Cost of CO_2 Avoided

As can be seen from the plot, lowering the adsorption and regeneration temperature without changing the adsorption-regeneration window did not change the cost of CO_2 avoided and the net plant efficiency. Increasing the temperature window resulted in higher cost for CO_2 avoided and a drop in net plant efficiency.

Among other key variables that can have a significant effect on the economics of the solid sorbent CO_2 capture technology is the adsorption capacity of the sorbent. The figure below presents the effect of adsorption capacity on the cost of CO_2 avoided. The figure also presents the distribution of the cost.

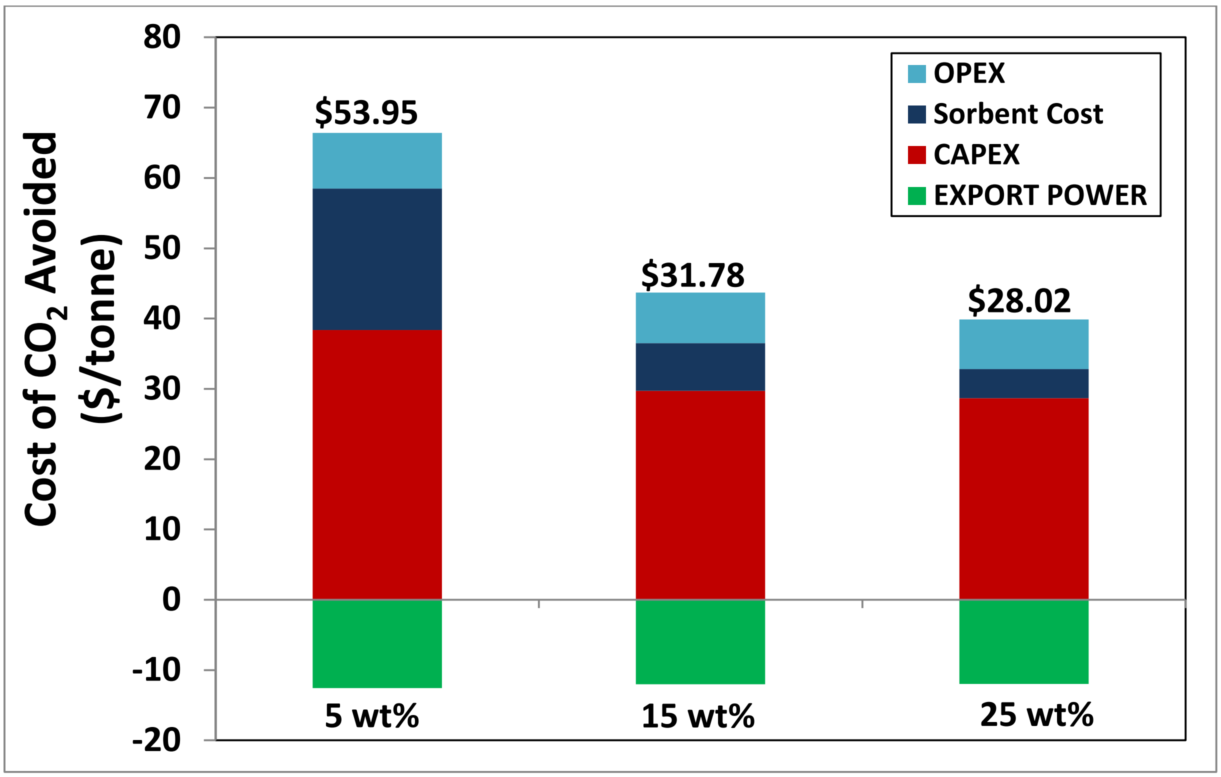


Figure 28. Effect of Adsorption Capacity on the Cost of CO_2 Avoided

As can be seen from the plot, cost of the CO_2 avoided improved from $53.95/tonne to $28.02/tonne with the increase in the adsorption capacity from 5 to 25 wt%. The cost distribution suggests that the major contributor to the cost is capital cost. Sorbent cost is inversely proportional to the adsorption capacity as indicated in the plot. Cost of CO_2 avoided due to export power generated from the steam turbine is indicated on the negative axis. This cost remains consistent (about $12/tonne) over the adsorption capacity range.

4.2.2.2.6 Sensitivity Analysis

Sensitivity analysis was carried out to determine the effects of various parameters of the RTI solid sorbent CO_2 capture technology on the cost of CO_2 avoided. The parameters investigated include: sorbent cost, feedstock cost, fuel cost, and efficiency of steam cycle.

Sorbent Cost

The figure below shows how the cost of CO_2 avoided changes with the sorbent cost. Cost of CO_2 avoided changed from \$25/tonne to \$40/tonne of CO_2 for the change in the sorbent cost from \$2/kg to \$40/kg.

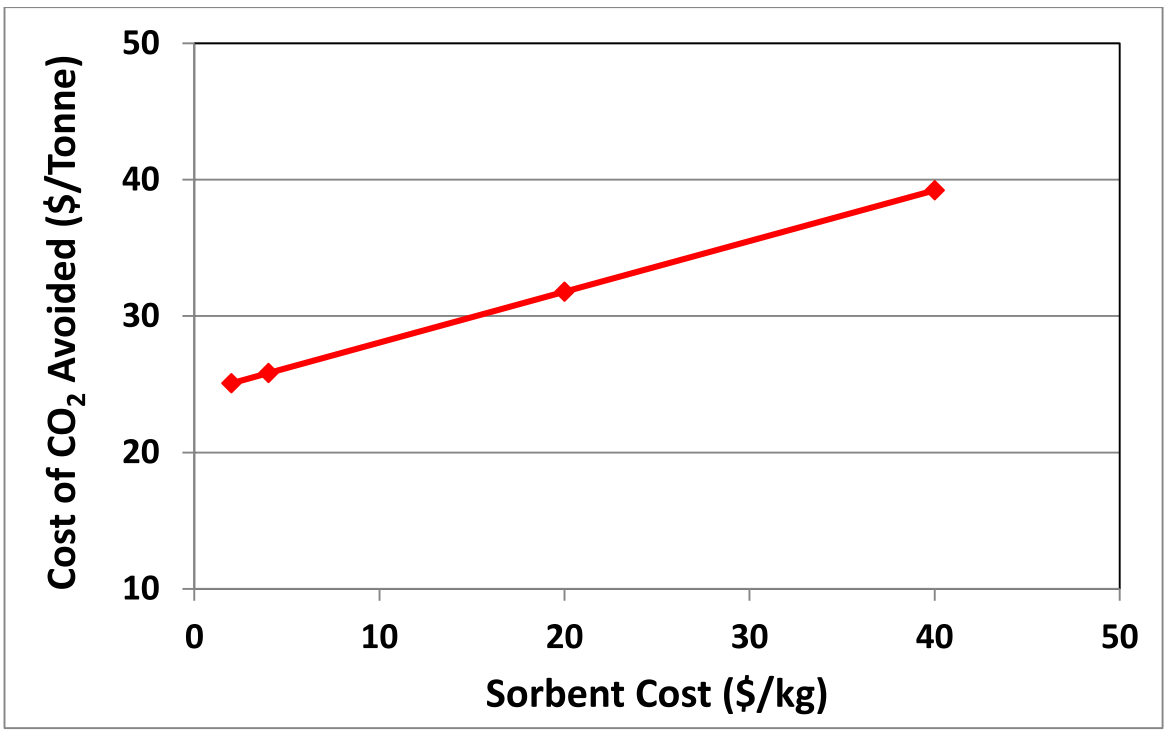


Figure 29. Effect of Sorbent Cost on the Cost of CO_2 Avoided

Natural Gas Cost

The figure below shows how the cost of CO_2 avoided changes with the natural gas cost. Cost of CO_2 avoided changed from \$12/tonne to \$40/tonne of CO_2 for a change in the natural gas cost from \$3/MMBtu to \$7.5/MMBtu.

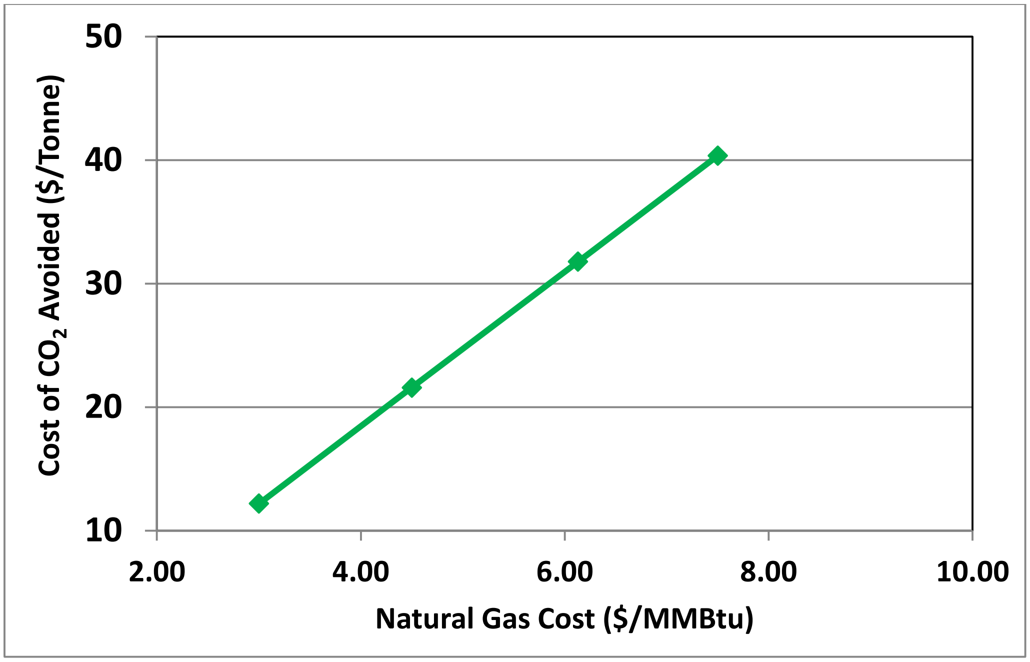


Figure 30. Effect of Natural Gas Cost on the Cost of CO_2 Avoided

Steam Cycle Efficiency Factor

The figure below shows how the cost of CO_2 avoided changes with the steam cycle efficiency factor. Cost of CO_2 avoided changed from $22/tonne to $38/tonne of CO_2 for the change in steam cycle efficiency factor from 0.45 to 0.36.

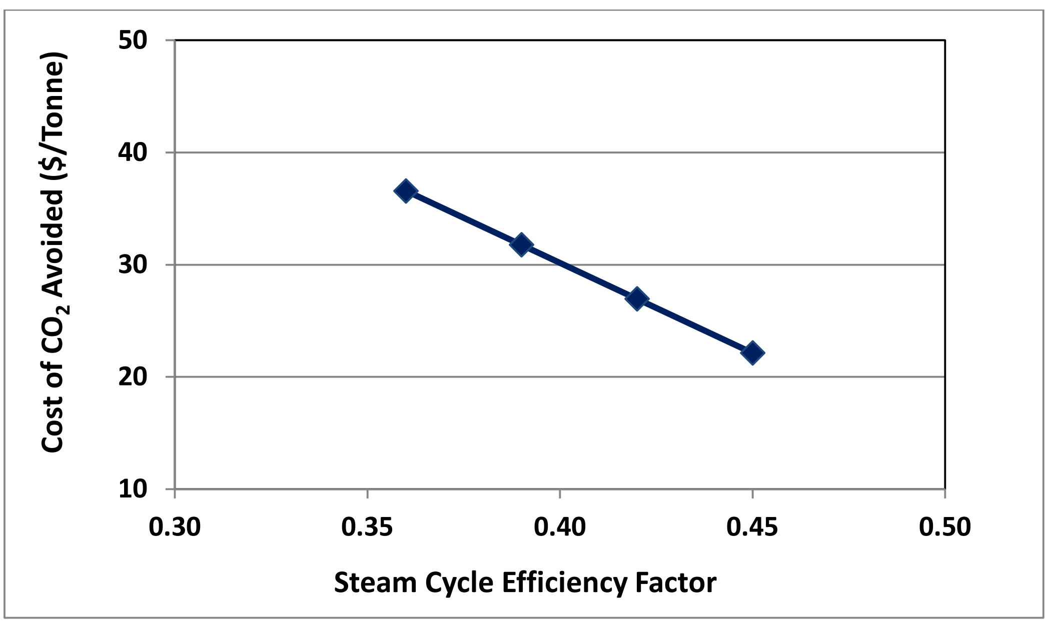


Figure 31. Effect of Steam Cycle Efficiency Factor on the Cost of CO_2 Avoided

5.0 Development of a Fluidizable, Temperature Swing Adsorption Sorbent for CO_2 Capture

The sorbents developed for reverse-temperature swing adsorption process showed stable performance after 20 cycles with CO_2 capture capacity ~10 wt%. Techno-economic evaluation confirmed a 1.6 % point improvement in energy efficiency compared to a similar DOE case of capturing CO_2 using the dual stage Selexol™ process. However, higher capital costs led to higher cost of electricity with CO_2 capture using RTI's RTSA process, thereby rendering it infeasible. On the contrary, the modified temperature swing adsorption process showed highly favorable results. However, the sorbent development efforts were focused only around materials suitable for reverse-temperature swing adsorption process. Experiments representing a classical TSA process were performed in a high pressure, high-temperature TGA using the most promising sorbent developed for the reverse-temperature swing adsorption process. The cyclic adsorption-desorption experimental data is plotted in Figure 32. The sorbent was loaded with CO_2 at 450°C and 400 psig total pressure. The partial pressure of CO_2 was 350 psig and steam made up the remaining 50 psig. Upon loading with CO_2,the sorbent was heated to 550°C under the same gas conditions - 350 psig CO_2 and 50 psig. The sorbent was fully regenerated under these conditions. The initial CO_2 loading under temperature swing adsorption process conditions was 18 wt%. However after 20 cycles, CO_2 capacity dropped to 8 wt%.

Although the sorbent working capacity stabilized, it had to overcome two challenges. The sorbent working capacity needs to be stable but also higher (>15 wt%) and the sorbent needs to be fluidizable to be used in the fluidized bed adsorption and regeneration reactors.

Characterization of the fresh and spent sorbent was carried out to understand the cause of deactivation when tested under TSA process conditions. BET surface area measurement indicated a significant drop in porosity (from 37 m^2/g to 5 m^2/g), and ICP analysis showed a significant decline in active ingredient content (from 0.76 % to 0.1%). Loss of the active ingredient could be attributed to its instability under the process conditions and could be related to decomposition under high temperatures especially under regeneration conditions. This could have resulted in higher carbon amount in the sorbent, as indicated by the ICP analysis in Table 20 for the spent sample.

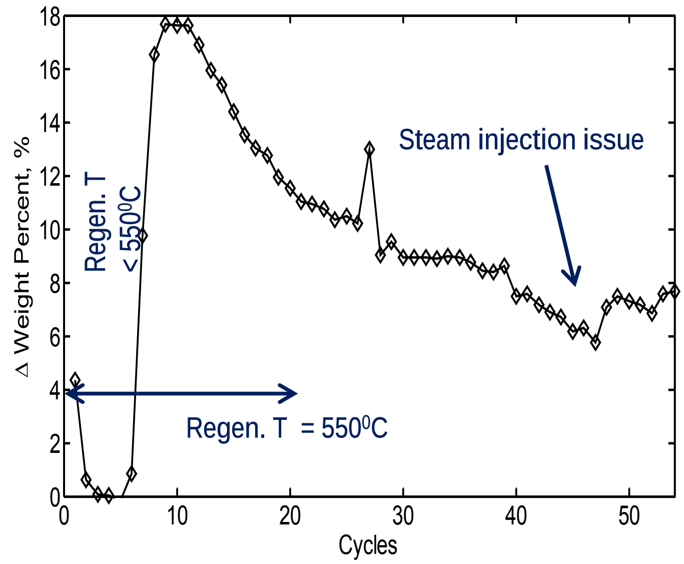


Figure 32. Sorbent Working Capacity under Temperature Swing Operation Conditions

Table 20. ICP Analysis of the Fresh and Spent Sorbent

Sample	BET Surface Area (m^2/g)	Pore volume (cc/g)	ICP, CHN analysis (wt.%)			
			Mg	Promoter	C	Al
Fresh sorbent	40	0.02	47.98	9.33	2.19	0.76
Regenerated (after 10 cycles)	5	0.002	47.89	7.36	2.54	< 0.1

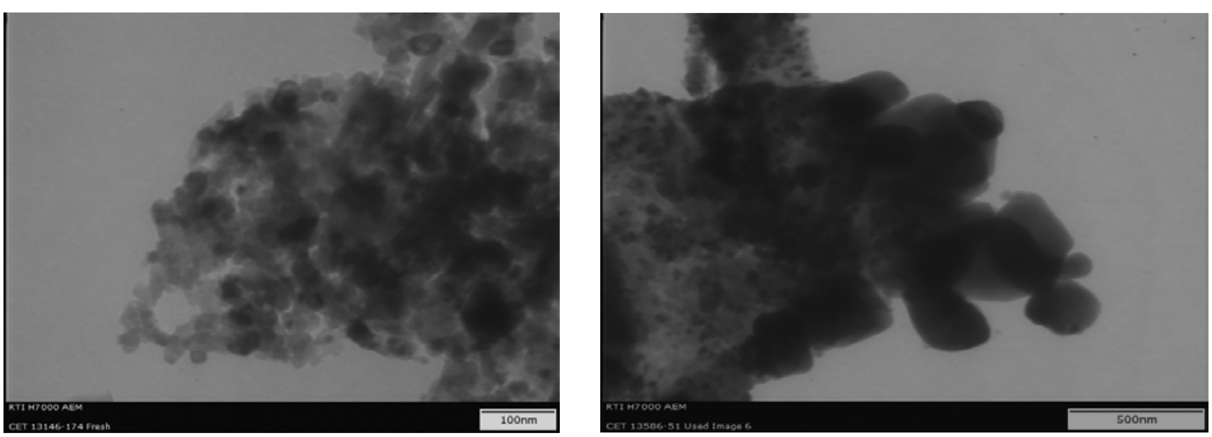


Figure 33. SEM images of the fresh and spent sorbent

SEM imaging was used to compare sorbent particle size for fresh and spent sorbent. These images show growth in crystal size of active phase MgO resulting in decreasing CO_2 capacity.

Table 21. Crystal Size of MgO of the Fresh and Spent Sorbent

	Fresh	Spent (deactivated)
MgO Particle Size (Å)	179	396

5.1 Approaches to Fluidizable Sorbents for TSA Process

The desired sorbents should be fluidizable and stable under TSA conditions, and with reasonable CO_2 capacity (target ≥ 15 wt%). Alkali promoted MgO-based sorbents were taken into consideration for sorbent development. To be a fluidizable material, need for a supported sorbent was proposed. The support candidates can be selected from commercially available materials like Al_2O_3 and SiO_2. To impart thermal stability to the sorbents, different promoter precursors were tested and selected based on our experience developing similar materials. In general, the growth of crystal size at high temperatures is a common problem under relatively harsh conditions. The following will address all those three issues.

5.1.1 Selection of the Supports

It is expected that the percentage of active phase and promoter on the support will be relatively high (maybe up to 70%) in order to achieve reasonable CO_2 capacity. In order to incorporate such high amounts, the support will need to have high surface area, large pore size, and large pore volume. Higher surface area (>500 m^2/g) means better dispersion for MgO and its promoter and less chance for MgO sintering. Large pore size (>5 nm) will be essential in lowering the possibility of pore blocking after loading active components. Although high pore volume is desirable, it is a balance between surface area and pore size. Additional criteria for the support is the sorbent should tolerate strong bases because of the basicity of MgO and alkali carbonates. Finally, the support should be fluidizable, and has reasonable particle size range (45 to 150 µm) and attrition resistance. A set of criteria for the desired support were developed in-house. Commercial supports that meet most of these criteria were extensively searched. Properties of some of the commercial silica supports are listed in Table 22. Surface area of treated supports is listed in Table 23.

Table 22. Properties of Selected Silica as the Support

Material description	BET SA (m2/g)	Pore volume (cc/g)	Pore size(nm)	Particle size (um)
Silica gel, Davisil, grade 644	300	1.15	15	75-150
Silica gel, Davisil, grade 646	300	1.15	15	250-500
Trisyl p100	730	1.2-1.4	5-6	50
CARiACT Q15	>300	>1.0	15	
CARiACT Q30	>300	>1.0	30	

Table 23. BET Surface Area after Support Pretreatment

Material	Sample ID	BET SA (m^2/g) (fresh support only	BET SA (m^2/g) calcined treated support
Silica gel, Davisil, grade 644	13580-49A	300	89.4
Silica gel, Davisil, grade 646	13580-49B	300	101.4
CARiACT Q30	13580-49C	>300	55.7
CARiACT Q15	13580-49D	>300	103.1
Trisyl p100	13580-49E	730	124.6

5.1.2 Active and Promoter Components

The prior most promising candidate was the mixture of promoters on MgO. However, it is a less desirable candidate for the TSA process as explained earlier. The base materials tested for RTSA process were the first candidates tested for TSA process. Selected sorbents were enahanced with a promoter using a desired precursor on Davisil silica gel as the support. These sorbents were selectively tested using high pressure TGA.

5.1.3 Approaches to Make Fluidizable Sorbent through Integration of Three Components-Active Phase MgO, Promoters and the Supports

Three approaches were explored for making the fluidizable CO_2 sorbent based on the consideration of functionality and chemical interaction among the components: active phase

MgO, promoters, and fluidizable supports. At higher temperature, the active phase MgO and the promoter will react with the support.

$$MgO + SiO_2 \rightarrow MgSiO_3$$
$$MgO + Al_2O_3 \rightarrow MgAl_2O_4$$

Therefore, a surface layer of magnesium silicate or magnesium aluminate will be formed. Similarly, the strong basic promoters will react with the supports and form respective silicates and aluminates on the surface. The formation of surface layers should increase the interaction with active phase (or the promoter). This increased affinity between the support surface and active phase or promoter should decrease their migration under TSA conditions and will prevent sintering to thereby improve the sorbent long-term stability. Several synthesis methods based on our extensive experience in developing similar thermally stable and fluidizable materials were tested.

5.2 Sorbent Testing

Sorbent Screening Test Conditions and Methodology

Three methods were developed to screen the sorbents for this high-temperature CO_2 capture and release application and to optimize the process conditions for sorbent materials with fluidized conditions. Method 1 was developed to screen base materials containing different MgO:promoter (P1 and P2) ratios. In method 1, a sample was loaded in the reactor vessel and any adsorbed species such as water were desorbed using a temperature ramp in an inert atmosphere of He and Ar. The reactor pressure was then increased to 400 psia using the BPR with inert gases (He and Ar). Then the reactor temperature was raised to an adsorption temperature of 350°C. Steam and CO_2 were introduced by maintaining the total pressure of the reactor at 400 psia with a CO_2 partial pressure (P_{CO2}) of 100 psi. Changes in the weight of the sample was recorded in a computer every 10 secs. The weight of the sample increased and reached a steady value. After 2 hours, the temperature of the reactor was increased to 550°C to regenerate the sample for another 2 hours and record the weight decrease and eventual steady value. Then the reactor temperature was lowered to the adsorption temperature for next cycle of adsorption-regeneration. Once the temperature reaches the adsorption temperature, CO_2 was introduced with a different partial pressure by adjusting the mass flow controller. For method 1, the cycle of P_{CO2} was 100-225-350-0-50-100 psia. After adsorption at 350 psia, P_{CO2} was reduced to 0 pisa to regenerate the sample to the initial condition and then increased to 50 psia to study adsorption at lower partial pressures. An adsorption-desorption cycle with P_{CO2} of 100 psia was done first and last to check the stability of materials after a series of adsorption and desorption cycles. Using this method, initial screening of base materials and base materials supported with Silica (SiO_2) was performed. Method 2 was developed to produce better isotherms with low and high P_{CO2} by modifying the adsorption-desorption cycles as 350-250-100-0-50-100 psia, keeping the adsorption and desorption temperatures 350 and 550°C. After the second screening using method 2, method 3 was developed to study the change in weight of sample during CO_2 adsorption at different adsorption and regeneration temperatures to study the performance of sorbents at optimized process conditions. In method 3, adsorption was performed at different adsorption temperatures (350-450°C) while keeping P_{CO2} at 100 psia and desorption was done at different desorption temperatures (500-580°C). Alumina supported materials calcined at different temperatures and base materials without alumina support were tested to study the optimized operating conditions and stability of the sorbent materials.

Figure 34 shows the screening results obtained by HP-TGA at different P_{CO2}. Maximum CO_2 loading observed was around 60 wt% for the base materials P1 and P2 with MgO at P_{CO2} of 100 psia and had a stable loading capacity of 40 wt% after a series of adsorption and desorption cycles. Sorbent with P1 and MgO had the lowest capacity to hold CO_2 in their sites. Therefore, sorbent materials with mixtures of P1 and P2 with MgO were tested with supported materials using method 2.

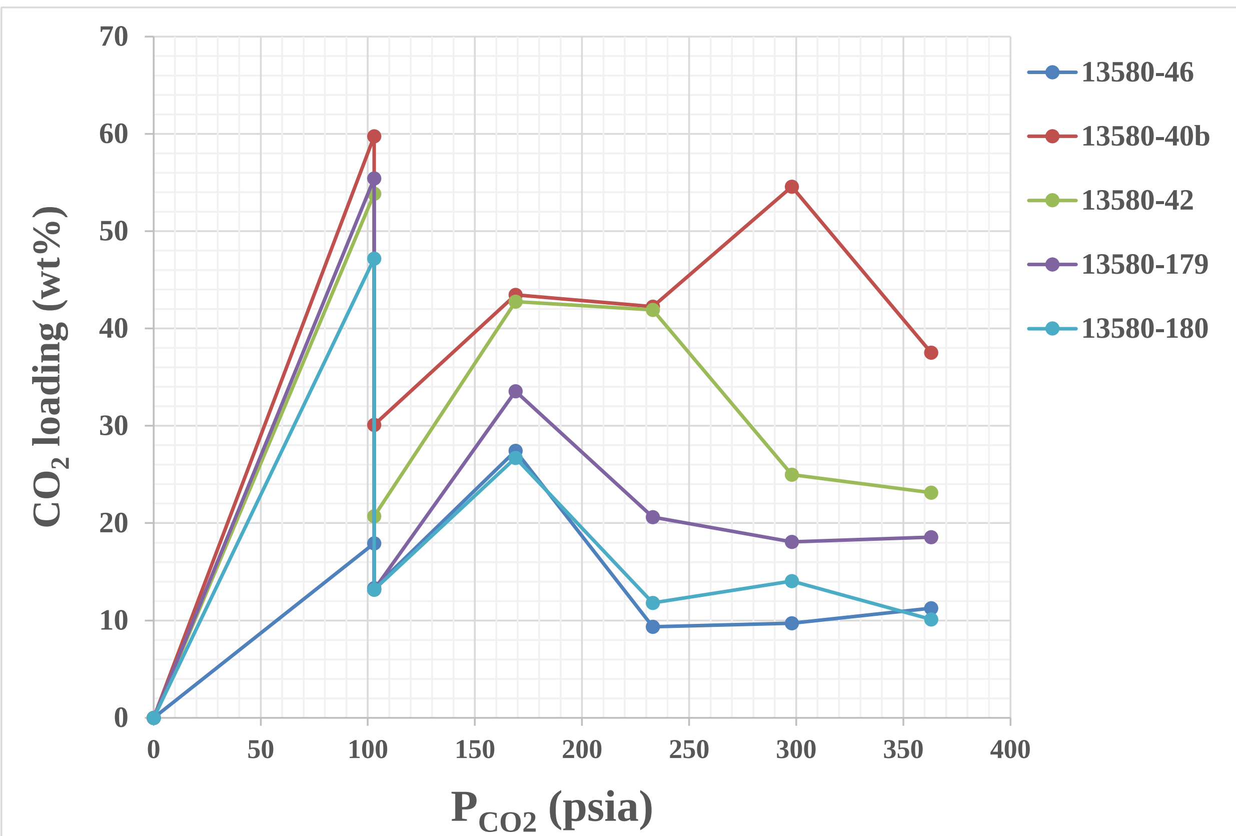


Figure 34. Screening of Base Materials with HP-TGA using Method 1

Figure 35 shows the screening results of sorbent materials on a silica support to make them suitable for fluidized conditions. Maximum CO_2 loading capacity of 45 wt% was obtained for 13580-64 at 100 psia P_{CO2}, but its capacity dropped from 45 wt% to 13 wt% at the second cycle at P_{CO2} of 100 psia. Sorbent material 13540-63A showed better stability than other materials; its capacity dropped from 35 wt% to 10 wt%.

The preparation conditions and materials used in the supported sorbents were then varied to optimize the performance of the sorbent materials using method 3. Figure 36 shows the screening results of alumina- and silica-supported sorbent materials. As P_{CO2} increased from 100 to 350 psia, CO_2 loading capacity of the sorbent material increased from 10 wt% to 55 wt%. Sample number 13580-66A exhibited a loading capacity of 10 wt% at 100 psia P_{CO2} and 52 wt% at 350 psia. 4 wt% of the CO_2 loading capacity was lost in the second cycle for this material compared to other sorbent materials as shown in Figure 37. Therefore, material 13580-66A was selected and tested for longer stability experiments and to find the optimized process conditions for adsorption and desorption with a larger number of adsorption-desorption cycles.

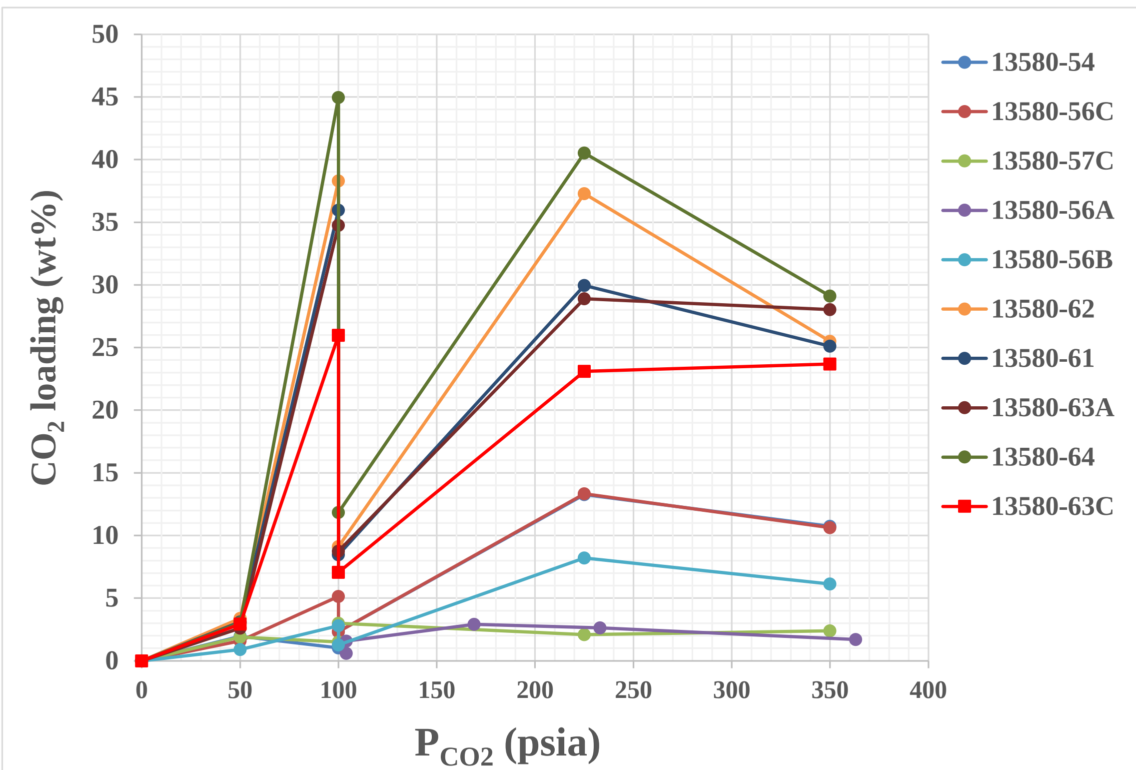


Figure 35. Screening of Silica (SiO_2) Supported Sorbent Materials with HP-TGA using Method 2

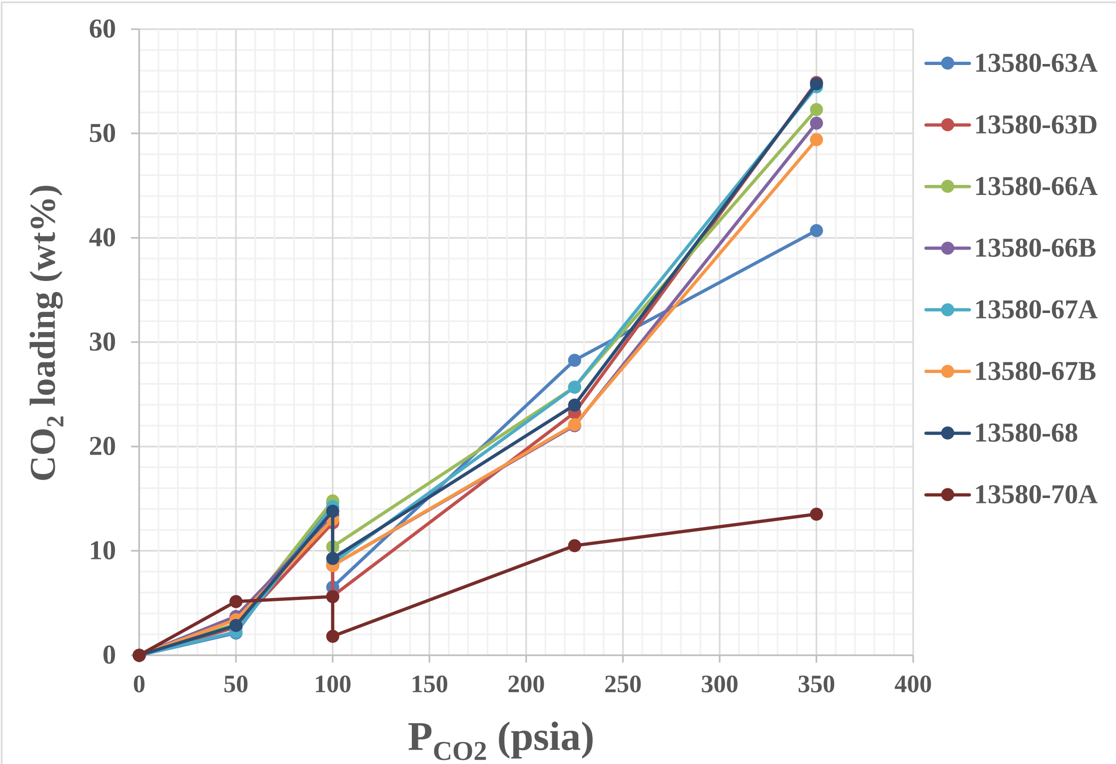


Figure 36. Screening of Supported Sorbent Materials with HP-TGA using Method-3

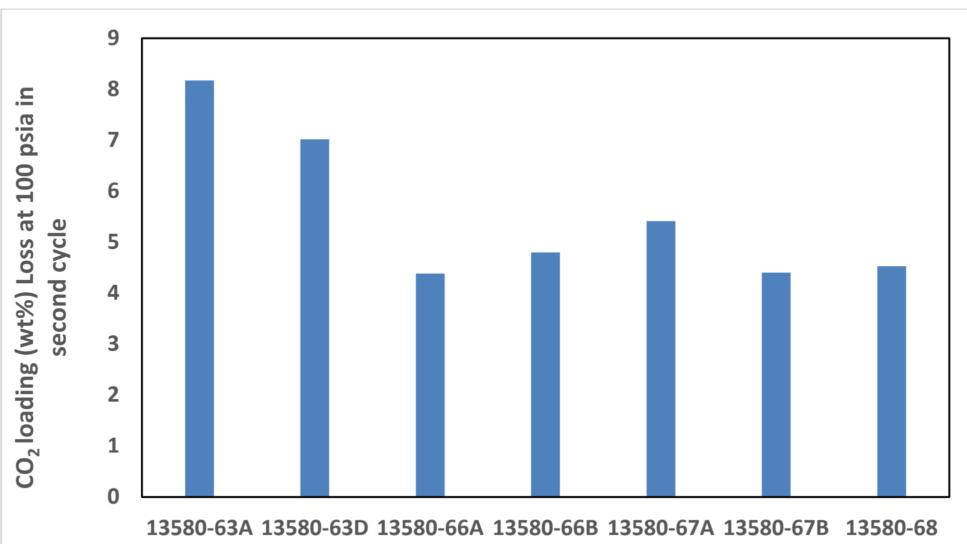


Figure 37. Stability of Sorbent Materials Screened by Method-3

Figure 38 shows the experimental results obtained for the best screened material (13580-66A). Adsorption and desorption temperatures were adjusted to find the optimized adsorber and desorber conditions. CO_2 loading capacity of 10 wt% was found for this material after 11 adsorption and desorption cycles. Optimized process conditions for this material for warm syngas application were found to be adsorption at 380-390°C at 100 psia and desorption at 565-575°C at 350 psia.

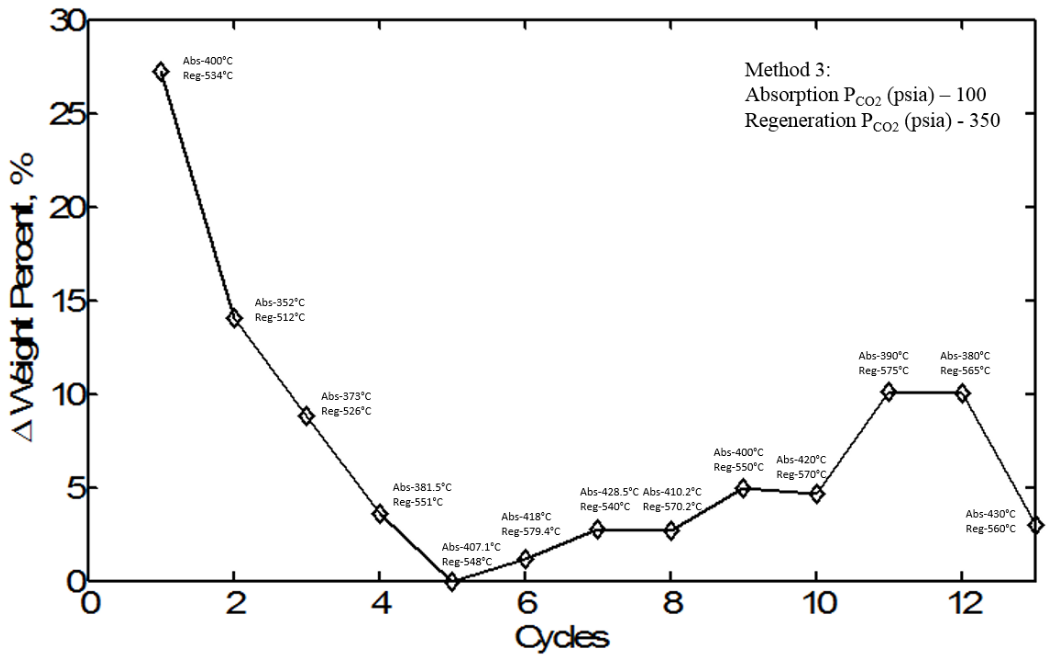


Figure 38. Working Capacity of Sorbent Material 13580-66A Using Method 3 with Varying Process Conditions for Adsorption and Desorption

Figure 39 shows the change in CO_2 loading capacity of three similar sorbent materials: an unsupported base sorbent (23580-64A), and two supported forms with different pretreatment conditions (13580-66A and 13580-70A). Sorbent material 13580-70A (8 wt%) was found to be more stable in all cycles than sorbent material 13580-66A (5-10 wt%). Optimized process conditions for the best sorbent material, 13580-70A, in warm syngas application were found to be adsorption at 380°C and 100 psia and desorption at 545°C and 350 psia. A larger number of cycles could be performed in the future to explore the long term stability of this material and further improvements could be made by changing the mixture ratios of the primary components.

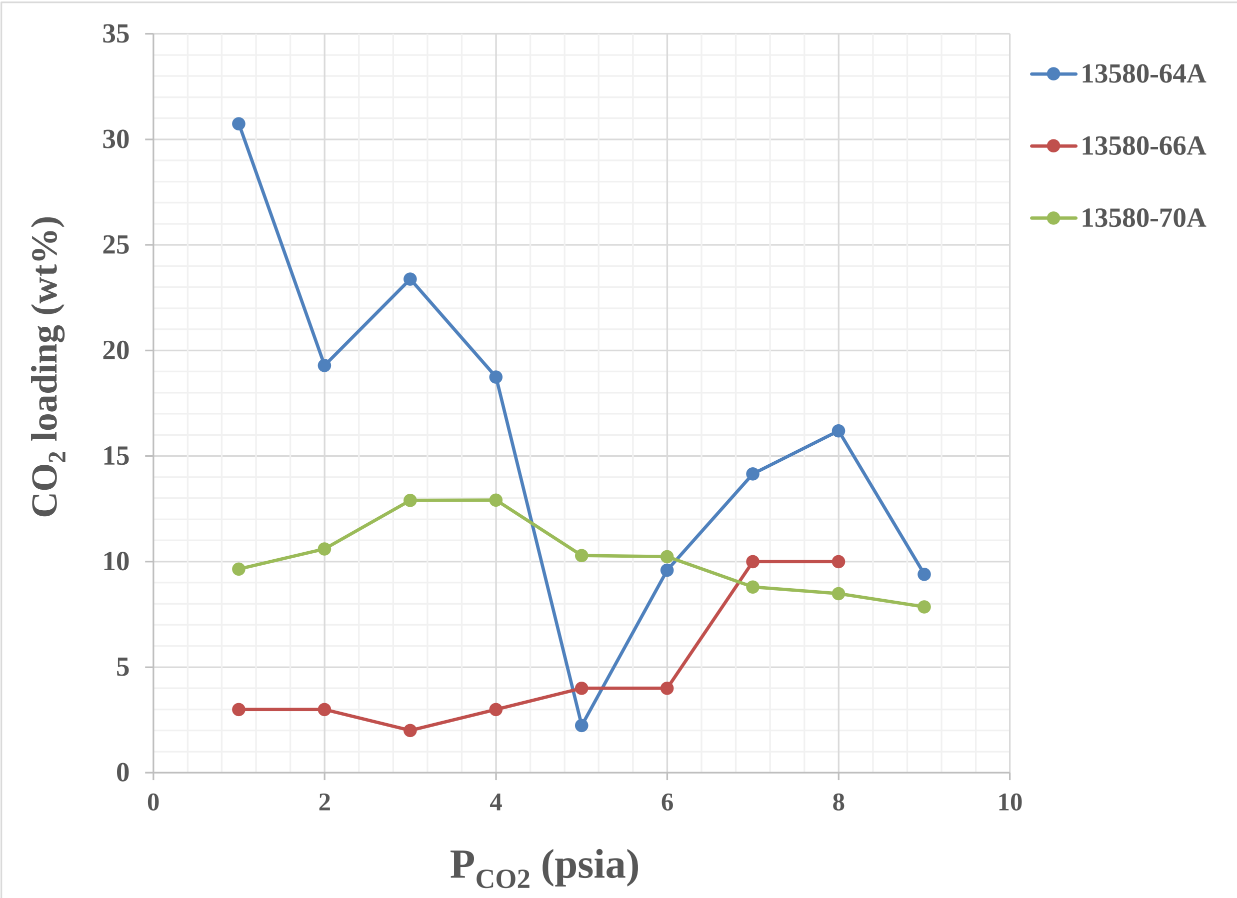


Figure 39. Stability of Best Material Screened in this Work with and without Support Material using Method-3

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i Personal communication with Ted Knowlton, Particulate Solid Research, Inc.

Appendix K

Ammonia/Urea Pre-FEED Study

Report Title: Value of Ammonia/Urea Retrofit of Existing IGCC Plants Utilizing RTI Warm Syngas Cleanup Technology

Type of Report: Topical

Reporting Period Start Date: April, 2013

Reporting Period End Date: June, 2014

Principal Authors: Nandita Akunuri, David L. Denton, Brian S. Turk

Date Report was Issued: June, 2014

DOE Award Number DE-FE0000489: Recovery Act: High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project

Sub-Task Number 1.7-A: Ammonia/Urea Integration Study

Name and Address of Submitting Organization:

RTI International
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Disclaimer

Table of Contents

1. Executive Summary

The integration of RTI's warm syngas desulfurization process (WDP) technology and its warm syngas trace contaminant removal process (TCRP) technologies with an advanced activated amine (aMDEA) technology (such as offered by BASF), or alternative carbon capture technologies, offers options to achieve syngas cleanup to very low contaminant levels at costs substantially below that of conventional processes, thus expanding the application of RTI's warm gas cleanup technologies beyond clean power generation to applications such as chemicals, fertilizers, fuels, and hydrogen. The integration of RTI WDP and BASF aMDEA technologies was selected and utilized in the 50-MWe pre-commercial demonstration plant designed, constructed and operated under DE-FE0000489 at Tampa Electric Company's (TEC) Polk 1 integrated gasification combined-cycle (IGCC) site near Tampa, FL, using a 20% slipstream of the syngas from the Polk 1 gasifier and producing an enriched-hydrogen product (~93% H_2 from a multi-stage sweet water-gas-shift process) with >90% carbon dioxide capture.

To help understand the potential value of these integrated syngas cleanup technologies for poly-generation and/or stand-alone chemicals/fertilizers/hydrogen production, a study (approximately pre-FEED level) was conducted to develop a techno-economic assessment of these options using ammonia and urea production as the study basis. Two scales of retrofit processes were considered:

- 20% syngas retrofit option - a 300 short-tons per day (stpd) ammonia process and/or its associated equivalent-scale urea process (sized at 520 stpd to use all 300 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to utilize all of the hydrogen produced from a project similar in size to the RTI demonstration project at TEC and to provide a case study involving 20% syngas polygeneration.
- 100% syngas retrofit option - a 1500 stpd ammonia process and/or its associated equivalent-scale urea process (sized at 2600 stpd to use all 1500 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to consider a full retrofit case to ammonia/urea production for a single-train IGCC such as TEC Polk 1 using the RTI WDP process, water-gas-shift (WGS), and an aMDEA process for syngas cleanup.

Because of similarity to TEC Polk 1 design and a desire to model retrofit of a single-train IGCC without carbon capture, the GE radiant-cooled gasifier cases from these DOE baseline studies were used as the foundation for the Base Case IGCC techno-economic analysis in this report:

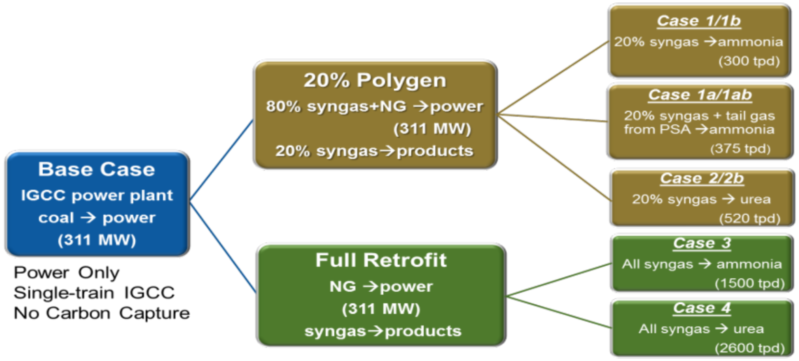
- "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity", DOE/NETL-2010/1397 (used Case 1 from this report, modified for 311-MW single-train IGCC).
- "Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases", DOE/NETL-341082312 (used Case 1 update to provide updated costs for the reference case).

The DOE baseline Case 1 study, selected from the above reports to serve as reference model for the IGCC in this report, was for a dual-train 622-MW IGCC but the desired model was for a single-train IGCC (such as for TEC Polk 1). However, the DOE study assumed two parallel trains all the way through except for the final combined cycle steam turbine, so it was relatively straightforward to modify the case for a single-train 311-MW IGCC by creating dual steam turbines and breaking out the capital and operating costs for each parallel single train. For purposes of this study, the construction/operation timeline and economic assumptions used in the DOE baseline studies were also used for these techno-economic analyses, except for assuming a 30-yr life for the Base Case IGCC. A gasification plant availability of 80% was assumed for single-train operation. For the retrofit cases where CO_2 was captured, no additional cost for sequestration or revenue generation for utilization of the captured CO_2 was assumed.

As in the DOE baseline studies, it was assumed here that the Base Case IGCC was constructed during the period of 2004-2007 and started up in 2007, and would operate through 2036. However, for each of the retrofit option cases in this report, it was further assumed that in 2014 a decision was made to retrofit the IGCC to either a 20% polygen ammonia or urea plant or to a full retrofit conversion to an ammonia or urea plant. The 20% polygen retrofit cases assumed it would take 2 years to construct the ammonia or urea facility with polygen startup in 2016, while the full retrofit cases would take 3 years to construct and would start up in 2017. During the construction of the ammonia/urea plants, it was assumed that the IGCC plant would continue to operate as much as possible. After retrofit conversion, it was assumed that natural gas would be used to fire the syngas turbine in place of any lost syngas now sent to the ammonia or urea plants (any required retrofits to the syngas turbine were included in the techno-economic analyses), so that 311 MW of electric power were co-produced in all cases. The economic timeframes for all of these study options were chosen to start in 2014 and to end at the end of 2036. The depreciated value for the Base Case IGCC plant in the year 2014 was used as the IGCC asset value starting point for each of the Base Case IGCC and retrofit cases.

For purposes of these techno-economic analyses, an established global technology supplier with extensive ammonia and urea plant licensing and retrofit experience was contracted to provide a feasibility study for the various scale ammonia and urea plants for potential integration with the Base Case IGCC (using the TEC Polk 1 IGCC and RTI demonstration facility as a basis). AMEC Kamtech, Inc. (who designed and constructed the RTI demonstration facility at the TEC Polk 1 site) was then contracted to provide a feasibility study for integration of each of the ammonia and urea plant options into a facility such as the existing TEC Polk IGCC site. For the 20% syngas retrofit cases (300 stpd ammonia case and corresponding 520 stpd urea plant case), this included any required modifications to existing TEC plant equipment (including additional purified nitrogen for feed to the ammonia facility) and to the RTI warm syngas cleanup demonstration facility (including a pressure swing adsorber (PSA) for final H_2 enrichment). For the full 100% syngas retrofit cases (1500 stpd ammonia case and corresponding 2600 stpd urea plant case), this included addition of a new or expanded full-scale RTI WDP and aMDEA carbon capture system, conversion of the existing syngas turbine to natural gas firing, and any equipment modifications required to integrate the ammonia/urea plants with the IGCC plant site.

For the techno-economic analyses for this study, the following option cases were modeled:



A brief description of each of these cases is as follows:

- Base Case: single-train 311-MW IGCC, no water-gas-shift (WGS) or carbon capture
- Case 1: 20% syngas polygen retrofit to a 300 stpd ammonia facility (full capital with no DOE funding support); hydrogen further enriched by PSA to ammonia specifications
- Case 1a: same as Case 1 but with alternative technology to enrich the H_2, eliminate the need to send PSA tailgas to the syngas turbine, and thus produce 375 stpd ammonia
- Case 1b: same as Case 1 but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA carbon capture (similar to DOE-funded 50-MWe demo plant at TEC)
- Case 1ab: same as Case 1a but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA carbon capture (similar to DOE-funded 50-MWe demo plant at TEC)
- Case 2: same as Case 1 except all the ammonia is used to make 520 stpd granulated urea
- Case 2b: same as Case 1b except all the ammonia is used to make 520 stpd granulated urea
- Case 3: 100% syngas retrofit to a 1500 stpd ammonia facility including a new full-scale warm syngas cleanup plant
- Case 4: same as Case 3 except all the ammonia is used to make 2600 stpd granulated urea

Techno-economic analyses for each of these cases were performed by RTI using the DOE baseline IGCC data and costs, feasibility study data and costs provided by the established global ammonia/urea technology licensor, and IGCC integration study data and costs provided by AMEC Kamtech, Inc. For the Base Case stand-alone IGCC, power prices were set at a level ($64.10/MWh) to achieve a 15% after-tax IRR. This power price was then carried forward into all the other study cases. Illinois # 6 coal ($68.60/ton) was used as the feedstock. Natural gas costs were assumed to be $3.50/MBtu and ammonia and urea prices ($500/ton and $400/ton, respectively) were based upon average U.S. prices for the 2012-2013 timeframe. The following table summarizes the techno-economic analyses results:

	Base Case IGCC (100% syngas to power)	Case 1 (20% syngas to NH3; 80% to power)	Case 1a (20% syngas to NH3; 80% to power)	Case 1b (20% syngas to NH3; 80% to power)	Case 1ab (20% syngas to NH3; 80% to power)	Case 2 (20% syngas to Urea; 80% to power)	Case 2b (20% syngas to Urea; 80% to power)	Case 3 (100% syngas to NH3; NG to power)	Case 4 (100% syngas to Urea; NG to power)
Input Fuels:	Coal	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG	Coal + NG
Products:									
Electricity, MW	311	311	311	311	311	311	311	311	311
Co-Product		Ammonia	Ammonia	Ammonia	Ammonia	Urea	Urea	Ammonia	Urea
Co-production Capacity, tpd		300	375 (extra H2 recovery)	300	375 (extra H2 recovery)	520	520	1500	2600
Capital Costs:									
2007 IGCC Capex, $M	$697	$697	$697	$697	$697	$697	$697	$697	$697
2014 IGCC Asset Value, $M	$383	$383	$383	$383	$383	$383	$383	$383	$383
Polygen Retrofit Block Capex, $M		$177	$189	$86 (plus federal support)	$98 (plus federal support)	$297	$206 (plus federal support)	$505	$837
After-tax IRRs:	**15.0%**	**14.2%**	**16.9%**	**19.3%**	**21.9%**	**13.6%**	**17.5%**	**22.6%**	**22.2%**

The above results indicate that full retrofit Cases 3 and 4 generate a significantly higher after-tax IRR than the Base Case stand-alone IGCC. 20% syngas retrofit Cases 1 and 2 produce after-tax IRRs that are reasonably good, but are slightly lower than for the Base Case stand-alone IGCC. Interpolation between Cases 1 and 3 and between Cases 2 and 4 would suggest that any IGCC polygen retrofit to ammonia or urea that utilizes at least 25-30% of the IGCC's syngas should result in an after-tax IRR greater than that of the Base Case stand-alone IGCC. If the warm syngas cleanup block (WDP + WGS + aMDEA for carbon capture) were to be supported with federal funding as in Cases 1b, 1ab, and 2b, then the after-tax IRRs for the 20% syngas retrofit cases would then be higher than the IRR for the Base Case stand-alone IGCC. However, if alternative technology to conventional PSA can be developed and utilized to enrich the hydrogen in the syngas, avoid sending PSA tailgas to the syngas turbine, and use the additional hydrogen to make additional ammonia, then the after-tax IRR of all modeled retrofit cases would be improved by several percent (as indicated in Cases 1a and 1ab) and would make the 20% syngas retrofit cases more attractive on an after-tax IRR basis than the stand-alone IGCC Base Case, without need for any federal support. The development of such an alternative to PSA should be considered as part of any future R&D efforts focused on polygen retrofits of IGCCs.

2. Introduction

Gasification is a technology that enables the production of syngas (primarily composed of hydrogen and carbon monoxide) from the partial oxidation of carbonaceous feedstocks such as coal. This syngas can be used as fuel in syngas turbines for the generation of electric power, but can also be converted into much higher value products such as chemicals, fertilizers (such as ammonia and urea), hydrogen, substitute natural gas, and transportation fuels. Polygeneration, or the co-production of electric power and chemicals, fertilizers, or fuels, is also possible with gasification-based syngas. Retrofit of an integrated gasification combined cycle (IGCC) plant from standalone power generation to polygeneration or to standalone chemicals or fuels production offers potential to increase the overall value creation for such a facility. However, the processes for conversion of syngas to such higher-value products or co-products often requires more rigorous cleanup of the syngas (to remove contaminants such as sulfur, mercury, arsenic, and carbon dioxide) than for stand-alone power generation.

The integration of RTI's warm syngas desulfurization process (WDP) technology and its warm syngas trace contaminant removal process (TCRP) technologies with an advanced activated amine (aMDEA) technology (such as offered by BASF), or alternative carbon capture technologies, offers options to achieve syngas cleanup to very low contaminant levels at costs substantially below that of conventional processes, thus expanding the application of RTI's warm gas cleanup technologies beyond clean power generation to applications such as chemicals, fertilizers, fuels, and hydrogen. The integration of RTI WDP and BASF aMDEA technologies was selected and utilized in the 50-MWe pre-commercial demonstration plant designed, constructed and operated under DE-FE0000489 at Tampa Electric Company's (TEC) Polk 1 integrated gasification combined-cycle (IGCC) site near Tampa, FL, using a 20% slipstream of the syngas from the Polk 1 gasifier and producing an enriched-hydrogen product (~93% H_2 from a multi-stage sweet water-gas-shift process) with >90% carbon dioxide capture.

To help understand the potential value of these advanced lower-cost syngas cleanup technologies for retrofit of an IGCC for poly-generation and/or stand-alone chemicals/fertilizers/hydrogen production, a study (approximately pre-FEED level) was conducted as part of Sub-task 1.7-A of this overall project to develop a techno-economic assessment of these options using ammonia and urea production as the study basis. Two scales of retrofit processes were considered:

- 20% syngas retrofit option - a 300 short-tons per day (stpd) ammonia process and/or its associated equivalent-scale urea process (sized at 520 stpd to use all 300 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to utilize all of the hydrogen produced from a project similar in size to the RTI demonstration project at TEC and to provide a case study involving 20% syngas polygeneration.
- 100% syngas retrofit option - a 1500 stpd ammonia process and/or its associated equivalent-scale urea process (sized at 2600 stpd to use all 1500 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to consider a full retrofit case to ammonia/urea production for a single-train IGCC such as

TEC Polk 1 using the RTI WDP process, water-gas-shift (WGS), and an aMDEA process for syngas cleanup.

These retrofit cases were then compared against a standalone IGCC power generation base case (using a DOE reference case study as the model for this base case) to determine if such retrofits would be economically viable and attractive.

3. Development of Base Case Stand-alone IGCC

3.1 Base Case Process Description

For the present study, the objective was to evaluate the potential value of warm syngas desulfurization (WDP) technology, developed by RTI International (RTI), when integrated with syngas poly-generation or stand-alone chemicals/fertilizers/hydrogen production for retrofit of an existing integrated gasification combined-cycle (IGCC) power generation plant such as Tampa Electric Company's (TEC) Polk 1 IGCC site near Tampa, FL. Because of the similarity to the TEC Polk 1 GE gasifier design and with the objective to model retrofit of an IGCC without carbon capture, DOE baseline Case 1 study from DOE/NETL-2010/1397 (DOE, 2010) was used as the foundation for the Base Case in this study.

The DOE baseline Case 1 study detailed in the report referenced above was for a dual-train IGCC power plant producing net power of 622 MWe. In Case 1 in the DOE report, the plant had two parallel trains all the way through except for the final combined cycle steam turbine. The block flow diagram for Case 1 detailed in the DOE report is presented in Figure 1.

Coal Receiving and Handling System: The process starts with two trains of the coal receiving and handling system. The coal is delivered to the site by 100-car unit trains comprised of 100 ton rail cars. The unloading is done by a trestle bottom dumper, which unloads the coal into two receiving hoppers. Coal from each hopper is fed directly into a vibratory feeder, and from the feeder is transferred on to a belt conveyor. Two conveyors with an intermediate transfer tower are assumed to convey the coal to the coal stacker, which transfers the coal to either the long term storage pile or to the reclaim area. The conveyor passes under a magnetic plate separator to remove tramp iron and then to the reclaim pile. The reclaimer loads the coal into two vibratory feeders located in the reclaim hopper under the pile. The feeders transfer the coal onto a belt conveyor that transfers the coal to the coal surge bin located in the crusher tower. The coal is reduced in size to 3 cm x 0 (1¼" x 0) by the crusher. A conveyor then transfers the coal to a transfer tower. In the transfer tower the coal is routed to the tripper, which loads the coal into one of three silos.

Coal Grinding and Slurry Preparation: Coal is then processed in two trains of the coal grinding and slurry preparation system. Coal from the silos is fed onto a conveyor by vibratory feeders located below each silo. The conveyor feeds the coal to an inclined conveyor that delivers the coal to the rod mill feed hopper. The feed hopper provides a surge capacity of about two hours and contains two hopper outlets. Each hopper outlet discharges onto a weigh feeder, which in turn feeds a rod mill. Each rod mill is sized to process 55 percent of the coal feed requirements of the gasifier. The rod mill grinds the coal and wets it with treated slurry water transferred from the slurry water tank by the slurry water pumps. The coal slurry is discharged through a trommel screen into the rod mill discharge tank, and then the slurry is pumped to the slurry storage tanks. The dry solids concentration of the final slurry is 63 percent.

Gasification: This plant utilizes two gasification trains to process a total of 5,083 tonnes/day (5,603 tpd) of Illinois No. 6 coal. Each of the 2 x 50 percent gasifiers operates at maximum capacity at 5.6 MPa (815 psia). The slurry feed pump takes suction from the slurry run tank, and the discharge is sent to the feed injector of the GEE gasifier (stream 6). Oxygen from the ASU is vented during preparation for startup and is sent to the feed injector during normal operation. The air separation plant supplies 4,171 tonnes/day (4,597 tpd) of 95 mol% oxygen to the gasifiers (stream 5) and the Claus plant (stream 3). Carbon conversion in the gasifier is assumed to be 98 percent including a fines recycle stream.

The gasifier vessel is a refractory-lined, HP combustion chamber. The coal slurry feedstock and oxygen are fed through a fuel injector at the top of the gasifier vessel. The coal slurry and the oxygen react in the gasifier at 5.6 MPa (815 psia) and 1,316°C (2,400°F) to produce syngas. The syngas consists primarily of hydrogen and carbon monoxide, with lesser amounts of water vapor and carbon dioxide, and small amounts of hydrogen sulfide, COS, methane, argon, and nitrogen. The heat in the gasifier liquefies coal ash. Hot syngas and molten solids from the reactor flow downward into a radiant heat exchanger where the syngas is cooled.

Raw Gas Cooling/Particulate Removal: Syngas is cooled from 1,316°C (2,400°F) to 677°C (1,250°F) in the radiant syngas cooler (SGC) (stream 9) and the molten slag solidifies in the process. The solids collect in the water sump at the bottom of the gasifier and are removed periodically using a lock hopper system (stream 8). The waste heat from this cooling is used to generate high-pressure (HP) steam. Boiler feed water (BFW) in the tubes is saturated, and then steam and water are separated in a steam drum. Approximately 412,096 kg/hr (908,500 lb/hr) of saturated steam at 13.8 MPa (2,000 psia) is produced. This steam then forms part of the general heat recovery system that provides steam to the steam turbine. The syngas exiting the radiant cooler is directed downwards by a dip tube into a water sump. Most of the entrained solids are separated from the syngas at the bottom of the dip tube as the syngas goes upwards through the water. The syngas exits the quench chamber saturated at a temperature of 232°C (450°F).

The slag handling system removes solids from the gasification process equipment. These solids consist of a small amount of unconverted carbon and essentially all of the ash contained in the feed coal. These solids are in the form of glass, which fully encapsulates any metals. Solids collected in the water sump below the radiant SGC are removed by gravity and forced circulation of water from the lock hopper circulating pump. The fine solids not removed from the bottom of the quench water sump remain entrained in the water circulating through the quench chamber. In order to limit the amount of solids recycled to the quench chamber, a continuous blow-down stream is removed from the bottom of the syngas quench. The blow-down is sent to the vacuum flash drum in the black water flash section. The circulating quench water is pumped by circulating pumps to the quench gasifier.

Syngas Scrubber /Sour Water Stripper: Syngas exiting the water quench passes to a syngas scrubber where a water wash is used to remove remaining chlorides, NH_3, SO_2, and PM. The syngas exits the scrubber still saturated at 206°C (403°F) before it is preheated to 223°C (433°F) (stream 10) prior to entering the COS hydrolysis reactor. The sour water stripper removes NH_3, SO_2, and other impurities from the scrubber and other waste streams. The stripper consists of a sour drum that accumulates sour water from the gas scrubber and condensate from SGCs. Sour water from the drum flows to the sour stripper, which consists of a packed column with a steam-heated reboiler. Sour gas is stripped from the liquid and sent to the SRU. Remaining water is sent to wastewater treatment.

COS Hydrolysis, Mercury Removal and Acid Gas Removal: Syngas exiting the scrubber (stream 10) passes through a COS hydrolysis reactor where about 99.5 percent of the COS is converted to CO_2 and H_2S (Section 3.1.5). The gas exiting the COS reactor (stream 11) passes through a series of heat exchangers and knockout (KO) drums to lower the syngas temperature to 35°C (95°F) and to separate entrained water. The cooled syngas (stream 12) then passes through a carbon bed to remove 95 percent of the Hg (Section 3.1.4).

Cool, particulate-free syngas (stream 13) enters the Selexol® absorber unit at approximately 5.2 MPa (755 psia) and 34°C (94°F). In this absorber, H_2S is preferentially removed from the fuel gas stream along with smaller amounts of CO_2, COS and other gases such as hydrogen. The rich solution leaving the bottom of the absorber is heated against the lean solvent returning from the regenerator before entering the H_2S concentrator. A portion of the non-sulfur bearing absorbed gases is driven from the solvent in the H_2S concentrator using N_2 from the ASU as the stripping medium. The temperature of the H_2S concentrator overhead stream is reduced prior to entering the reabsorber where a second stage of H_2S absorption occurs. The rich solvent from the reabsorber is combined with the rich solvent from the absorber and sent to the stripper where it is regenerated through the indirect application of thermal energy via condensation of low-pressure (LP) steam in a reboiler. The stripper acid gas stream (stream 14), consisting of 18 percent H_2S and 61 percent CO_2 (with the balance mostly N_2), is then sent to the Claus unit.

Claus Unit: Acid gas from the first-stage stripper of the Selexol® unit is routed to the Claus plant. The Claus plant partially oxidizes the H_2S in the acid gas to elemental sulfur. About 5,307 kg/hr (11,699 lb/hr) of elemental sulfur (stream 15) are recovered from the fuel gas stream. This value represents an overall sulfur recovery efficiency of 99.6 percent.

Acid gas from the Selexol® unit is preheated to 232°C (450°F). A portion of the acid gas along with all of the sour gas from the stripper and oxygen from the ASU are fed to the Claus furnace. In the furnace, H_2S is catalytically oxidized to SO_2 at a furnace temperature greater than 1,343°C (2,450°F), which must be maintained in order to thermally decompose all of the NH_3 present in the sour gas stream.

Following the thermal stage and condensation of sulfur, two reheater and two sulfur converters are used to obtain a per-pass H_2S conversion of approximately 99.9 percent. The Claus Plant tail gas is hydrogenated and recycled back to the Selexol® process (stream 16). In the furnace waste heat boiler, 12,432 kg/hr (27,408 lb/hr) of 4.2 MPa (605 psia) steam are generated. This steam is used to satisfy all Claus process preheating and reheating requirements as well as to produce some steam for the medium-pressure steam header. The sulfur condensers produce 0.34 MPa (50 psig) and steam for the LP steam header and 2.9 MPa (415 psig) for IP steam.

Power Block: Clean syngas exiting the Selexol® absorber is re-heated (stream 18) using HP BFW and then expanded to 3.2 MPa (460 psia) using an expansion turbine (stream 19). The syngas stream is diluted with nitrogen from the ASU (stream 4) and enters the advanced F Class CT burner. The CT compressor provides combustion air to the burner and also 17 percent of the air requirements in the ASU (stream 21). The exhaust gas exits the CT at 589°C (1,093°F) (stream 22) and enters the HRSG where additional heat is recovered until the FG exits the HRSG at 132°C (270°F) (stream 23) and is discharged through the plant stack. The steam raised in the HRSG is used to power an advanced, commercially available steam turbine using a 12.4 MPa/562°C/562°C (1800 psig/1043°F/1043°F) steam cycle.

Air Separation Unit: In Case 1 the ASU is designed to produce a nominal output of 4,171 tonnes/day (4,597 tpd) of 95 mol% O_2 for use in the gasifier (stream 5) and Claus plant (stream 3). The plant is designed with two production trains. The air compressor is powered by an electric motor. Approximately 13,051 tonnes/day (14,387 tpd) of nitrogen are also recovered, compressed, and used for dilution in the GT combustor (stream 4). About 4 percent of the GT air is used to supply approximately 17 percent of the ASU air requirements (stream 21).

Balance of Plant:

(a) <u>Steam Generation Island</u>: The steam generation island comprises of the heat recovery steam generator (HRSG), steam turbine generator and auxiliaries, condensate system, feedwater system, main and reheat steam systems, circulating water system, raw water system, fire protection system and cycle makeup water system.

(b) <u>Accessory Electric Plant</u>: The accessory electric plant consists of switchgear and control equipment, generator equipment, station service equipment, conduit and cable trays, and wire and cable. It also includes the main power transformer, all required foundations, and standby equipment.

(c) <u>Instrumentation and Control</u>: An integrated plant-wide distributed control system (DCS) is provided. The DCS is a redundant microprocessor-based, functionally DCS. The control room houses an array of multiple video monitor (CRT) and keyboard units. The CRT/keyboard units are the primary interface between the generating process and operations personnel. The DCS incorporates plant monitoring and control functions for all the major plant equipment. The DCS is designed to be operational and accessible 99.5 percent of the time it is required (99.5% availability). The plant equipment and the DCS are designed for automatic response to load changes from minimum load to 100 percent. Startup and shutdown routines are manually implemented, with operator selection of modular automation routines available. The exception to this, and an important facet of the control system for gasification, is the critical controller system, which is a part of the license package from the gasifier supplier and is a dedicated and distinct hardware segment of the DCS. This critical controller system is used to control the gasification process. The partial oxidation of the fuel feed and oxygen feed streams to form a syngas product is a stoichiometric, temperature- and pressure-dependent reaction. The critical controller utilizes a redundant microprocessor executing calculations and dynamic controls at 100- to 200-millisecond intervals. The enhanced execution speeds as well as evolved predictive controls allow the critical controller to mitigate process upsets and maintain the reactor operation within a stable set of operating parameters.

The above described process is for the original case presented in the DOE report (DOE, 2010) for a dual-train IGCC plant producing 622 MWe of electricity. To make this case more similar to the 250 MWe plant in the Polk power plant and to make it more suitable for the existing warm gas clean up unit, this original case was modified to represent a single-train IGCC power plant producing 311 MWe of power. The modifications done to this case are discussed in detail in the next section.

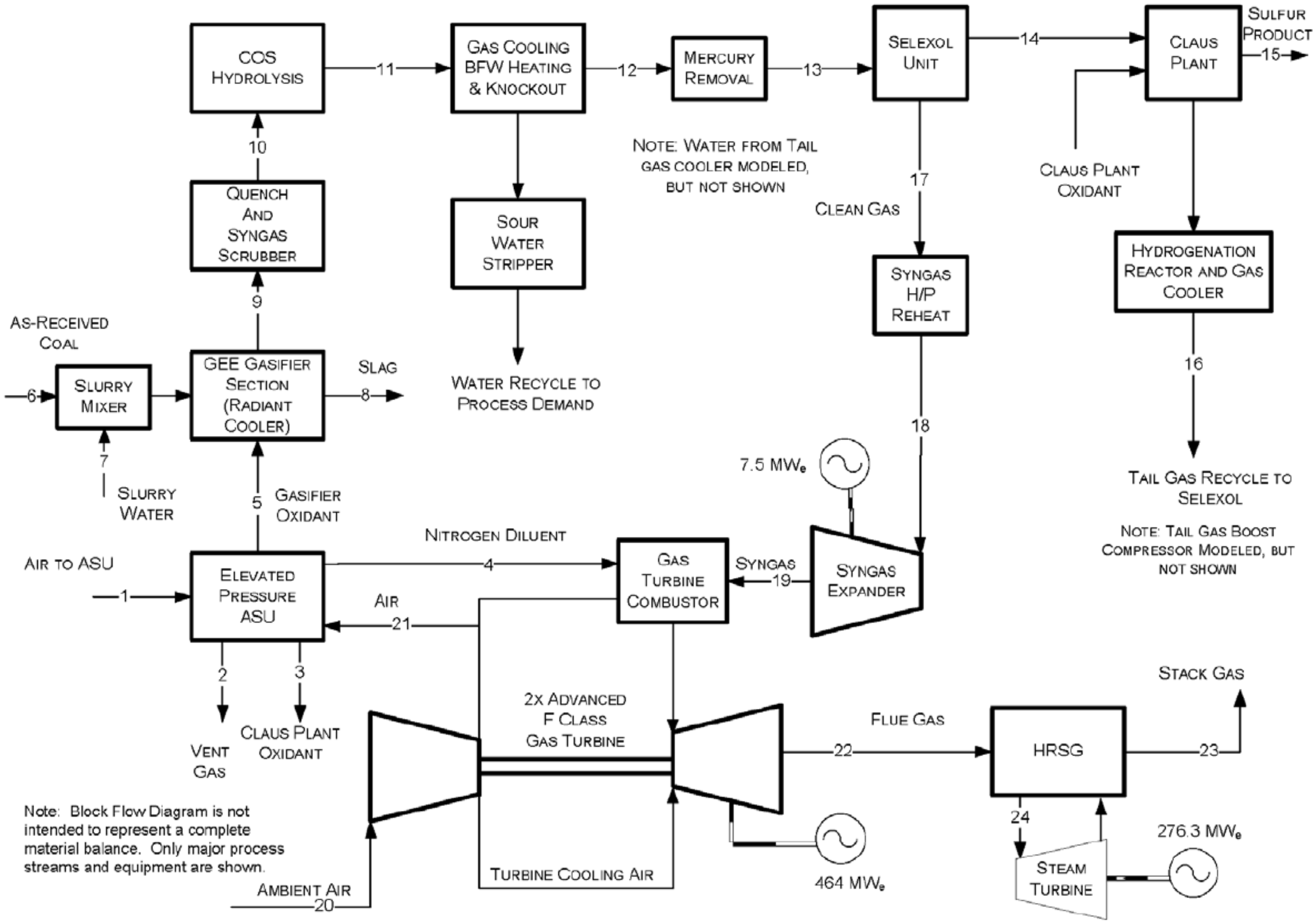


Figure 1. Block flow diagram of the Base Case (Case 1 in the DOE report)

3.2 Modification of the DOE Baseline Study

For the present study, to keep it similar in size to the TEC Polk 1, we modified the DOE Case 1 for a single train 311 MWe IGCC case. For the original DOE Case 1 process description, the major subsystem configuration is summarized in Table 1.

Table 1. Power plant original case in DOE report - major subsystems count

Subsystem Type	Number of Trains
Air separation units (ASUs)	2
Coal receiving and handling	2
Slurry preparation and slurry pumps	2
Gasification including gasifier, SGC, quench & scrubber	2
Syngas clean-up process	2
Selexol® AGR, single-stage	2
Claus based SRU	1
CT/HRSG tandems	2
Steam turbine	1

As shown in the table above, most of the major subsystems in the original case described in the DOE report have two trains, to produce net electricity of 622 MWe. To modify this plant into an IGCC plant producing 311 MWe of electricity, the equipment cost was obtained by using the capital cost for a single train wherever two trains were employed in the original case and in the subsystem areas where a single train was used in the original case, a size exponent factor was applied to estimate the capital cost for a half-sized unit in a 311 MWe plant. All other assumptions considered in the original study have been considered to be the same in this study.

3.3 Base Case Economic Model Assumptions

The process model system assumptions considered in the Base Case are the same as the ones assumed in the IGCC Case 1 of the DOE report. The system assumptions for the Base Case are listed in Table 2. Except for using a single train system, the other operational assumptions considered for the original case were maintained to be the same.

Table 2. Base Case plant configuration

System Assumptions	Base Case
Gasifier pressure, MPa (psia)	5.6 (815)
O_2:Coal ratio, kg O_2/kg dry coal	0.91
Carbon conversion, %	98
Syngas HHV at gasifier outlet, kJ/Nm3 (Btu/scf)	8,663 (233)
Steam cycle MPa/°C/°C (psig/°F/°F)	12.4/562/562 (1800/1043/1043)
Condenser pressure, mm Hg (in. Hg)	51 (2.0)
Combustion turbine	1 x Advanced F Class (232 MW output each)
Gasifier technology	GEE Radiant only
Oxidant	95 vol % oxygen
Coal	Illinois No. 6
Coal slurry solids content, %	63
COS hydrolysis	Yes
Sour gas shift	No
H_2S separation	Selexol®
Sulfur removal, %	99.7
Sulfur recovery	Claus plant with tail gas recycle to Selexol®/elemental sulfur
Particulate control	Water quench, scrubber and AGR absorber
Mercury control	Carbon bed
NOx control	Multi-nozzle quiet combustor (MNQC)(LNB) and N_2 dilution
CO_2 Separation	No

The economic assumptions considered for the analyses are summarized in Table 3. The IRR was computed for the Base Case for the economic analysis period from the year 2014 to the year 2036. For purposes of similar comparison with the various retrofit cases to be studied, the IGCC plant was treated as if it was purchased in 2014 at its depreciated capital cost in 2014 USD. From the year 2014, the plant is assumed to be run at a capacity factor of 80% from the year it was acquired (2014) to the end of the economic analysis period (2036). In the year 2014, the total investment required, which is equal to the depreciated cost of the IGCC plant, was assumed to be invested as 40% equity and the remaining 60% of the investment amount was assumed to be financed at an interest rate of 8%.

Table 3. Economic assumptions for the Base Case

Parameter	Value
Taxes	38%
Capacity factor	80%
Interest rate	8%
Capital depreciation	20 years; 150% double declining method
% of total capital that is depreciated	100%

Total debt financed	60%
Term of loan	20 years
Capital expenditure period	3 years (2004-2007)
Operational period	Power plant : 30 years (2007-2036)
Economic analysis period (for calculating IRR)	23 years (capital expenditure period + plant operational period); (2014-2036)
Escalation of revenue, O & M costs, & fuel	3%
Repayment term of debt	20 years
Grace period on debt repayment	0 years
Working capital	Zero for all parameters

4. Retrofit Case Descriptions

4.1 Retrofit Cases Basis

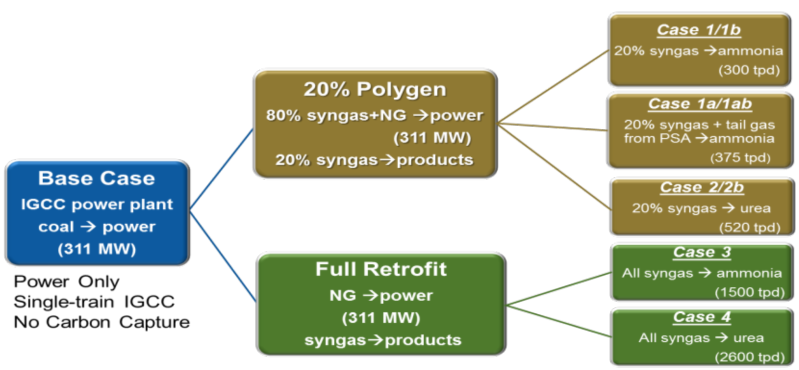
To evaluate the potential value of integrating the IGCC power plant with RTI warm syngas cleanup technologies and using part or all of the syngas for valuable chemicals or fertilizer production, several cases were considered in the present study to represent each of the possible retrofit scenarios. Ammonia and urea were selected as target products for the retrofit cases because they can utilize hydrogen from a retrofit such as the RTI demonstration facility at the TEC IGCC site, can utilize nitrogen from the air separation plant, and can utilize (for urea production) approximately one-third of the captured carbon dioxide. A study (approximately pre-FEED level) was then conducted to develop a techno-economic assessment of these options. Two scales of retrofit processes were considered:

- 20% syngas retrofit option - a 300 short-tons per day (stpd) ammonia process and/or its associated equivalent-scale urea process (sized at 520 stpd to use all 300 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to utilize all of the hydrogen produced from a project similar in size to the RTI demonstration project at TEC and to provide a case study involving ~20% syngas polygeneration.
- 100% syngas retrofit option - a 1500 stpd ammonia process and/or its associated equivalent-scale urea process (sized at 2600 stpd to use all 1500 stpd of ammonia production and approximately a third of all captured CO_2). This scale was sized to consider a full retrofit case to ammonia/urea production for a single-train IGCC such as TEC Polk 1 or the selected DOE study Base Case using the RTI WDP process, WGS, and an aMDEA process for syngas cleanup.

As described in Section 3.3, it was assumed here that the Base Case IGCC was constructed during the period of 2004-2007 and started up in 2007 and would operate through 2036. However, for each of the retrofit option cases, it was further assumed that in 2014 a decision was made to retrofit the IGCC to either a 20% polygen ammonia or urea plant or to a full retrofit conversion to an ammonia or urea plant. The 20% polygen retrofit cases assumed it would take 2 years to construct the ammonia or urea facility, starting construction in 2014 with polygen startup in 2016, while the full retrofit cases assumed it would take 3 years to construct, starting construction in 2014 with full retrofit start up in 2017. During the construction of the ammonia/urea plants (and the associated RTI WDP, WGS, and aMDEA plants), it was assumed that the IGCC plant would continue to operate as much as possible. After retrofit conversion, it was assumed that natural gas would be used to fire the syngas turbine in place of any lost syngas now sent to the ammonia or urea plants (any required retrofits to the syngas turbine were included in the techno-economic analyses), so that 311 MW of electric power were co-produced in all cases. The economic timeframes for all of these study options were chosen to start in 2014 and to end at the end of 2036. The depreciated value for the Base Case IGCC plant in the year 2014 was used as the IGCC asset value starting point for each of the Base Case IGCC and retrofit cases (treated as if the IGCC plant was sold to the retrofit owner/operator in 2014 at its depreciated book value).

For purposes of these techno-economic analyses, an established global technology supplier with extensive ammonia and urea plant licensing and retrofit experience was contracted to provide a feasibility study for the various scale ammonia and urea plants for potential integration with the Base Case IGCC (using the TEC Polk 1 IGCC and RTI demonstration facility as a basis). AMEC Kamtech, Inc. (who designed and constructed the RTI demonstration facility at the TEC Polk 1 site) was then contracted to provide a feasibility study for integration of each of the ammonia and urea plant options into a facility such as the existing TEC Polk IGCC site. For the 20% syngas retrofit cases (300 stpd ammonia case and corresponding 520 stpd urea plant case), this included any required modifications to existing TEC or Base Case IGCC plant equipment (including additional purified nitrogen for feed to the ammonia facility) and to the RTI warm syngas cleanup demonstration facility (including a pressure swing adsorber (PSA) for final H_2 enrichment). For the full 100% syngas retrofit cases (1500 stpd ammonia case and corresponding 2600 stpd urea plant case), this included addition of a new or expanded full-scale RTI WDP and aMDEA carbon capture system, conversion of the existing syngas turbine to natural gas firing, and any equipment modifications required to integrate the ammonia/urea plants with the IGCC plant site.

For the techno-economic analyses for this study, the following option cases were modeled:



These cases are summarized in Table 4. As shown in Table 4, the Base Case is the IGCC power plant only, as described in Section 3.2. Cases 1 & 1b refer to the cases in which approximately 20% of the IGCC's syngas is sent to RTI's warm gas cleanup facility, WGS, aMDEA, PSA and then to the ammonia production plant, producing a total of 300 stpd ammonia. The rest of the syngas is sent to the turbine block and the 20% syngas that is now sent to the ammonia block is made up for at the turbine feed point by an energy-equivalent amount of natural gas so that the same amount of power (311 MWe) is made in all the cases. Cases 1a & 1ab refer to the cases in which alternative technology to PSA is used to enrich the hydrogen, thereby eliminating the need to consume PSA tailgas hydrogen in the syngas turbine and enabling production of a total of 375 stpd ammonia. In Cases 2 & 2b, just like in Cases 1 & 1b, 300 stpd ammonia is produced, but this is further sent to a urea production block to produce 520 stpd of granulated urea. In Case 3, all the IGCC syngas is sent to a RTI warm gas cleanup, WGS, aMDEA, and PSA block, from where all the cleaned and shifted hydrogen syngas is sent to the ammonia block to produce a total of 1500 stpd ammonia. An energy-equivalent amount of natural gas is sent to the syngas turbine block (now modified to run on 100% natural gas), so that the total power production is maintained at 311 MWe. In Case 4, the 1500 stpd ammonia produced in Case 3 is further sent to a urea production block to produce 2600 stpd of granulated urea. In all the cases with ‘b’ added to the case name, the integrated warm gas cleanup, WGS, and aMDEA facility is assumed to be funded by DOE (as with the RTI demonstration facility at the TEC IGCC site). Therefore, in these cases, new capital investment would be required only for the power plant integration and for the ammonia and/or urea production blocks.

Table 4. Description of all the cases considered in the study

Base Case	Single train 311MWe IGCC plant, no water gas shift (WGS) or carbon capture (described in section 3.2)
Case 1	20% syngas polygen retrofit to a 300 stpd ammonia facility (full capital with no DOE funding support); hydrogen further enriched by PSA to ammonia specifications
Case 1b	Same as Case 1 but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA carbon capture (similar to a DOE-funded 50 MWe demo plant at TEC)
Case 1a	Same as Case 1, but with alternative technology to enrich the H_2, eliminate the need to send PSA tailgas to the syngas turbine, and thus produce 375 stpd ammonia
Case 1ab	Same as Case 1a but assuming a DOE-funded RTI warm syngas cleanup facility with WGS and aMDEA carbon capture (similar to a DOE-funded 50 MWe demo plant at TEC)
Case 2	Same as Case 1 except all the ammonia is used to make 520 stpd granulated urea
Case 2b	Same as Case 1b except all the ammonia is used to make 520 stpd granulated urea
Case 3	100% syngas retrofit to a 1500 stpd ammonia facility including a full-scale warm syngas cleanup plant
Case 4	Same as Case 3 except all the ammonia is used to make 2600 stpd granulated urea

The process description for each of these cases and how it integrates with the IGCC power plant is described in detail in the next section.

4.2 Modifications of Base Case IGCC for the Various Retrofit Cases

The Base Case process has been described in detail in Section 3.2. The retrofit cases have been developed based on the utilization of either part or all the syngas produced from the IGCC plant and the end product in each of the retrofit cases is a combination of power and either ammonia or granulated urea. The process description for each of the retrofit cases is detailed in this section.

Cases 1 & 1b: 20% syngas polygen retrofit to a 300 stpd ammonia facility

The main difference between Cases 1 & 1b is that in Case 1, the investment for warm syngas cleanup and carbon capture block is included in the economic analysis, while in Case 1b, the warm gas clean up and carbon capture block is assumed to be funded by the DOE. The warm gas cleanup and carbon capture block are very similar to the DOE-funded RTI 50 MWe demo plant at Tampa Electric Company, thus enabling Case 1b to provide a better understanding of the potential value of integrating the existing RTI demo unit at TEC with an ammonia production facility. Other than for the DOE cost-sharing provision in Case 1b, the process description for these two cases is exactly the same.

The process block diagram for these two cases is shown in Figure 2. The process starts with the IGCC plant considered in the Base Case. After quenching the syngas, 20% of the syngas from the IGCC plant is sent to the RTI warm gas cleanup and carbon capture block and the remaining 80% syngas is sent to the power block for electricity generation. The shifted and cleaned 20% syngas stream is then sent to a PSA unit where a purified H_2 stream is produced for ammonia production. From the PSA unit, the H_2 rich stream is sent to the ammonia production block from which 300 stpd ammonia is produced. The ammonia produced is sent to the ammonia storage unit and then pipelined to the customer.

The tail gas from the PSA unit is sent to the power block for electricity generation. Because some of the original IGCC syngas is now utilized for ammonia production, an energy-equivalent amount of natural gas is sent to the turbine/power block, so that the total production of 311 MWe of electricity is maintained. The nitrogen stream required for ammonia production is generated by an air separation plant/ PSA plant.

Cases 1a & 1ab: 20% syngas polygen retrofit to a 375 stpd ammonia facility

The main difference between Cases 1a & 1ab is that in Case 1a, the capital cost for the warm gas cleanup and carbon capture block is considered in the economic analysis, while in Case 1ab, the investment required for this block is assumed to be funded by the DOE. The process description for both these cases is otherwise the same. Cases 1a & 1ab are very similar to Cases 1 & 1b. The only difference is that in Cases 1a & 1ab, an alternative to PSA is used to enrich the hydrogen, thus eliminating or reducing the PSA tailgas stream back to the syngas turbine and enabling more purified hydrogen to be supplied to the ammonia block. Therefore in this case, a total of 375 stpd of ammonia is assumed to be produced.

Cases 2 & 2b: 20% syngas polygen retrofit to a 520 stpd granulated urea facility

Cases 2 & 2b are an extension of Cases 1 & 1b. Similar to Cases 1 & 1b, the main difference between these two cases is also that in Case 2b, the warm gas cleanup and carbon capture technology block is assumed to be funded by the DOE. The process description otherwise remains the same for both these cases, and the block flow diagram for the process is shown in Figure 3. In Cases 2 & 2b, 20% of the syngas from the IGCC plant is sent to RTI's warm gas cleanup technology, WGS, aMDEA, and PSA and the resultant purified hydrogen is sent to the chemical production block. In the chemical production block, the hydrogen rich syngas is first sent to the ammonia production block, in which 300 stpd of ammonia is produced. Ammonia, along with about a third of the CO_2 rich stream from the CO_2 capture system in the warm gas cleanup unit is then sent to a urea production block. The molten urea from this block is further sent to a urea granulation process, from which the finished product of 520 stpd granulated urea is produced and is sent to the urea storage facility.

Case 3: 100% syngas polygen retrofit to a 1500 stpd ammonia facility

In this case, 100% of the IGCC's syngas is used for the production of ammonia, while an energy-equivalent amount of natural gas is sent to the modified syngas turbine power block to be able to produce 311 MWe of power. The block flow diagram for this process is shown in Figure 4. As shown in the figure, syngas coming from the IGCC plant after syngas quenching is sent to a RTI warm gas cleanup, WGS, aMDEA, and PSA blockdesigned to handle all the syngas (10.6 mmscfh). From this warm gas cleanup and carbon capture block, the hydrogen rich syngas is sent to an ammonia production block, from which 1500 stpd of ammonia is produced and is sent to the ammonia storage facility and then pipelined to the customer. From the overall process, the two end products are1500 stpd ammonia and 311 MWe power.

Case 4: 100% syngas polygen retrofit to a 2600 stpd granulated urea facility

This case is an extension of Case 3. The block flow diagram for this case is shown in Figure 5. As shown in the figure, 100% of the syngas from the IGCC plant is sent to the warm gas clean up and carbon capture block. From this block, hydrogen rich syngas is sent to a PSA unit where H_2 is separated and is sent to the ammonia production block, in which 1500 stpd of ammonia is produced. The intermediate product, ammonia, is sent to a urea production block, along with approximately one-third of the captured carbon dioxide from the gas cleanup block, and the molten urea product is sent to a urea granulation unit, from which the final product of 2600 stpd granulated urea is obtained. The final granulated urea is sent to a urea storage facility. The tail gas from the PSA unit and an energy-equivalent amount of natural gas is sent to the modified syngas turbine power block to maintain the power production the same as the Base Case, at 311 MWe.

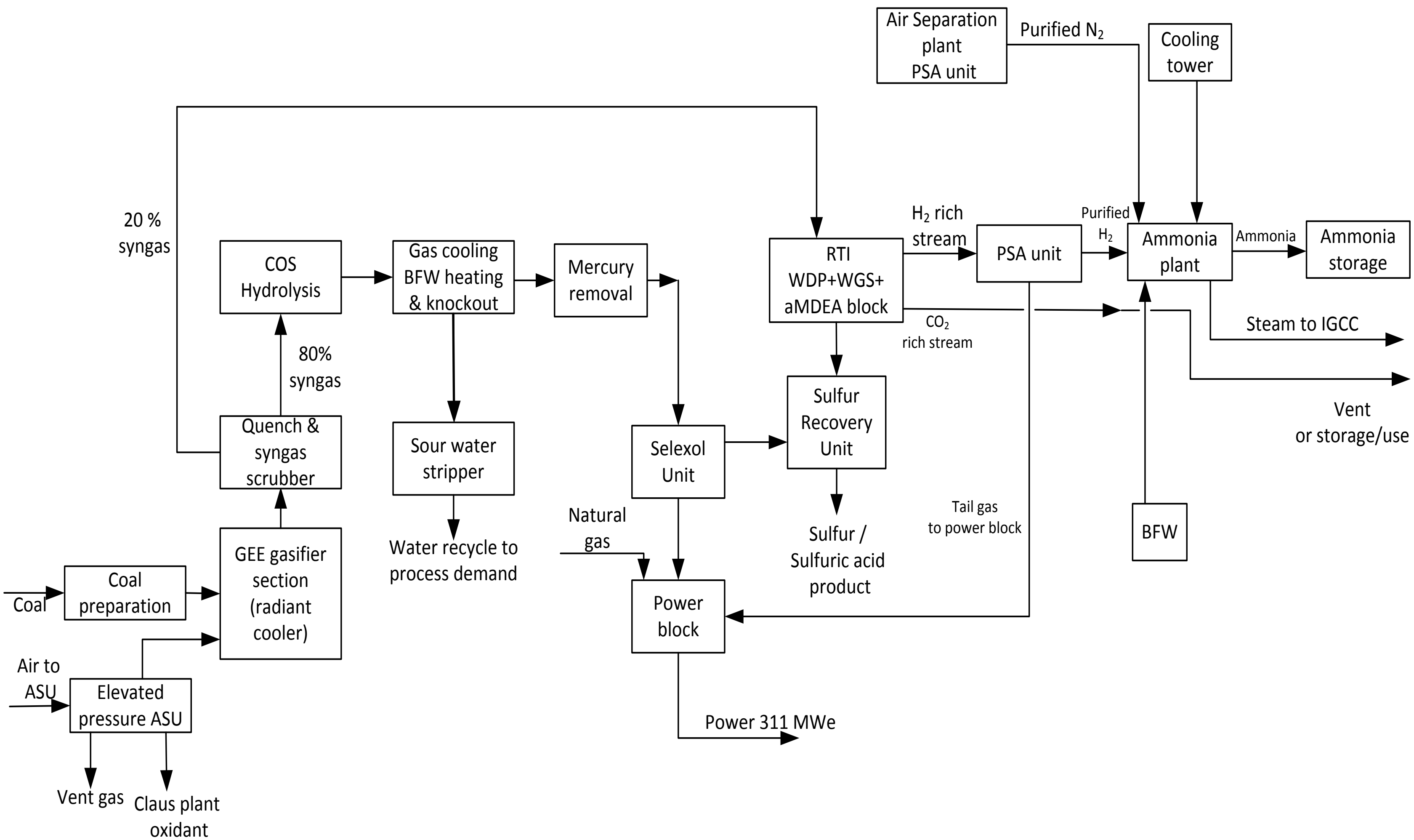


Figure 2. Block flow diagram of Cases 1 & 1b; 20% syngas retrofit to produce 300 stpd Ammonia

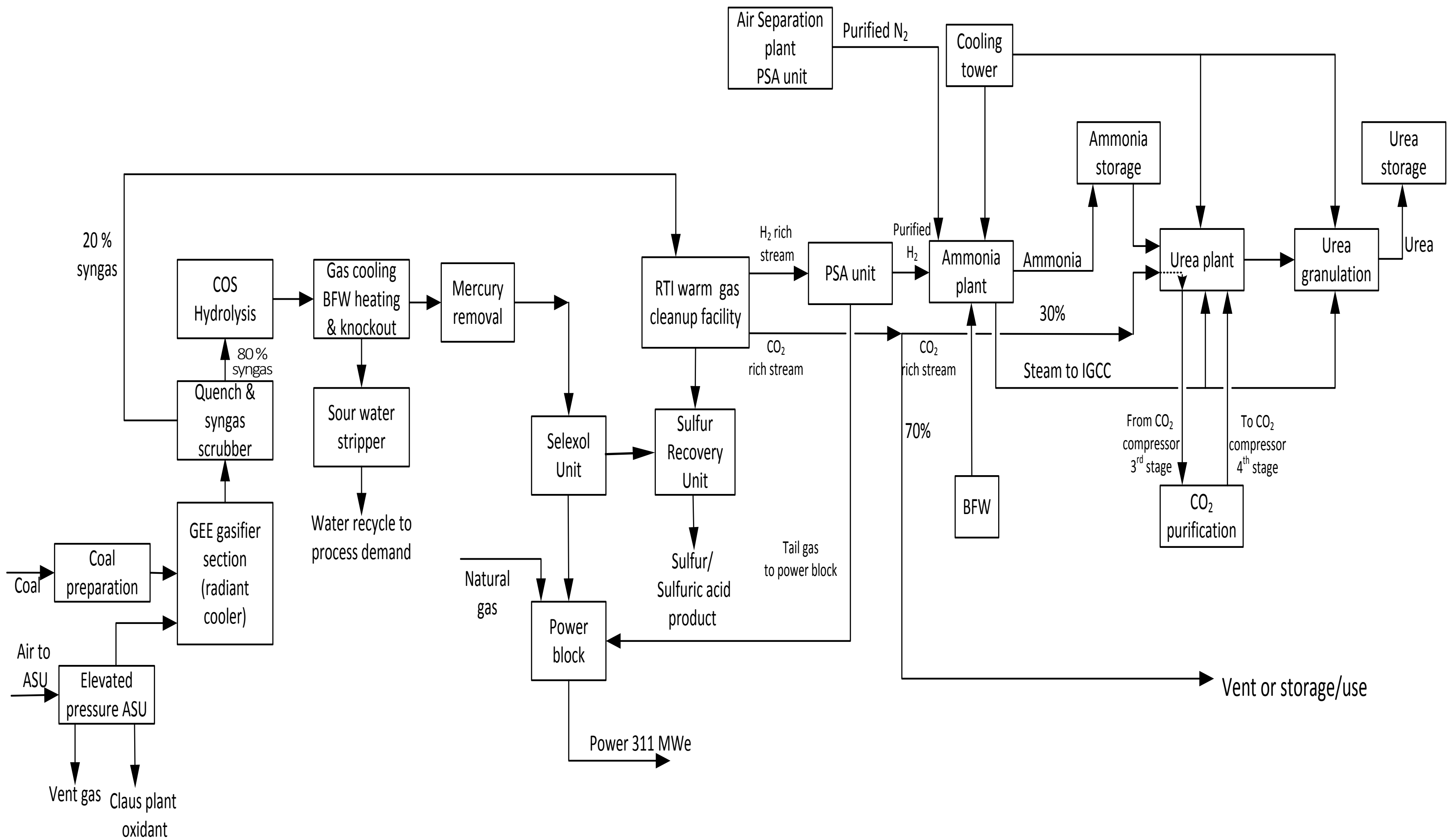


Figure 3. Block flow diagram of Cases 2 & 2b; 20 % syngas retrofit to produce 520 stpd granulated urea

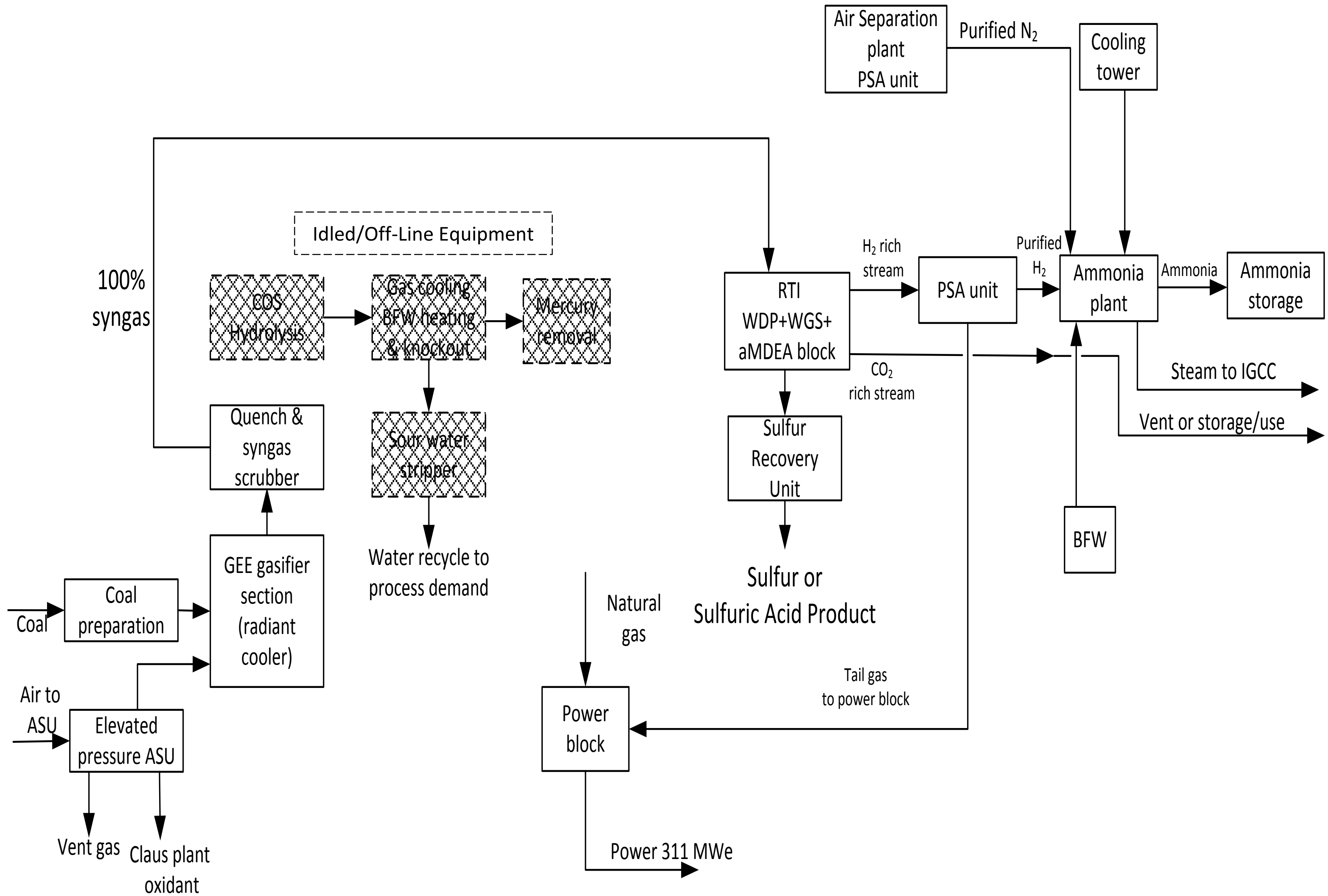


Figure 4. Block flow diagram of Case 3; 100% retrofit syngas production of 1500 stpd ammonia

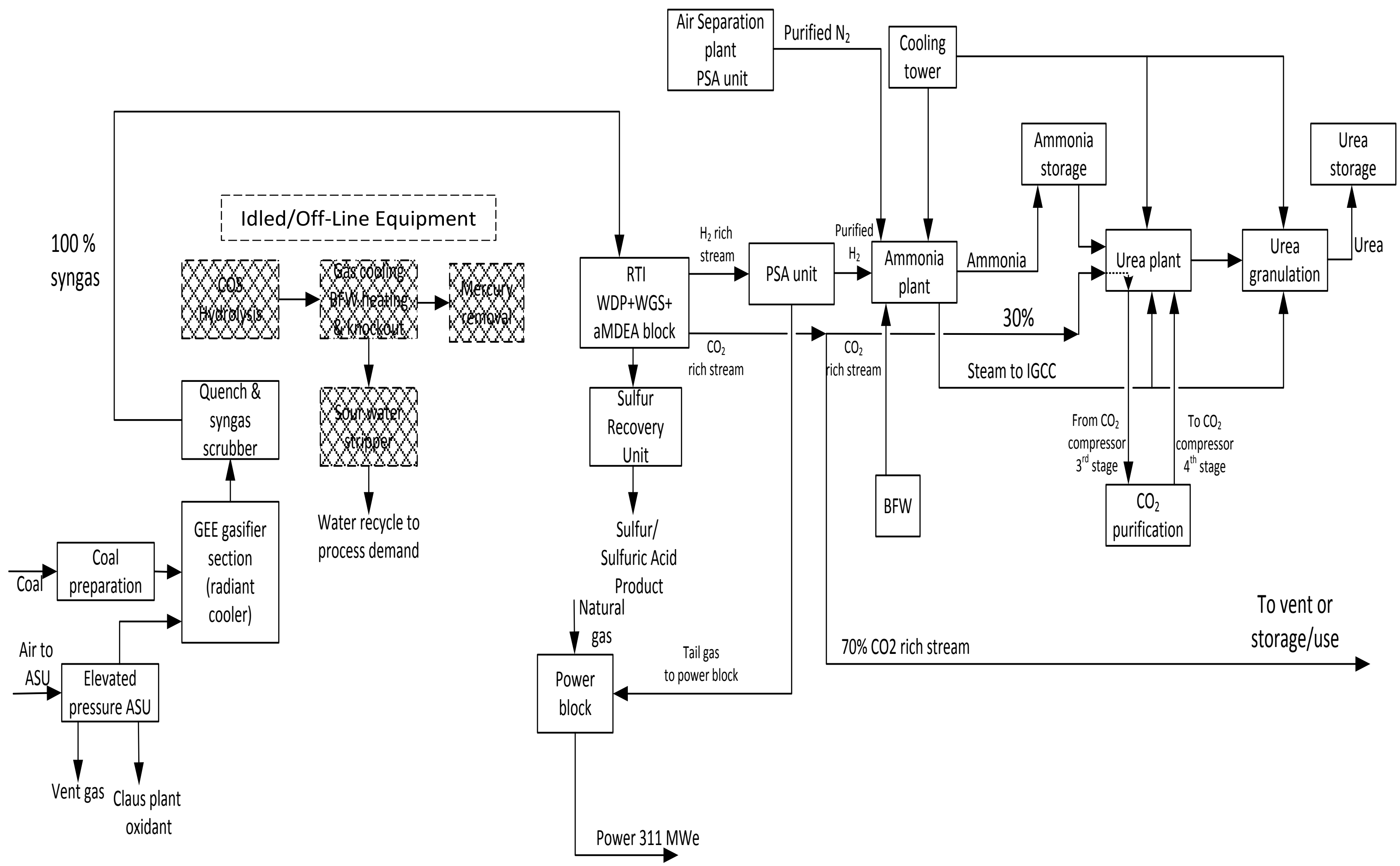


Figure 5. Block flow diagram of Case 4; 100% syngas retrofit to produce 2600 stpd granulated urea

4.3 Retrofit Cases Economic Model Assumptions

The economic model assumptions made for the syngas retrofit cases are summarized in Table 5. Though most of the economic assumptions taken for both the 20% and 100% syngas retrofit cases are the same, some of the assumptions, such as the capital expenditure period are different. All the costs considered in the study are in 2014 USD.

Capital Expenditure Period: For the 20% syngas retrofit cases, because of the smaller scale of the unit to be constructed, the capital expenditure period for these cases has been assumed to be 2 years, while for the 100% syngas retrofit cases, it has been assumed to be 3 years. Because of this assumption, for the smaller scale cases (all the 20% retrofit cases), the operational period starts a year ahead of the 100% retrofit cases. That is, for the 20% retrofit cases, the operational period is 21 years, from the year 2016 to 2036, while for the 100% retrofit cases, the operational period is 20 years, from the year 2017 to 2036.

Depreciation Method: 150% double declining method considered over a period of 20 years was assumed as the depreciation method for all the cases. This is in agreement with the depreciation method taken in the DOE report as well as in the Base Case.

Capacity Factor: For all the 20% retrofit cases, the operating or capacity factor was assumed to be 80%. However, for the 100% syngas retrofit cases, for the process of syngas conversion to ammonia/urea, the capacity factor was assumed to be 80%, while for the electricity generation process with natural gas as feed, the capacity factor was assumed to be 85%. This is because, syngas production is dependent on the operation of the gasifier and hence, it is realistic to assume a capacity factor of 80%, but for electricity generation process using NG as feed, it is more realistic to assume a capacity factor of 85% because this process is independent of the gasifier operation. This assumption is in agreement with the DOE report, in which the capacity factor for similar NGCC cases was assumed to be 85%.

Total Debt Financed: In this study, for all the cases, it was assumed that 60% of the total initial investment was debt leveraged and the remaining 40% was equity.

Escalation of Costs: During the economic evaluation period, the escalation of all costs including raw material costs, utility costs and product prices was assumed to be 3%. This is in agreement with the assumptions considered in the DOE report.

Table 5. Summary of the economic assumptions for all the syngas retrofit cases

Parameter	20% syngas retrofit cases (Cases 1, 1b, 1a, 1ab, 2 &	100% syngas retrofit cases (Cases 3 &4)
Taxes	38%	38%
Capacity factor	80%	80% for Ammonia/Urea production; 85% for power block
Interest rate	8%	8%
Capital Depreciation	20 years; 150% double declining method	20 years; 150% double declining method
% of total capital that is depreciated	100%	100%
Total Debt financed	60%	60%
Term of Loan	20 years	20 years
Capital Expenditure period	2 years (2014-2015)	3 years (2014-2016)
Operational period	Power plant : 30 years (2007-2036); Ammonia/Urea plant: 21 years (2016-2036)	Power plant : 30 years (2007-2036); Ammonia/Urea plant: 20 years (2017-2036)
Economic Analysis period (for calculating IRR)	23 years (capital expenditure period + plant operational period); (2014-2036)	23 years (capital expenditure period + plant operational period); (2014-2036)
Escalation of revenue, O & M costs, & Fuel costs	3%	3%
Repayment term of debt	20 years	20 years
Grace period on debt	0 years	0 years
Working capital	Zero for all parameters	Zero for all parameters

Other information required to calculate the yearly cash flows would be the raw material and product price information. For all the cases, the product or raw material prices considered in the economic evaluation are summarized in Table 6.

Table 6. Summary of product and raw material prices considered in the study

Feed, Raw Materials		Products	
Illinois No. 6 Coal, $/ton	$ 68.60	Power, $/MWh	$64.10
Natural Gas, $/MBtu	$3.50	Ammonia, $/ton	$500
		Urea, $/ton	$400

5. Feasibility Studies from Ammonia/Urea Technology Provider and AMEC

5.1 Criteria for Selection of Ammonia/Urea Technology Provider and AMEC

For purposes of this study, it was desired to get as accurate an estimate of the integrated ammonia and urea plant options as possible. The desired level of estimate for this study was a Class 4 estimate according to the recommended practices of the Association for the Advancement of Cost Engineering (AACE), roughly a $\pm$ 30% budget estimate of capital costs. To improve the likely accuracy of the estimate, it was decided to subcontract the capital cost estimation and feasibility studies for the ammonia and urea plant blocks to an established global ammonia/urea technology licensor/provider having experience with plants in the design capacity range of our desired options. A survey of established technology licensors/providers was conducted and a global technology licensor/provider was selected that had well over 100 ammonia and urea plants in operation, including a number in our desired design capacity range and a number that were retrofit applications at brownfield sites.

To improve the accuracy and understanding of the integration issues between the existing IGCC plant, RTI's warm syngas cleanup block (including WGS and aMDEA carbon dioxide capture), and the desired ammonia/urea plants, it was decided to use AMEC Kamtech, Inc., who designed and constructed the RTI demonstration facility at the TEC Polk 1 site, to conduct the capital cost estimation and feasibility studies for integrating these various site and technology blocks with the ammonia and urea plant blocks. Their knowledge and experience of the IGCC site and added RTI cleanup block at the Polk demonstration site was considered to be critical to ensuring the quality of this aspect of the overall techno-economic analyses. The accuracy of AMEC's capital cost estimates was also considered to be roughly $\pm$ 30%.

5.2 Description of Approach and Assumptions for Feasibility Studies

For evaluating the cash flow of any process, it is essential to know the capital costs and the operating costs for the process. In this section, the capital cost and operating cost information for all the retrofit cases is discussed in detail.

For the ammonia and urea production blocks for all the retrofit cases, the estimated capital cost was estimated by the selected technology licensor/provider and this information was used in the economic evaluation study. The capital cost estimates for RTI's warm gas cleanup unit were provided by AMEC. Also, AMEC provided an initial study to estimate the integration costs of the warm gas cleanup unit block and the ammonia/urea production blocks for different scenarios. As discussed in Section 3.2, the capital cost of the IGCC plant was estimated by determining the cost of a single train IGCC plant producing 311 MWe of power from the cost data available in the DOE report. The capital cost estimated for the power plant in the DOE report is for a new plant. In the present study, the assumption was that the Base Case IGCC power plant was transferred or bought at its depreciated book value in the year 2014, following seven years of operation as a stand-alone IGCC. 150% double declining method was used for determining the depreciated cost of the power plant as specified in the selected DOE case study. The initial value of the IGCC plant and the depreciated book value of the IGCC plant in the year 2014 are as listed in Table 7.

Table 7. Summary of the IGCC plant capital cost considered in the study

Description	Value
Initial capital cost IGCC plant in 2004	$696,791,958
Depreciated cost of IGCC plant in 2014	$382,562,843

The capital cost information for the rest of the plant in each of the retrofit cases was obtained from the ammonia/urea technology provider and AMEC. The summary of the capital costs considered in the study is presented in Table 8.

Table 8. Summary of the capital costs for the WGCU + product blocks of all the retrofit cases

	Case 1 (300 tpd NH_3)	Case 1b (300 tpd NH_3)	Case 1a (375 tpd NH_3)	Case 1ab (375 tpd NH_3)	Case 2 (520 tpd Urea)	Case 2b (520 tpd Urea	Case 3 (1500 tpd NH_3)	Case 4 (2600 tpd Urea
Ammonia Plant Costs ($M)	$40.50	$40.50	$52.51 (extra NH_3 from use of tail gas H_2)	$52.51 (extra NH_3 from use of tail gas H_2)	$40.50	$40.50	$103.28	$103.28
Urea Plant Costs ($M)	$ -	$ -	$ -	$ -	$106.65	$106.65	$ -	$229.50
Integration Capital Costs ($M)	$124.45 (no federal support)	$33.29 (plus federal support)	$124.45 (no federal support)	$33.29 (plus federal support)	$149.96 (no federal support	$58.80 (plus federal support	$389.85 (no federal support	$503.95 (no federal support
Ammonia Pipeline ($M)	$12.00	$12.00	$12.00	$12.00	$ -	$ -	$12.00	$
Total ($M)	**$176.95**	**$85.79**	**$188.96**	**$97.80**	**$297.11**	**$205.95**	**$505.12**	**$836.73**

The operating cost of the process is determined by estimating the total raw material, labor and utility costs. For the Base Case, the operating costs have been calculated based on the labor requirement, labor wages, utility and raw material consumption and price information from the selected DOE report. This information is summarized in Table 9.

Table 9. Summary of the operating costs for the Base Case

Initial & Annual Operating and Maintenance Expenses
Case 1-GEE Radiant 320 MW IGCC w/o CO2 Capture

Operating and Maintenance								
Operating Labor								
Operating Labor Rate			39.7	$/h				
Operating Labor Burden:			30%	of base				
Labor O/H Charge Rate:			25%	of Labor			2	
	Skilled Operator		2					
	Operator		4					
	Foreman		1					
	Lab Tec's, etc		2					
		Total	9				Annual Cost	Annual Unit Cost
							$	$/kW-net
Annual Operating Labor Cost							$ 4,068,932	$ 12.715
Maintenance Labor Cost							$ 8,298,074	$ 25.931
Admin. & Support Labor							$ 3,855,883	$ 12.050
Property Taxes & Insurance							$ 14,878,837	$ 46.496
Total Fixed Operating Costs							**$ 31,101,725**	**$ 97.193**
Variable Operating Costs								$/kWh-net
Maintenance Material Costs							$ 15,992,834	0.00713
								0.00000
	Consumables		**Consumption Initial**	**/Day**	**Unit Cost**	**Initial Cost**	**Annual Cost $**	**Annual Unit Cost $/kW-net**
Water (/1000 USG)			**-**	**1,705**	**$ 1.67**	**-**	**$ 831,182**	**0.00**
Chemicals								
MU & WT Chem. (lb)			-	10,156	$ 0.27	$ -	$ 800,660	$ 0.00036
Carbon (Mercury Removal) (lb.)			27,416.50	37.50	$ 1.63	$ 44,689	$ 17,849	$ 0.00001
COS Catalyst (m3)			211	0.15	$ 3,751.70	$ 791,609	$ 158,847	$ 0.00007
Water Gas Shift Catalyst (ft3)			-	-	$ 771.99	$ -	$ -	$ -
Selexol Solution (gal)			142,679	22.50	$ 36.79	$ 5,249,160	$ 241,710	$ 0.00011
SCR Catalyst (m3)			-	-	$ -	$ -	$ -	$ -
Ammonia (19% NH3) (ton)			-	-	$ -	$ -	$ -	$ -
Claus Catalyst (ft3)			-	1	$ 203.15	$ -	$ 57,540	$ 0.00003
	Subtotal Chemical					**$ 6,085,458**	**$ 1,276,606**	**$ 0.00057**
Others								
Supplemental Fuel (Mbtu)			-	-	-	$ -	$ -	$ -
Gases, N2 etc. (/100 scf)			-	-	$ -	$ -	$ -	$ -
L.P. Steam (/1000 pounds)			-	-	$ -	$ -	$ -	$ -
	Subtotal Others					**$ -**	**$ -**	**$ -**
Waste Disposal								
Spent Mercury Catalyst (lb.)			-	38	$ 0.65	$ -	$ 7,118	$ 0.00000
Flyash (ton)			-	-	$ -	$ -	$ -	$ -
Slag (ton)			-	307.50	$ 25.11	$ -	$ 2,254,627	$ 0.00101
	Subtotal Waste Disposal					**$ -**	**$ 2,261,744**	**$ 0.00101**
By-product & Emissions								
Sulfur (tons)			-	70	$ -	$ -	$ -	$ -
	Subtotal By-Product					**$ -**	**$ -**	**$ -**
Total Variable Operating Costs						**$ 6,085,458**	**$ 20,362,366**	**$ 0.00908**
Fuel (ton)			-	2,802	$ 68.60	$ -	**$ 59,624,745**	**$ 0.02659**
Total						$ 6,085,458	$ 100,349,477	$ 0.04475

The utility consumption for the retrofit cases is summarized below in Table 10.

Table 10. Utility summary for all the retrofit cases

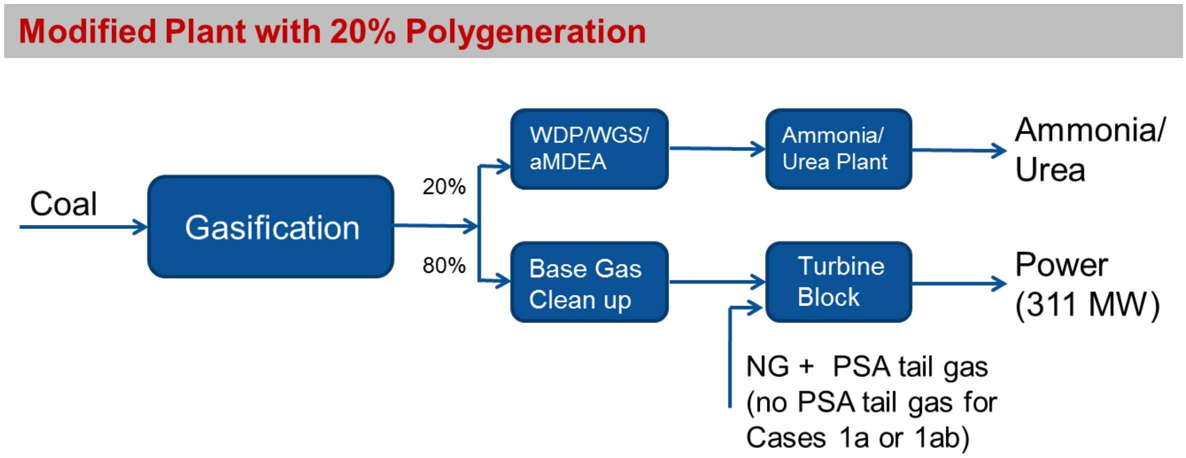
Utility	Cases 1 & 1b 300 stpd Ammonia	Cases 1a & 1ab 375 stpd Ammonia	Cases 2 & 2b 300/520 stpd Ammonia/Urea	Case 3 1500 stpd Ammonia	Case 4 1500/2600 stpd Ammonia/Urea
HP Steam (1620 psig), lb/hr Normal	37,366	46,708	55,214		
MP Steam (480 psig), lb/hr normal	(30,070)	(37588)	(13,675)	(135,500)	64,659
LP Steam (65 psig), lb/hr normal	(1,349)	(1,686)	(6,589)	(6,745)	(32,965)
Nitrogen, lb/hr	7,788	9,735	7,788	38,940	38,940
BFW, lb/hr MP	56,135	70,169	58,891	276,083	291,242
BFW, lb/hr LP	-	-	39,177	169,685	195,905
Condensate, lb/hr LP	(31,909)	(39,886)	(31,909)	(159,545)	(159,545)
Condensate, lb/hr MP			(37,000)	(4,013)	(189,013)
Cooling Water, cold lb/hr	3,773	4,716	10,817	61,532	86,144
Cooling Water Makeup, GPM	94	118	270	288	904
Power, HP	11,143	13,929	15,868	94,530	117,350
Fuel Gas for CO_2 Purification, lb/hr	-	-	705	-	3,525

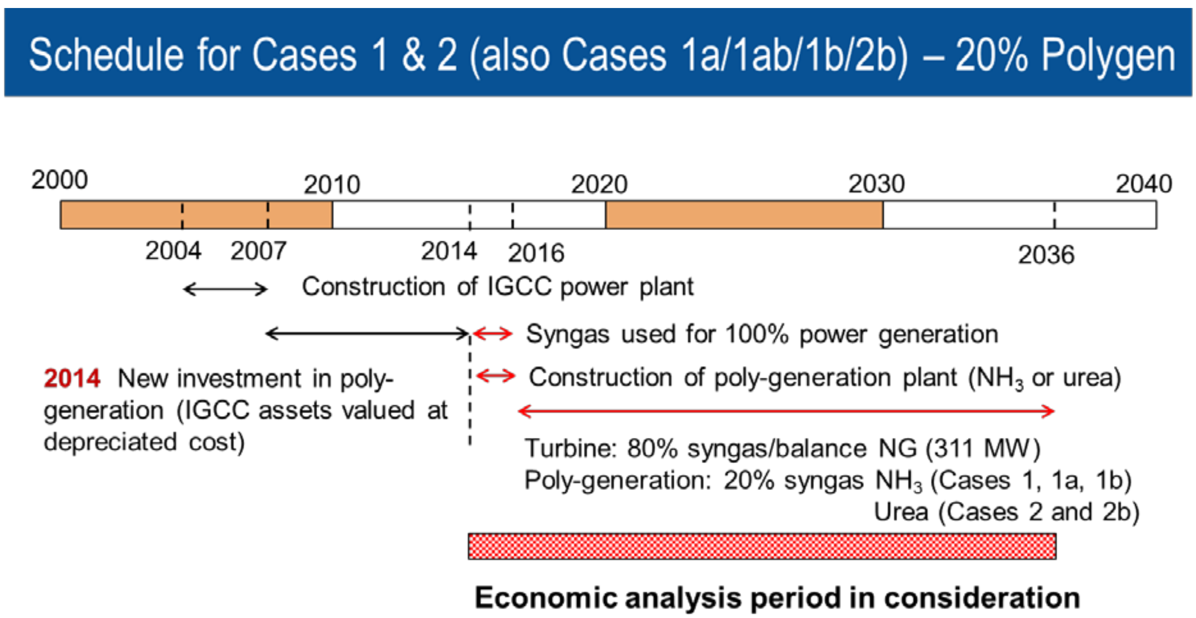
6. Techno-economic Analyses by RTI

6.1 Approach and Assumptions for Techno-economic Analyses

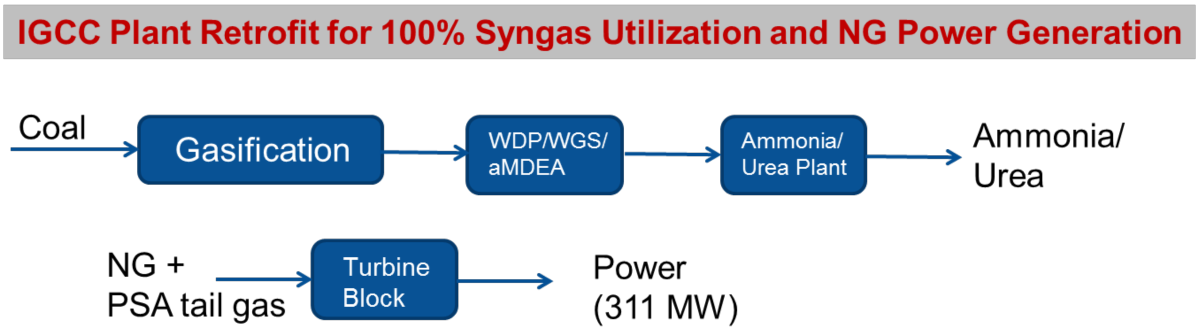
In this study, as discussed earlier, the economic evaluation period was considered to be from the years 2014 to 2036. In the year 2014, the IGCC plant was assumed to be transferred or bought at its depreciated book value in 2014 USD, and the power plant was assumed to be operated from the same year onwards till 2036. In the Base Case, no further product block investment was considered during the economic evaluation period, but in the retrofit cases, the warm gas cleanup unit and the ammonia/urea product blocks were assumed to be constructed from the year 2014 onwards.

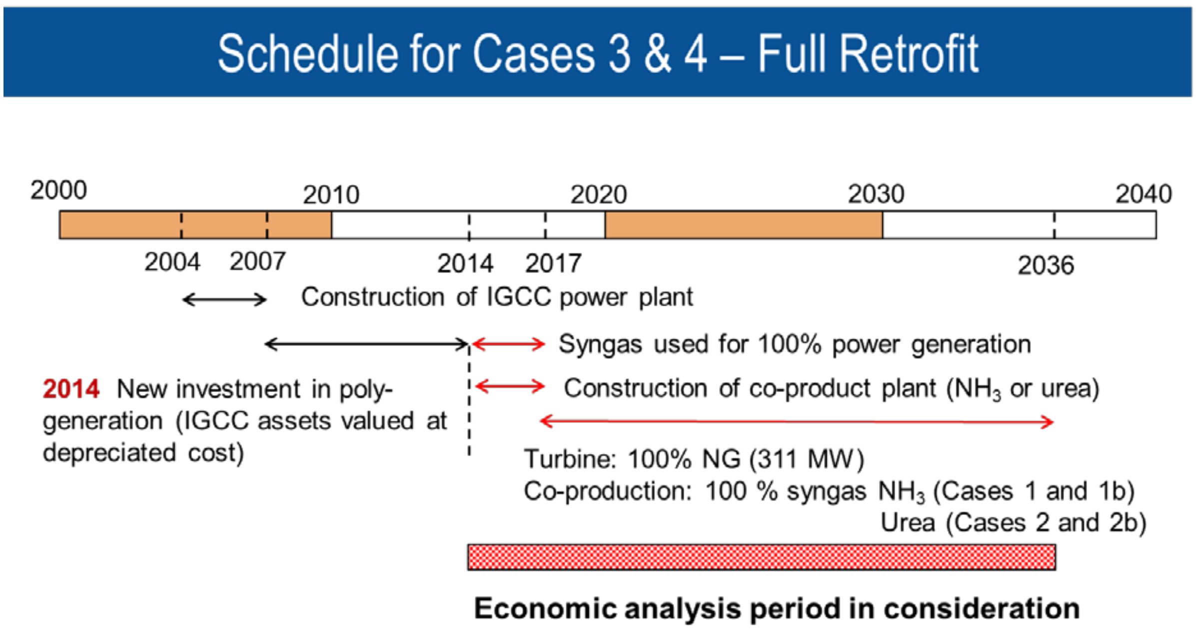
For the 20% retrofit cases, the construction period was assumed to be 2 years and therefore, from the year 2016, for the 20% syngas retrofit cases, the ammonia/urea product blocks were assumed to start operation, and continue to operate till 2036, while natural gas equivalent to the amount of syngas energy consumed for ammonia/urea production is fed to the syngas turbine power block, so that 311 MWe of power is produced, consistent with the Base Case.





For the 100% retrofit cases, the construction period was assumed to be 3 years and therefore, the construction of the warm gas cleanup unit and the ammonia/urea product blocks was assumed to be completed by the end of 2016. In the 100% retrofit cases, the operation was assumed to start in the year 2017 and continue until the year 2036. While the power plant is in operation from 2014 to the end of 2016 with syngas as the feed, from the beginning of 2017, the syngas turbine is retrofitted for full natural gas feed and natural gas is fed to the power block to generate 311 MWe of power, while all the syngas is routed to the warm gas clean up and product blocks.





Using the capital cost and operating cost information provided in Section5.2, the yearly cash flow values were calculated for each of the cases. Starting from the year of construction beginning (2014) to the end of the economic analysis period (2036), for every year, the taxable income, net revenue after taxes, and the operating cash flow were calculated. Based on the operating cash flow values for the entire economic evaluation period, the internal rate of return (IRR) was calculated for each case.

For each year in the economic analysis period, the earnings before interest and taxes (EBIT) was calculated as the difference between the total annual revenue and the total annual expenses. While estimating EBIT, depreciation is also considered as an expense. The taxable income was then calculated as the difference between the total annual revenue and the total annual expenses, less the depreciation and the interest payment. As discussed in Section 4.3, 38% of the taxable income was assumed to be taxes. The net revenue was then calculated as the difference between EBIT and the taxes plus interest payment. Since, depreciation is not a tangible cost or a real cash flow, the annual depreciation amount is added back to the net revenue to estimate the operating cash flow for a year. The operating cash flows for the entire economic evaluation period are considered to calculate the IRR for each case.

6.2 Summary of Results for Base Case IGCC and Various Retrofit Cases

The economic analysis approach and the procedure for calculating the IRR for all the cases in the study was discussed in detail in the previous section. The electricity price at which the IRR of the Base Case would be 15% was estimated to be $64.1/MWh, the same basis as used for fixing the electricity price in the selected DOE Base Case study. The electricity price was fixed at this value for all the retrofit cases and the IRR for each of the retrofit cases was determined. This method facilitates a fair comparison of all the cases and provides a better understanding of the merits and demerits of each case. The summary of IRRs determined for all the cases compared against the Base Case is provided in Table 11.

The incremental IRR shown in the last row of Table 11 refers to the computation for just the product blocks without considering the power block. The schematic for the computation of the incremental IRR is described in Figure 6. As shown in the figure, only the area lying within the dashed block is considered for the computation of the incremental IRR. The objective is to evaluate the economic feasibility of the standalone investment of converting syngas to ammonia or urea product. It considers whether it would make economic sense for an investor to purchase syngas and any needed utilities across the fence from the IGCC plant, sell tailgas and any exported utilities across the fence back to the IGCC plant, sell ammonia/urea product on the open market, and make the capital investments necessary within the dashed block area plus any incremental investments needed in the IGCC plant (such as conversion of the syngas turbine to accept more natural gas).

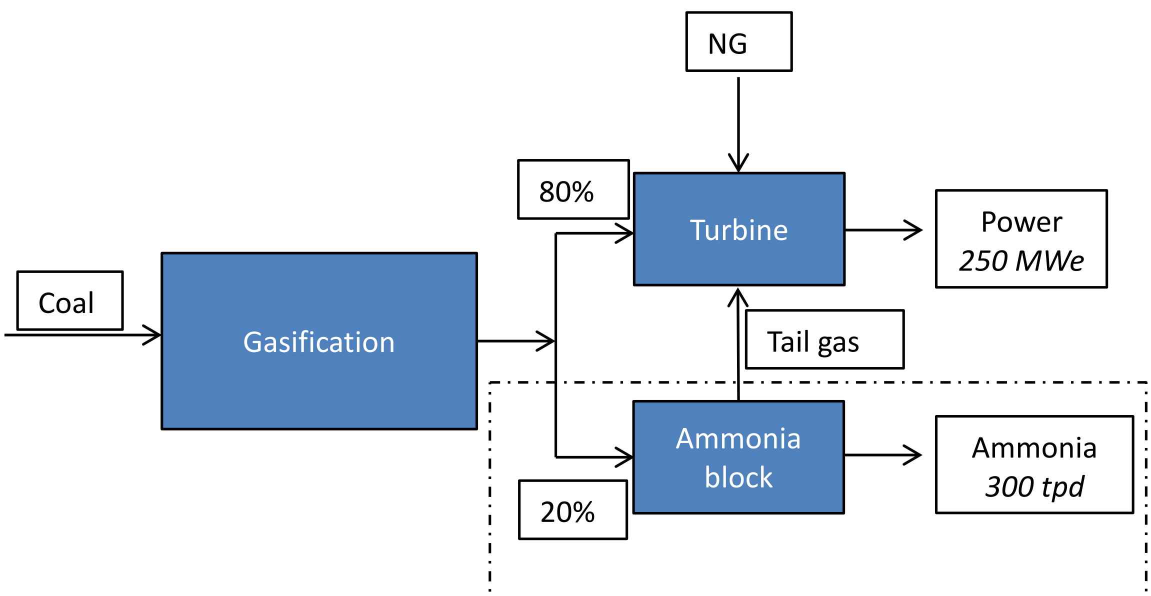


Figure 6. Schematic of the incremental IRR computation

The techno-economic study results, as shown in Table 11, indicate that both full retrofit Cases 3 and 4 generate a significantly higher after-tax IRR than the Base Case stand-alone IGCC and would thus be viable economic investments. The high IRR for these cases highlights the fact that though a significant amount of capital investment is required for the product block construction and though additional feed such as natural gas is used for the power block, the high value of the ammonia or urea products obtained from the retrofit process makes the overall process much more profitable than the Base Case with just electricity as the product.

20% syngas retrofit Cases 1 and 2 (those without any federal funding support for the warm syngas cleanup and carbon capture block) produce after-tax IRRs that are reasonably good, but are slightly lower than for the Base Case stand-alone IGCC. Incremental IRRs for these two cases would indicate that these would not be viable economic options if treated as across-the-fence transactions. Interpolation between Cases 1 and 3 and between Cases 2 and 4 would suggest that any IGCC polygen retrofit to ammonia or urea that utilizes at least 25-30% of the IGCC's syngas would likely result in an after-tax IRR equal to or greater than that of the Base Case stand-alone IGCC.

However, if the warm syngas cleanup block (WDP + WGS + aMDEA for carbon capture) were to be supported with federal funding as indicated in the 20% syngas retrofit Cases 1b, 1ab, and 2b, then the after-tax IRRs for these cases would then be higher than the IRR for the Base Case stand-alone IGCC. The incremental IRRs for Cases 1b and 1ab also indicate that these would be viable economic options if treated as across-the-fence transactions. Case 2b would be less desirable if treated as an across-the-fence transaction because of the significantly higher capital required for the urea plus ammonia block versus just the ammonia block.

If alternative technology to conventional PSA can be developed and utilized to enrich the hydrogen in the syngas, avoid sending PSA tailgas to the syngas turbine, and use the additional hydrogen to make additional ammonia, then the after-tax IRR of all modeled retrofit cases would be improved by several percent (as indicated in Cases 1a and 1ab) and would make the 20% syngas retrofit cases more attractive on an after-tax IRR basis than the stand-alone IGCC Base Case, even without any federal support. But the incremental IRR for Case 1a would indicate that it might not be attractive if treated as an across-the-fence transaction. The development of such an alternative to PSA should be considered as part of any future R&D efforts focused on polygen retrofits of IGCCs.

Though a comparative study reveals that the IRR for a number of the retrofit cases is higher than the Base Case IGCC, it is important to understand the main factors that impact the IRR of each of the retrofit cases. To do so, sensitivity analyses were performed on each of the cases to understand the impact of the main factors on the process IRR. The results of the sensitivity analyses are shown in Figure 7& Figure 8. The sensitivity analyses for the 20% syngas retrofit cases are shown in Figure 7. From this figure, it is evident that all for all the cases, because electricity is the main product, the process IRR seems to be the most sensitive to the electricity price. The next most important factor for these cases is the secondary product price (ammonia/urea price). Because the additional capital investment required for the 20% retrofit cases is smaller than that for the 100% syngas retrofit cases, the impact of a change in capital investment does not have a huge impact on the process IRR. Similarly, because the amount of natural gas used in the 20% syngas retrofit cases is lower when compared to the 100% syngas retrofit cases, the process IRR is not very sensitive to changes in NG prices.

The sensitivity analyses for full retrofit Cases 3 & 4 are presented in Figure 8. For Case 3, 1500 stpd ammonia, it should be noted that for all the sensitivity factors, even in the worst case scenario, the lowest IRR obtained is still higher than the Base Case IRR. For this case, though electricity price is the factor that the process IRR is most sensitive to, the impact of ammonia price on the process IRR is also very high. This is because of the scale of production of ammonia is 5 times that of the 20% syngas retrofit cases and therefore has a higher contribution to the process IRR. Because the uncertainty limits for the cost estimates of the ammonia plant are at ±30%, the sensitivity analysis has been carried out to understand the effect of change of capital investment in this range on the overall process IRR. As can be seen in Figure 8, a change in capital investment does have a significant impact on the process IRR, but is not a very high impact factor like the electricity and ammonia prices.

The sensitivity analysis for Case 4, shows a different trend. The process is very sensitive to the price of urea. If the price of urea reduces to $315/ton, the process IRR becomes equal to the Base Case IRR of 15% and any further price reduction will result in a lower IRR. However, based on price trend of granulated urea, $400/ton is a very realistic price for granulated urea and at this price, the process IRR is significantly higher than the Base Case, at 22%. Electricity price is the next most impactful factor for this process, because of the scale of production of electricity (~311 MWe) and its contribution to the cash flows. The capital cost of the gas cleanup, ammonia and urea blocks together is also a big factor that has an equal impact on the process IRR as the electricity prices. Out of the factors evaluated for Case 4, NG price was found to be the least impactful factor on the process economics.

Table 11. Summary of calculated IRR for Base Case and all retrofit cases

	Base Case	Case 1	Case 1b	Case 1a	Case 1ab	Case 2	Case 2b	Case 3	Case 4
		(20% syngas to NH_3; 80%to power); 300 stpd ammonia		(20% syngas to NH_3; 80%to power); 375 stpd ammonia		(20% syngas to NH_3; 80%to power); 520 stpd granulated urea		(100% syngas to NH_3; NG to power); 1500 stpd ammonia	(100% syngas to urea; NG to power); 2600 stpd granulated urea
Input Fuels	Coal	Coal	Coal	Coal	Coal	Coal	Coal	Coal	Coal
		Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Products	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity
Power, MWe	311	311	311	311	311	311	311	311	311
Co-Product		Ammonia	Ammonia	Ammonia	Ammonia	Urea	Urea	Ammonia	Urea
Co-Product Capacity, stpd		300	300	**375 (extra H_2 recovery)**	**375 (extra H_2 recovery)**	520	520	1500	2600
Capital Costs									
IGCC Plant Capex, $M	$697	$697	$697	$697	$697	$697	$697	$697	$697
Depreciated IGCC Plant Capex, $M	$383	$383	$383	$383	$383	$383	$383	$383	$383
Product Area Capex, $M		$177	$85.8 (plus federal support)	$189	$97.8 (plus federal support)	$297	$206 (plus federal support)	$505	$837
IRR	**15.0%**	**14.2%**	**19.3%**	**16.9%**	**21.9%**	**13.6%**	**17.5%**	**22.6%**	**22.2%**
Incremental IRR	**-**	**4.8%**	**19.7%**	**10.5%**	**26.1%**	**5.4%**	**12.4%**	**-**	**-**

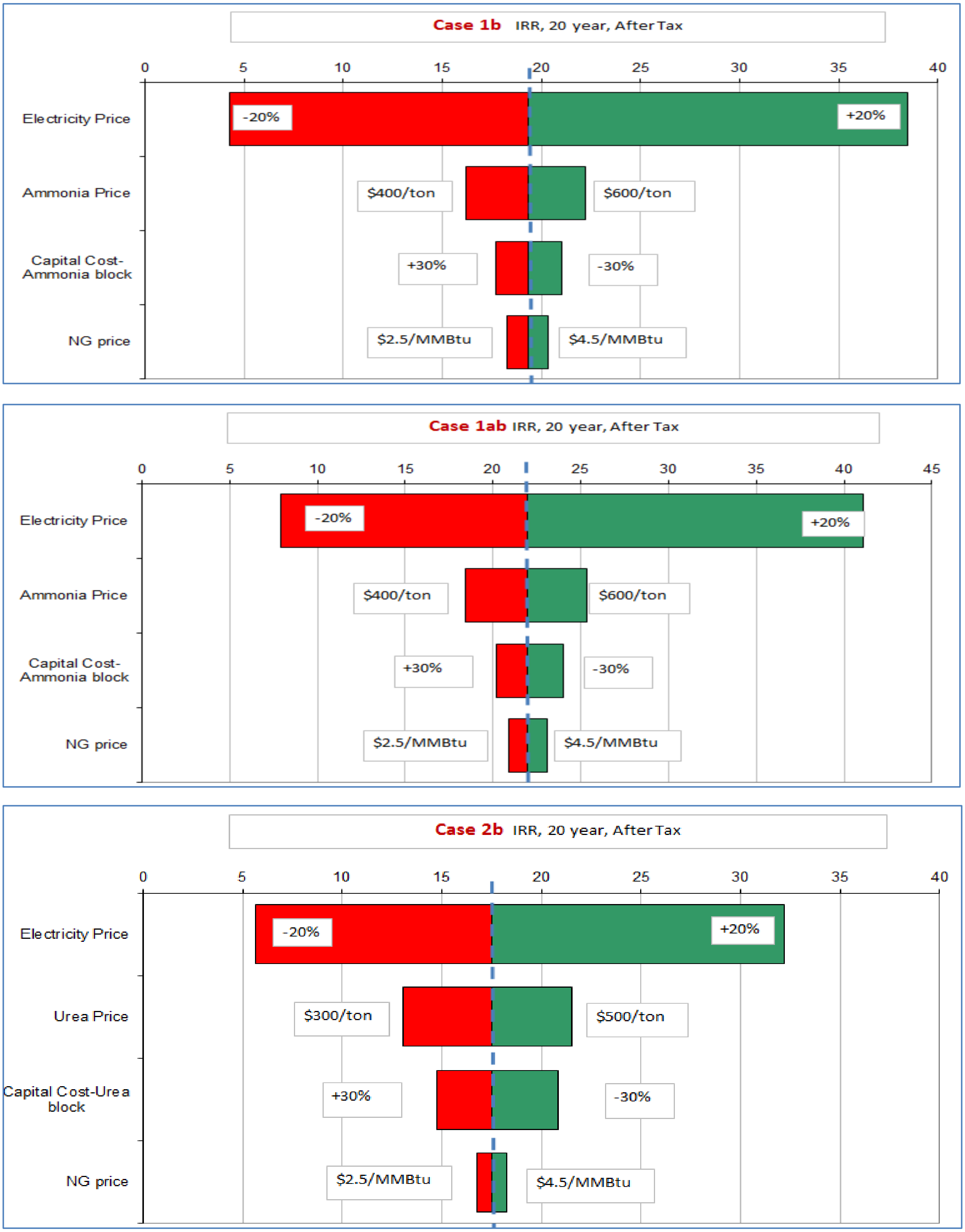
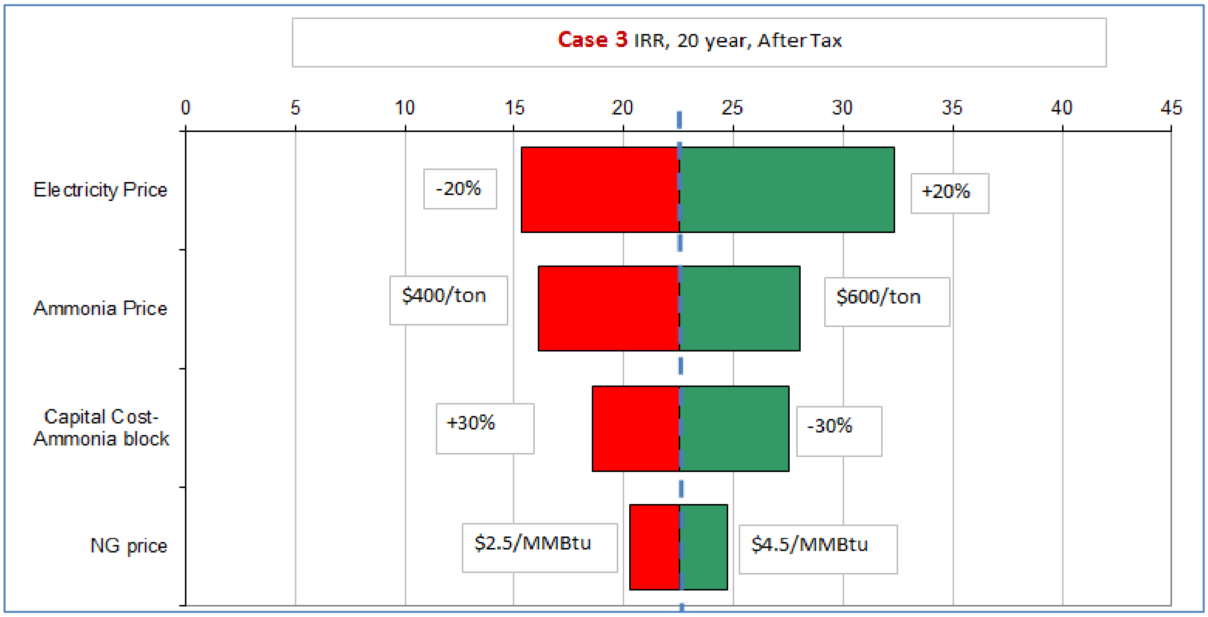


Figure 7. Sensitivity analyses of the 20% retrofit syngas cases; chart at the top shows the sensitivity analysis for Case 1b, second chart shows the sensitivity analysis for Case 1ab, and the one at the bottom shows the sensitivity analysis for Case 2b



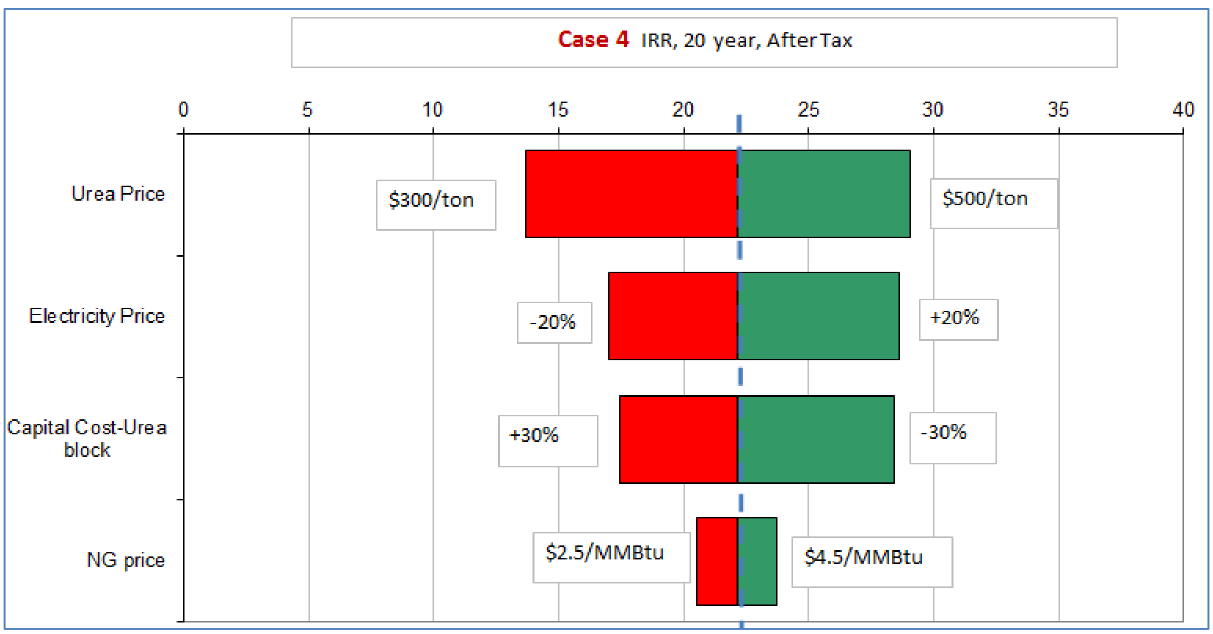


Figure 8. Sensitivity analyses for Cases 3 & 4

References

AMEC. (2013). *RTI Ammonia Integration Project TEC Polk Station Power Plant, Mulberry, Florida; Study and Cost Estimates.* AMEC Project Number 173463.

DOE. (2010). *Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity.*

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Appendix L

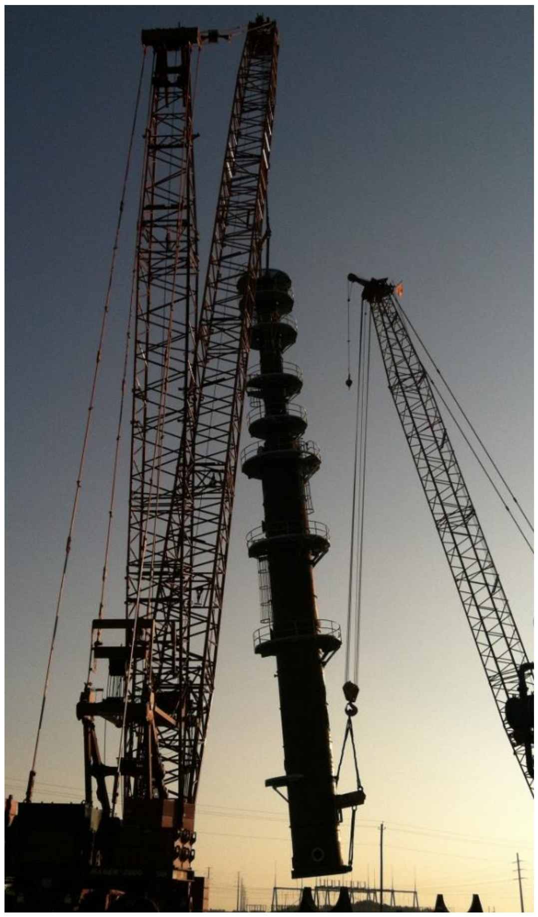
Ammonia FEED Study

RTI INTERNATIONAL

amec foster wheeler

RTI Ammonia Integration Project
TEC Polk Station Power Plant
Mulberry, Florida

Ammonia Integration FEED Report



AMEC Project Number 176858
Revision 1
February 2015

RTI Ammonia Integration Project
TEC Polk Station Power Plant
Mulberry, Florida

FEED Study and Cost Estimates

Project Number 176858
Revision 1-B February
2015

DISCLAIMER

This report was prepared exclusively for RTI by Amec Foster Wheeler. The quality of information, analysis, estimates, and conclusions contained herein are consistent with the level of Amec Foster Wheeler's services and is based on: i) information available at the time of preparation, ii) data supplied by outside sources, iii) the conditions and qualification set forth in this document. This report is intended for the specific project application as defined herein and is subject to the terms and conditions of the contract with Amec Foster Wheeler. No guarantee of ultimate project cost, financial or product performance is intended or implied. Any use of, or reliance on, or decisions based on this report by any third party does so at its sole risk and discretion.

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1. EXECUTIVE SUMMARY

RTI International (RTI) engaged Amec Foster Wheeler (AFW) to develop a FEED Study to develop a +/- 10% cost estimate for an Ammonia production facility at the Tampa Electric Company (TEC) Polk Power Station near Mulberry, Florida. The Polk Power Station includes an integrated gasification combined cycle unit (IGCC) and four simple cycle gas turbines. Total production at the Polk Power Station is approximately 940 megawatts (MW) with an IGCC capacity of approximately 260 MW. RTI is currently commissioning a Warm Gas Cleanup (WGCU) System demonstration facility at the site to remove CO_2 and H_2S from a syngas slipstream.

The subject project is for producing Ammonia utilizing the hydrogen stream from the WGCU demonstration facility. This study consisted of an initial Pre-FEED design optimization study (Phase 1) followed by the subject Ammonia Integration FEED study (Phase 2).

The Phase 1 Pre-FEED study resulted in TEC and RTI selecting Case 3A, consisting of the WGCU with LTS and Methanation with TEC DGAN Nitrogen source, for the Phase 2 Ammonia Integration FEED study. This selection increased the Ammonia Plant Capacity to 380 STPD.

During Phase 2 FEED study, AFW developed H&MB, PFDs, P&IDs, 3D Model, and Equipment Specifications for the OSBL process and subcontracted for the ISBL Ammonia process H&MB, PFDs, P&IDs, General Layouts, and Equipment Specifications. AFW obtained vendor quotes for all equipment and developed preliminary engineering and associated material quantity take-offs to generate a +/-10% capital cost estimate (CAPEX).

The estimated project budget CAPEX is $98.9 million based on 2015 costs with no escalation factor and consists of the following primary project components:

Project Component	Description	Estimated CAPEX (US$ millions)
OSBL Plant	WGCU LTS, Methanation, DGAN Nitrogen, Ammonia Storage/Loadout, Utilities	$50.6
ISBL Plant	Ammonia Plant	$48.3
Total Estimated Costs		**$98.9**

The preliminary project schedule is estimated to be 36 months following project funding.

2. INTRODUCTION

RTI commissioned AFW to develop a FEED study to develop a +/- 10% cost estimate for an ammonia production facility at the Tampa Electric Company (TEC) Polk Power Station near Mulberry, Florida for the project stakeholders, which include TEC, the US Department of Energy (DOE) and RTI.

2.1. Project Background

The existing TEC Polk Power Station consists of an integrated gasification combined cycle unit (IGCC) and four simple cycle gas turbines. Total production of the Polk Power Station is approximately 940 megawatts (MW) with an IGCC capacity of approximately 260 MW. RTI is currently commissioning a WGCU demonstration facility to remove CO_2 and H_2S from a slipstream of syngas (approximately 20% of the total plant syngas flow).

The project scope consisted of an initial Pre-FEED design optimization study (Phase 1) followed by the subject Ammonia plant FEED study (Phase 2).

RTI previously engaged AFW in 2013 for a pre-feasibility study to develop grade estimates for both 300 and 1500 STPD ammonia plants. That study developed order of magnitude capital cost estimates for systems designed to utilize the syngas stream from the existing gasifier to synthesize ammonia and/or urea. AFW utilized a recognized technology vendor to assist in the development of the ammonia plant deliverables and inputs to support the subject Phase 2 FEED study.

The Phase 1 Pre-FEED study involved the optimization of the 2013 development phase preliminary design utilizing the following steps:

1. WGCU System Modifications:
   - Case 1 – WGCU as-is with added PSA
   - Case 2 – Case 1 with LTS
   - Case 3 – WGCU with LTS and Methanation
2. Nitrogen Supply Optimization:
   - Base Case – Stand Alone Nitrogen Plant
   - Case A – Use existing TEC DGAN Nitrogen with purification

3. Ammonia Storage & Distribution
    - Ammonia Storage System
    - Ammonia Distribution Line
4. Plant Siting & Layout
    - WGCU Modifications Layout
    - Ammonia Plant Location
    - Ammonia Storage
5. Selected Case and Revised Project Budget

TEC and RTI selected Case 3A (WGCU with LTS and Methanation with TEC DGAN Nitrogen source) for the Phase 2 Ammonia Integration FEED Study based on the following:

- Highest estimated Ammonia production at 380 STPD;
- Lowest estimated incremental Ammonia CAPEX;
- Lowest estimated Plant OPEX costs;
- Eliminates higher maintenance PSA and associated compressor;
- Less integration required with power plant.

AFW has summarized the Phase 1 Pre-FEED results in the RTI Ammonia Integration Project Pre-FEED Study and Cost Estimates Report issued in July 2014.

The subject Phase 2 FEED Study developed the necessary engineering deliverables to enable the AFW estimating group to perform detailed material quantity take-offs and generate the +/- 10% CAPEX estimate for the approved WGCU System Case 3A and the 380 STPD Ammonia plant based on the selected vendor's technology. All the proprietary equipment, instrumentation and piping specialties costs for the ISBL Ammonia plant were provided by the selected vendor and the ISBL detailed material quantity take-offs were developed by AFW.

2.2. Project Scope

AFW developed the overall project scope definition, budget order of magnitude cost estimates and preliminary operating cost estimates for the cases listed above. The following items were generated and utilized in this FEED study:

- Discipline Design Criteria
- Equipment List
- OSBL PDP (H&MB, PFDs, P&IDs, HAZOP)

- ISBL PDP (H&MB, PFDs, P&IDs, Layouts, HAZOP) - provided by ammonia vendor
- Mechanical / Piping PDP (Plot Plan, Equipment General Arrangements, Tie-In List, 3D Model Views)
- Electrical PDP (Single Line Diagram, Distribution, Grounding, Lighting)
- Instrumentation & Controls PDP (Network Diagram)
- Discipline MTOs (Piping, Electrical, Controls, Structural, Civil)
- Equipment Quotations
- Division of Responsibility Matrix
- Project Services Estimate
- CAPEX Estimate
- Project Schedule
- Cash Flow Curve
- Ammonia Feasibility Study

2.3. Study Objectives

The objective of the Phase 1 Pre-FEED study was to evaluate several options for optimizing the Ammonia Plant Outside Battery Limits (OSBL) facilities to increase Ammonia production and cost efficiency to determine the most cost effective option for the Phase 2 FEED study.

The objective of the Phase 2 FEED study was to complete the project preliminary engineering to a sufficient level to develop a +/-10% Project CAPEX estimate and the Plant OPEX estimate.

3. DESCRIPTION OF EXISTING FACILITIES

3.1. Polk Station Power Plant

The 940 megawatt Polk Station Power Plant consists of 4 simple cycle gas turbines and one IGCC unit operating on a petcoke/coal mixture. The simple cycle units operate on natural gas. The plant began commercial operation in 1996 with the IGCC unit, followed by two simple cycle units in 1998 and 1999 with the remaining two units in 2000 and 2002.

3.2. Existing IGCC Area

The IGCC plant consists of the following process units:

- Air separation unit (ASU)
- Gasification plant
- Low temperature gas cooler
- Acid gas removal unit (amine system)
- Power block
- Sulfuric acid plant
- Utilities and balance of plant

The ASU is a cryogenic unit that provides oxygen primarily for the gasification process with some residual amounts going to the sulfuric acid plant. Nitrogen produced from the ASU is used primarily in the gas turbine as a diluent and to provide additional capacity, as well as supplying seals and inerting gas to the gasification equipment.

The gasification plant produces syngas from a petcoke/coal slurry and an O_2-rich mixture. Sulfur removed from the syngas is used to produce approximately 200 TPD of sulfuric acid. The clean syngas is fed to a GE-7FA gas turbine for power generation. Waste heat from the gas turbine and gasifier is used to produce steam in the heat recovery steam generator, which in turn supplies a 123 MW steam turbine.

Various balance of plant systems include plant power distribution, plant and instrument air, cooling water, boiler feed water, auxiliary steam, plant controls and data acquisition, and flare stack

3.3. Warm Syngas Cleanup Demonstration Plant

RTI is currently commissioning a WGCU Demonstration Plant to remove CO_2 and H_2S from a syngas slipstream. This 1.5 MM SCFH WGCU consists of the following test units designed to demonstrate RTI's warm syngas cleaning technologies and carbon capture at near-commercial scale and typical operating conditions:

- Warm desulfurization process (WDP)
- Water gas shift (WGS) reactor system
- Low temperature gas cooler (LTGC)
- Activated Amine (aMDEA) for CO2 capture

Sulfur removed from the syngas is sent to the sulfuric acid plant. CO2 removed from the syngas is currently vented to the atmosphere, but provisions for future injection into a deep saline aquifer or collection for other process needs exist. Cleaned syngas from RTI's system is currently returned as fuel to the combustion turbine.

4. FEED DESIGN BASIS

4.1. Ammonia Feed Stream Composition:

Description	Specification
H2	73.2 mol%
N2	24.4 mol%
NH3	0.0 mol%
CH4	1.6 mol%
Ar	0.8 mol%
Total S	≤ 0.1 ppm vol
Total Oxygen Compounds	< 10 ppm vol as atomic oxygen (CO+2CO2+2O2+H2O)
Other Catalyst poisons (Cl, As, etc.)	0 (NIL)
H2/N2 Ratio	2.7 +/- 1% molar
Temperature	122°F
Pressure	250 psig

4.2. FEED Process Design Criteria

Please refer to **Appendix** for the Project Design Criteria that were used as the design basis for the Phase 2 FEED study.

5. DESCRIPTION OF PROPOSED NEW FACILITIES

5.1. Project Scope of Work

The project FEED Scope consists of Case 3A from the Pre-FEED study and includes the following process operations:

- WGCU System Modifications
- Nitrogen Generation
- Ammonia Feed Water Removal
- Ammonia Plant
- Ammonia Storage
- Ammonia Truck Loadout
- Cooling Water System
- Air Separation Unit Air Compression

The FEED scope is summarized on Block Flow Diagram 92127-PFD-280-31 included in the OSBL PDP Package.

5.2. WGCU System Modifications

Case 3A from the Pre-FEED study was selected as the optimum modifications to the existing WGCU System for increased Hydrogen feedstock to the Ammonia Plant. In Case 3A the amount of hydrogen would be increased by initially cooling the syngas after it leaves the WGS Reactor in the WGCU and passing it through a LTS catalyst bed. The cooled syngas would first be sent through a hydrogen sulfide guard bed followed by a carbonyl sulfide and arsenic guard bed since these compounds can poison the LTS catalyst. The outlet of the LTS catalyst bed would then be fed to the inlet of the Steam Generator 502 in the WGCU. Syngas from the WGCU aMDEA unit would then be fed to a Methanation catalyst bed to react the residual carbon monoxide and carbon dioxide with a portion of the hydrogen in the stream to convert the residual carbon monoxide and carbon dioxide to methane and water.

Clariant modeled and designed the LTS catalyst bed to maximize the amount of hydrogen in the outlet. Clariant modeled and designed the Methanation catalyst bed to ensure all carbon monoxide and carbon dioxide was reacted out of the syngas.

5.3. Nitrogen Generation

Case 3A utilizes existing TEC DGAN nitrogen with added purification which was selected as the preferred source of nitrogen to the Ammonia Plant. TEC's existing Air Separation Plant produces a DGAN nitrogen stream with a maximum of 2.5 mole percent oxygen that is not fully utilized by the Polk Power Station. In the Case 3A design, the excess DGAN nitrogen stream would initially be compressed to 275 psig. A Deoxo catalyst process has been developed by BASF to reduce the oxygen of the available DGAN nitrogen to less than 10 ppm. The process involves feeding a portion of the Methanation process outlet gas and the DGAN nitrogen to a Deoxo catalyst bed. The catalyst reacts the oxygen in the DGAN nitrogen with hydrogen in the Methanation process outlet gas to form water.

5.4. Ammonia Feed Water Removal

The enriched hydrogen stream from the Methanation catalyst bed outlet and purified nitrogen stream from the Deoxo Catalyst beds are mixed at stoichiometric ratios (3 H_2 to1 N_2). The water in the combined stream is then reduced to less than 10 ppm using a series of coolers, a knockout vessel, a coalescing filter, and a molecular sieve bed before being fed to the Ammonia process.

5.5. Ammonia Plant

The design of the ammonia synthesis loops was performed by a recognized technology provider. Their Ammonia Converter consists of multiple catalytic converter beds operating at 2,100 psig. The Ammonia Feed stream is compressed and fed to the ammonia converter through a series of cross exchange pre-heaters. A hydrogen recovery unit (HRU) recycles the unreacted hydrogen and nitrogen from the process tail gas back to the Ammonia Converter and allows the inerts to leave the process.

Ammonia liquid product is passed through a closed loop refrigeration system and warmed up to 60°F before being sent to pressurized (250 psig) storage tanks.

5.6. Ammonia Storage

Ammonia product from the facility will be pumped to a new ammonia storage tank area to the west of the production plant. The ammonia will be stored at an approximate pressure of 250 psig at 60 degrees F. The storage tanks will be shop-fabricated horizontal bullet type, installed in a curbed area to contain any possible spillage. The tanks will be sized to hold approximately three days of ammonia plant production. Maximum filling of each tank will be limited to 85%, in order to allow room for vapor expansion.

5.7. Ammonia Truck Loadout – Base Case

TEC requested that the FEED Study Base Case include provisions for ammonia from the storage tank area to be pumped to trucks for distribution to customers.

5.8. Ammonia Distribution Line – Alternate Case

In the FEED Study Alternate Case, ammonia from the storage tank area will be pumped through a new buried pipeline to an existing underground ammonia pipeline located approximately nine miles north of the plant. The new pipeline proposed routing will proceed west from the ammonia storage tanks to Highway 37, where it will turn north and run along the same general route as an existing water line until it reaches the location of the existing east-west ammonia pipeline at the intersection of Highway 37 and Highway 640. Ammonia line pressure at the tie in point to the existing ammonia pipeline will need to be 250-300 psig (to be confirmed).

TEC commissioned AECOM Technical Services to complete an Ammonia Pipeline Feasibility Study. The study scope included two alternate pipeline routings that roughly followed Old Highway 37 and the adjacent railroad track. The alternate routes were more costly with longer construction schedules as compared to the proposed Highway 37 route. Both routing options will require multiple variances and lengthy permitting.

The AECOM Ammonia Pipeline Feasibility Study and a Pipeline Routing are included in this report as **Appendix** .

5.9. Cooling Water System

The existing Polk Station cooling system will not be adequate to support the WGCU and Ammonia Plant cooling water requirements. The FEED scope includes a new cooling water system with a 20,000 gpm 3-cell field erected cooling tower to cover the new cooling water requirements for the project.

5.10. Air Separation Unit Air Compression

TEC's existing Air Separation Unit does not currently produce enough DGAN nitrogen to supply the ammonia plant. As a result, dual air compressors have been included in this project to provide an additional 1,000 KSCH of air to TEC's existing Air Separation Unit.

5.11. Plant Layout

The proposed TEC Polk Station Ammonia Production Plant is shown on **Figure 5.1 – TEC Ammonia Integration Site Plan (below).**

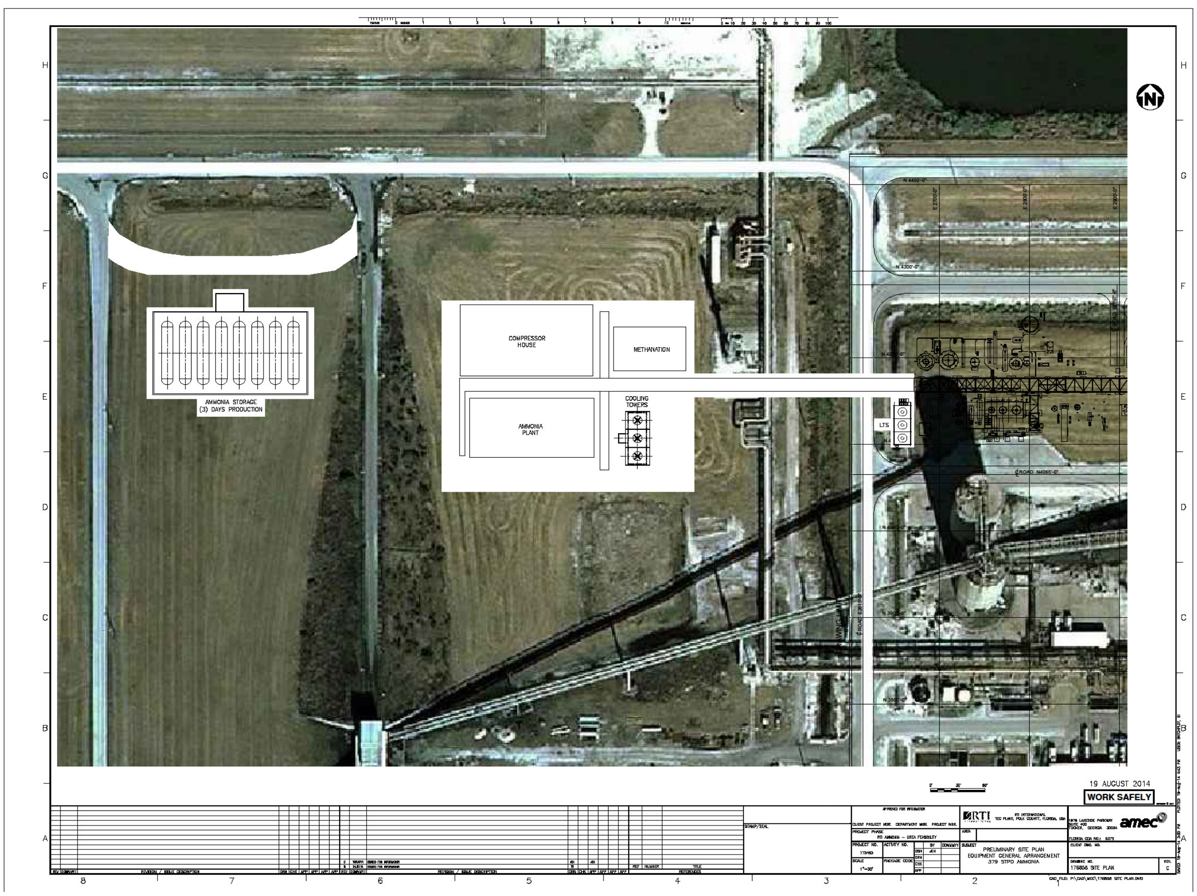

Figure 5.1 – TEC Ammonia Integration Site Plan

The Ammonia Production Plant Layout utilizes the existing WGCU pipe rack and the adjacent property located on the north-west side of the plant as follows:

- WGCU System LTS equipment is located at the west end of the WGCU system on the existing pipe rack;
- The existing pipe rack is extended over the road to the west of the WGCU system;
- The new Methanation unit and Cooling Tower system are located on the west side of the site between the WGCU system and the plant fuel road;
- The proposed Ammonia plant is located adjacent to the Methanation unit and Cooling Tower;
- Ammonia storage tanks and truck loadout located on the west side of the plant fuel road;
- The proposed plant layout maintains a 200' minimum clearance from existing flare;
-

5.12. FEED Scoping Documents

A Mechanical Equipment List is attached as **Appendix** . The OSBL H&MB, PFDs, and P&IDs are included as the OSBL PDP Package.

6. CAPITAL COST ESTIMATE

6.1. Basis of Estimate

The project capital cost estimate (CAPEX) was developed using TIMBERLINE estimating software based on the FEED documentation listed in Section 5.10, supported by labor installation information from past AMEC similar industrial projects. The CAPEX is based on an EPCM project execution approach with TEC as the overall Project Manager as detailed in the Project Division of Responsibility (DOR) Matrix **(Appendix D**) and as summarized below:

- **Project Execution**

  The CAPEX is based on EPCM project execution strategy with TEC acting as Project Manager.

- **Project Schedule**

  The CAPEX is based on a 36 month project schedule and a July 2015 notice to proceed for award of the major process and plant engineering contracts.

- **Work Schedule**

  The CAPEX is based on working a fifty (50) hour work week with five 10-hour shifts per week, Monday through Friday. The associated premium time (10 hr/week) has been included in the estimate.

- **Plant Equipment**

  Supply and installation is included for the plant equipment based upon the flow sheets and equipment list included in this report.

- **Materials**

  Commodity materials are based on the MTOs in this report, with pricing based on in-house current cost data, experience from recent similar projects and budget pricing provided by vendors and subcontractors.

- **Labor**

  Labor is based upon merit shop labor rates applicable to the Polk County, Florida. Included in labor cost are craft fringe benefits, per diem, payroll taxes and insurance.

- **G&A Costs**

  G&A costs are included for contractor construction management, construction equipment and operating costs.

- **Indirect Costs**

  Indirect Costs have been included for contingency, escalation, ammonia technology license, spare parts, vendor erection assistance, plant start-up and commissioning, and the project engineering, procurement, construction management services.

6.2. Estimate Accuracy

This Project CAPEX has a +/- 10% accuracy based on December 2014 preliminary engineering progress and January 2015 pricing.

6.3. Direct Costs Description

The CAPEX represents the estimated total cost for Process Equipment, Balance-of-Plant Equipment, Engineering, Procurement Services, Commodity Materials, Equipment, Construction Labor, Supervision, and Construction Management to construct the proposed 380 STPD Ammonia Plant as defined herein by the project FEED documents, discussed in meetings with RTI and TEC, and as further qualified in this report.

6.3.1. Civil Costs

Sitework

Services to design, supply and erect the Sitework and underground utilities work were estimated as part of this FEED study.

Foundations

Services to design, supply and install buildings, equipment, and miscellaneous foundations for the proposed project. The preliminary foundation design has been based on assumption of existing soils adequate to support 4000 PSF for foundations loadings. The final design will be based on a project specific report provided by Owner’s geotechnical engineer. Foundations will include excavation, backfill, concrete, reinforcing steel, formwork, inserts and anchor bolts. Foundations have been included for the project structures and equipment.

6.3.2. Structural Steel

Services to design, supply and erect the structural and miscellaneous steel required for the various buildings, structures, platforms, walkways and supports associated with the plant are included.

6.3.3. Architectural

Services to design, supply and erect the building enclosures and supporting Electrical and Mechanical Rooms are included.

6.3.4. Equipment (Process / Mechanical)

Supply of plant process and utility equipment are per the OSBL PDP and ammonia vendor ISBL PDP packages. The CAPEX also includes catalyst, molecular sieve, support media, and initial lubricant fills.

Construction services to supply the required labor, construction equipment, materials, tools and supervision to receive, store and erect the plant equipment described in the DOR and are shown on the plant layouts and described in the project flow sheets.

The CAPEX includes freight costs and is based on equipment being transported to the site in the largest practical & shippable sub-assemblies. Installation will be in accordance to the supplier's drawings and specifications. The vendor will supply sub-assembly fasteners. Contractor will supply balance of installation fasteners.

6.3.5. Piping Systems

Services to complete the detail engineering and supply the required materials, labor, construction equipment, tools and supervision to receive, store and erect the project piping system described in the DOR.

6.3.6. Mechanical Insulation Systems

Services to complete the detail engineering and supply the required materials, labor, construction equipment, tools and supervision to receive, store and install the insulation for piping and processing equipment.

6.3.7. HVAC

Services to complete the detail engineering and to supply the required materials, labor, construction equipment, tools and supervision to receive, store and erect the project platework described in the DOR and are shown on the plant layouts, equipment list, and are described below:

Electrical Rooms:

The plant electrical equipment rooms will be cooled to 80F using air-cooled packaged air conditioning units. Air conditioning units will not include heating or humidity control. The units will use 100% recirculation air to minimize filter loading and not include any outside air intakes for pressurization of the room. Cooling coil condensate will be piped to spill on grade.

Mechanical Rooms:

Compressor rooms will have mechanical ventilation and no heating. Ventilation systems will use filtered wall supply fans and exhaust relief louvers. Louvers will be fixed blade type with no dampers. Ventilation rates were sized to provide approximately one air change every minute to provide adequate heat removal.

6.3.8. Electrical

Services to complete the detail engineering and to supply the required materials, labor, construction equipment, tools and supervision to receive, store and erect the project electrical system described in the DOR as described below:

Main Substation – Existing

Electrical Equipment:

Provide and install the following equipment:

- 13.8kV switchgear/starter lineup
- Unit Substations
- Bus Duct
- 480V MCC's
- Medium Voltage VFD's & Isolation transformers
- UPS
- I/O Cabinets

- 480/277V transformer and panel board for lighting and HVAC
- 480-208/120V transformer and panel board for receptacles
- 480-208/120V shielded isolation transformer and panel board for instrumentation

Distribution:

Power Distribution from the Substation to the Electric Rooms (ER) will be via utility bridge, with underground duct bank to ammonia storage tanks.

Wiring and Raceways:

In general cable trays will be used for main routing from electrical rooms to the users. Rigid galvanized (RGS) conduit will be used with a minimum size of ¾”. Motor and control cables will be run in separate conduits for 480V power conductors larger than #6 AWG. 600V power wiring will be Type “TC”. Minimum sizes will be #12 AWG for power and #14 AWG for control. Medium Voltage motor wiring cable will be with EPR insulation and CPE jacket, shielded, 100% insulation.

Grounding:

Grounding will be #4/0 AWG bare soft-drawn copper wire. All connections will utilize thermal welds.

Lighting and Receptacles:

A lighting system will be provided with lighting levels consistent with industry standards utilizing LED fixtures where possible. Photoelectric controls will be provided for outdoor lighting poles. Indoor room lighting will be manually switch controlled. Indoor platform lighting and outdoor task lighting will be switched at the panel board. Emergency lighting with self-contained battery packs will be installed in the electric rooms and for stairwells and egress walkways in enclosed buildings.

Convenience receptacles will be provided at maintenance areas and in the electric rooms. Outdoor receptacles will be duplex, 120V, and weatherproof GFCI type. Welding receptacles (480V) will be provided in each area.

Grounding and Lightning Protection:

Steel structures will be grounded and bonded. Lightning protection systems will be provided for the plant and lab/research structures.

Heat Tracing:

Not required.

6.3.9. Instrumentation and Control Systems

Services to complete the detail engineering and to supply the required materials, labor, construction equipment, tools and supervision to receive, store and erect the project instrumentation and controls system work described in the DOR and the Instrumentation & Controls PDP documents as described below:

Instrumentation:

Supply of the anticipated plant process and utility system instrumentation is included**.** Wiring will be directly from the field devices to the I/O cabinets. Analog instrument wiring will be twisted pair cable with aluminum mylar shield, #16 AWG with PVC jacket. Control wiring will be at a minimum size of #14 AWG. All instruments will be provided with 4-20 madc analog signals or 24 vdc digital signals as required.

Controls System:

The Plant Control System will be DCS based to communicate on the existing network. The structure of the system includes a cabinet, power supplies, a controller pair, communication and I/O modules as required to add the new instrumentation to the existing ABB DCS system. The safety system (ESD) will be an extension of the existing Foxboro-Triconex system. The systems, along with I/O - Marshalling cabinets will be located in the new RTI-2 Electrical Room. Where the equipment is OEM provided, the OEM may include a standalone processor rack and the required instrumentation termination cabinets. All processor cabinets and PLC's will be interconnected on the communication network.

Wiring for field instrumentation will be provided for the process and auxiliary equipment. All remote I/O will be contained in cabinets located in the electric room. Start/Stop switches will reside in the DCS. Local disconnects and start-stop stations are not included.

6.3.10. Contractor G&A Costs

Contractor support services associated with the project as described below:

- Support Costs
- Site Services & Facilities
- Equipment, Tools & Supplies

- Fuel & Maintenance
- Sales Tax (excluding Process Equipment)
- General Expenses
- Construction Project Personnel
- Contractor OH&P

6.4. Indirect Costs Description

6.4.1. Engineering Services

Engineer to provide the process and detailed engineering services necessary to execute the project design as defined by the DOR. The following describes the proposed scope of services and approach in summary to perform the engineering work.

The following is a summary of engineering deliverables:

General:

- Design Standards
- Technical Specifications
- Engineering Schedule
- Engineering Drawing List
- Vendor Drawings Review
- Shop Drawing Review
- Document Control of Engineering & Vendor Drawings
- Field Technical Support

Process Engineering:

The project process engineering deliverables listed below will be split between the ammonia process technology supplier and the plant engineer as per the DOR.

- Updated Heat & Material Balances
- Process Flow Diagrams
- P&ID's
- Utility Flow Diagrams
- Equipment Specifications
- Equipment Data Sheets
- Equipment List

Mechanical & Piping Engineering:

- Plant 3D Model
- Plant General Arrangement Drawings
- Electrical & Compressor Room HVAC
- Piping Specifications
- Piping Orthographic Drawings
- Piping Isometric Drawings
- Pipe Supports

Civil/Structural/Architectural Engineering:

- Site Preparation Drawings
- Storm Water Drainage
- Underground Utilities
- Roads & Paving
- Building and Equipment Foundation Drawings
- Building Structural Drawings (Steel, and Concrete)
- Equipment Support Drawings (Steel, and Concrete)
- Pipe Bridge Drawings
- Miscellaneous Steel Drawings

Electrical, Controls and Instrumentation Engineering:

- Single Line Diagrams
- MCC's
- Motor List
- Wiring Schematics
- Power and Control Location Plans
- Cable Tray Layouts
- Conduit and Cable Schedules
- Grounding and Lighting Plans
- Lightning Protection Drawings
- Communication Plans
- Duct Bank Plans & Sections

- DCS Programming
- HMI Configuration

6.4.2. Procurement Services

Engineer as Owner's Procurement Agent, will be responsible for procurement of:

- Process Equipment
- Utility Equipment
- Electrical System Equipment
- Instrumentation & Control System Equipment
- Shop Fabricated Tanks
- Construction Services

6.4.3. Project Management Services (Owner's Costs)

TEC will be the overall Project Manager, responsible for:

- Project Management
- Environmental Permitting
- Environmental, Health, Security & Safety Program Management
- Contract Administration
- Construction Management
- Start-Up & Commissioning Management
- Training Management
- Site Security

TEC requested that AWF include an allowance of 6% of Total Costs in the CAPEX to cover the Owner PM Services.

6.4.4. Other Indirect Costs

Item	Description
Technology Fee	Ammonia Technology License Fee included in CAPEX
Vendor Reps	Allowance of 2.5% of Equipment Costs is included in CAPEX for Vendor field installation support services.
Commissioning	Allowance of 2% of Total Direct Costs is included in CAPEX for Vendor and Contractor support of commissioning.

Spare Parts	Allowance of 2% of Equipment Costs is included
Contingency	Allowance of 5% of Total Costs is included

6.4.5. Not Included in CAPEX

To further define the scope of the estimate, the items not included are listed below:

- Escalation
- Bonds
- Builder's Risk Insurance
- Sales Taxes on Purchased Equipment
- Financing Costs or Capitalized Interest Costs
- Permitting Expenses
- Legal Costs

6.5. Capital Cost Estimate

The Project CAPEX represents the Project cost for Engineering, Site Development, Equipment, Commodity Materials Supply, Field Craft Labor, Supervision, Construction Management, and General Conditions in accordance with the project scope of work described in the DOR. The Project CAPEX is in included in **Appendix E.**

6.5.1. Estimated Price – Base Case (in $Millions)

Description	Effort Hours	Labor	Material	Subcontract	Equipment	TOTAL
Sitework	301	$0.011	$0.040	$0.275	$0	$0.325
Civil	38,360	$1.573	$1.241	$1.421	$0	$4.235
Structural	20,914	$1.283	$2.417	$0.098	$0	$3.798
Equipment	16,049	$0.642	$0.351	$0.220	$32.165	$33.378
Piping	146,406	$6.133	$3.371	$2.421	$0	$11.925
Electrical	33,556	$1.244	$1.598	$0.102	$2.540	$5.484
Instrumentation	7,110	$0.299	$0.212	$0	$2.030	$2.541
Contractor G&A Cost						$18.220
Total Direct Costs	**232,296**					**$79.906**
Technology Fee						$0.450
Erection Supervision						$0.918
Sales Tax - Materials						$0.646
Spare Parts						$0.735
Owner's Costs						$3.701
Commissioning						$1.234
Engineering						$6.560
Total Indirect Costs						**$14.244**
Contingency						$4.708
Total Estimated Costs						**$98.858**

6.5.2. Estimated Price – Alternate Case (with Ammonia Distribution Pipeline)

TEC requested that the FEED Study include an Alternate Case with an ammonia distribution pipeline from the storage tank area to an existing underground ammonia pipeline located approximately nine miles north of the plant.

Project Component	Description	Estimated CAPEX (US$ millions)
Base Case FEED Estimate	From Section 6.5.1	$98.9
Ammonia Truck Load Out Station	AFW Cost Estimate	($1.1)
Ammonia Distribution Pipeline	AECOM Cost Estimate	$10.4
Total Estimated Project Costs	**Alternate Case**	**$108.2**

The AFW Ammonia Truck Load Out cost estimate is included in this report as **Appendix F** and the AECOM Ammonia Distribution Pipeline Estimate in included in **Appendix** .

6.6. Projected Cash Flow

The Project Cash Flow Curve is included in this report as **Appendix G.**

7. PROJECT SCHEDULE

7.1. Project Schedule

Please refer to **Appendix H** for the Level 2 Project Schedule. The Project Schedule is based on EPCM Project execution approach with TEC as the Project Manager. It is based on based on TEC authorization for start of the EPC Pricing phase in July 2015.

The estimated Project Schedule key milestones are:

- Project Authorization – July 2015
- Ammonia License Award – July 2015
- Engineering Award – July 2015
- Environmental Permits Award – December 2016
- Construction Mobilization – January 2017
- Construction Complete – April 2108
- Final Completion – July 2018
- Plant In Service – August 2018

Please note, this preliminary Project Milestone Schedule is based on preliminary indicative process supplier information and current delivery patterns. The durations need to be verified in the EPCM execution phase of the project.

8. APPENDICES

Appendix A	Project Design Criteria
Appendix B	Ammonia Pipeline Feasibility Study and Ammonia Pipeline Routing Drawing
Appendix C	Equipment List
Appendix D	Division of Responsibility Matrix
Appendix E	CAPEX Estimate
Appendix F	Ammonia Truck Load Out Estimate
Appendix G	Cash Flow Curve
Appendix H	Project Schedule

Appendix Process Design Criteria

SITE CONDITIONS

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:						
Revision No.:	A					
Revision Date:	October 20, 2014					

DESIGN AND VERIFICATION CODES

Design Input
CI = Customer Input
SI = AMEC Input
R = Regulatory Requirement
G = Geotechnical Consultants Input
MD = Manufacturers' Data

Principal Design Output
DS = Design & Material Standard/Specfctn
PD = P&ID/P&C/flowsheet
OL = One Line Diagram
LD = Logic Description
PS = Process Functional Specification
SP = Site Plan & Facility Layout
EL = Equipment Layout
ES = Equipment Specification

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

Discipline
Ci = Civil
St = Structural
Ar = Architectural
Me = Mechanical
Pi = Piping
Pr = Process
El = Electrical
In = Instrument & Controls
He = HVAC

Verification Method
Ch = Checking
DR = Design Review
AC = Alternate Calculation
CR = Constructability Review
HA = HAZOP Study
CE = Compare to existing
LT = Lab Testing

All staff members are responsible for ensuring that they are using the correct revision of this document.

Project No.:	**176858**
Project Title:	**176858-RTI Ammonia FEED Study Site Conditions Rev A**
Major Area:	TEC Plant, Polk County, Florida
Discipline:	**Process**
Document Owner:	Bruce Stevens
Project Document No.:	
Revision No.:	October 20, 2014
Revision Date:	

Design Input | Design Output | Discipline | Verification Method | Rev. No.

Local Meteorological Conditions

Local meterological conditions at the Polk Power Station (PPS), located near Tampa, Florida are summarized below.

Elevation of Site

The site elevation in the plant is 144 ft. +/- 1 ft.

Dry Bulb Temperature, Relative Humidity and Cooling Water (Pond) Temperature

The following ambient conditios are used by TEC for design and rating calculations:

a) Dry bulb temperature – impacts MAC and CT
b) Relative humidity – for cooling tower and evaporative cooler design
c) Pond water temperature – for condenser/steam turbine and many auxiliaries

Polk Power Station Ambient Conditions

Case	Ambient Dry Bulb T (°F)	Relative Humidity (%)	Pond Water Intake T (°F)
High T Design	92	53	92
Average T Design	75	85	81
Low T Design	42	78	68
Low Low T Rating	0	50	62
Low T Rating	32	50	62
Iso – Rating	59	65	73
High T Rating	100	35	94

Average T Design conditions will be used for Air Compressor design.

Additionally, for design purposes, the following temperatures will be used.
Ambient Air Temperature: 75°F
Minimum Design Metal Temperature (MDMT): 25°F, 20°F for safety critical equipment.

Barometric Pressure

Atmospheric pressure, psia	14.7

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**176858-RTI Ammonia FEED Study Site Conditions Rev A**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:						
Revision No.:	October 20, 2014					
Revision Date:						

Precipitation

Design precipitation, inch/h	3.1
Mean Annual Precipitation, inch	52.3

Wind Loads

Governing Code	ASCE 7-10
Basic Wind Speed, V	145 mph (3-second gust at 33 ft above ground)
Risk Category	III
Exposure Category	C

Seismic Loads

Governing Code	ASCE 7-10
Site Class	E
Risk Category	III
Importance Factor	1.25
S_s	0.082g (mapped spectral response acceleration at short periods)
S_1	0.032g (mapped spectral response acceleration at a period of 1 second)
S_{DS}	0.137g (design spectral response acceleration at short periods)
S_{D1}	0.075g (design spectral response acceleration at a period of 1 second)
Seismic Design Category	A

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**176858-RTI Ammonia FEED Study Site Conditions Rev A**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:						
Revision No.:	October 20, 2014					
Revision Date:						

APPROVED BY:

Customer	
Project Manager Project Engineer	Gary Messer

Department Manager		Area or Discipline Leader	
Civil		Civil	
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical		Electrical	
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced.

DESIGN CRITERIA AND VERIFICATION PLAN
PROCESS

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

PROJECT SUMMARY	CI		PR	DR	A
This project consists a FEED study to develop a +/- 10% cost estimate of producing Ammonia by utilizing the hydrogen stream from RTI's 1.5 MM SCFH Warm Syngas Cleanup (WGCU) demonstration facility at the TEC Polk Power Station located in Polk County, Florida. The Phase 1 Pre-FEED Study concluded that the Phase 2 FEED study will incorporate: • Clariant's Low Temperature Shift (LTS) and Methanation catalyst processes to enrich hydrogen from RTI's WGCU Steam Generator 501, • BASF's Deoxo Catalyst process to purify TEC's existing DGAN nitrogen, • Ammonia Plant technology with Hydrogen Recovery Unit (HRU) to recycle hydrogen and nitrogen after inerts separation. • A Hydrogen Sulfide (H2S) guard bed utilizing Clariant technology will also be added upstream of the LTS catalyst process. • Finally, a Carbonyl Sulfide (COS) and Arsenic (As) guard bed utilizing Clariant technology will also be added upstream of the LTS catalyst process.					

DESIGN AND VERIFICATION CODES

Design Input	Principal Design Output	Discipline	Verification Method
CI = Customer Input	DS = Design & Material Standard/Specfctn	Ci = Civil	Ch = Checking
SI = AMEC Input	PD = P&ID/P&C/flowsheet	St = Structural	DR = Design Review
R = Regulatory Requirement	OL = One Line Diagram	Ar = Architectural	AC = Alternate Calculation
G = Geotechnical Consultants Input	LD = Logic Description	Me = Mechanical	CR = Constructability Review
MD = Manufacturers' Data	PS = Process Functional Specification	Pi = Piping	HA = HAZOP Study
	SP = Site Plan & Facility Layout	Pr = Process	CE = Compare to existing
	EL = Equipment Layout	El = Electrical	LT = Lab Testing
	ES = Equipment Specification	In = Instrument & Controls	
		He = HVAC	

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

All staff members are responsible for ensuring that they are using the correct revision of this document.

Project No.:	**176858**	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

DESIGN CAPACITY	CI	PD/ DS	PR	DR	A
The LTS unit shall be designed to process 9,040 lbmol/hr of syngas leaving the WGCU's Steam Generator 501 and entering the LTS H2S guard bed with the following composition and process conditions:					

	Lbmol/hr
H2	2935
CO	181
CO2	2232
CH4	6
H2S	2.9E-02
COS	2.3E-03
NH3	2
N2	314
Ar	32
H2O	3339
As	4.4E-03
Se	0
Hg	0
Total Flow	9040
Temperature, F	640
Pressure, psig	340

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The syngas leaving the COS guard bed will be cooled to 380 F before entering the LTS catalyst reactor. The syngas composition leaving the LTS catalyst reactor at Start of Run (SOR) catalyst performance will be:

	Lbmol/hr
H_2	3103
CO	13
CO_2	2399
CH_4	6
H_2S	<0.1 ppmv
COS	<0.1 ppmv
NH_3	0
N_2	314
Ar	32
H_2O	20
As	0
Se	0
Hg	0
Total Flow	5886
Temperature, F	416
Pressure, psig	325

The Hydrogen enriched syngas will then be sent through the remainder of the WGCU process.

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Project Title:	**RTI Ammonia Plant FEED Study**					
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Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

The Hydrogen enriched syngas leaving the WGCU Amine Absorber will be sent to a Methanation catalyst reactor after initially being heated with the following composition and process conditions:

	Lbmol/hr
H2	3090
CO	13
CO2	45
CH4	6
H2S	<0.1 ppmv
COS	<0.1 ppmv
NH3	0
N2	313
Ar	32
H2O	20
As	0
Se	0
Hg	0
Total Flow	3519
Temperature, F	590
Pressure, psig	284

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
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Discipline:	**Process**					
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Project Document No.:	176858-110-DCVP Process					
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The syngas composition leaving the Methanation catalyst reactor with Start of Run (SOR) catalyst performance will be:

	Lbmol/hr
H2	2871
CO	0
CO2	0
CH4	63
H2S	<0.1 ppmv
COS	<0.1 ppmv
NH3	0
N2	313
Ar	32
H2O	123
As	0
Se	0
Hg	0
Total Flow	3403
Temperature, F	780
Pressure, psig	283

A slipstream containing 40 lbmol/h of Hydrogen will be sent from the Methanation reactor outlet to the Deoxo catalyst reactor. This hydrogen amount represents 110 mole % of the stoichometric quantity to react out the 2.5 mole % maximum oxygen in the DGAN nitrogen stream.

The DGAN nitrogen supplied by TEC at 30 psig will be compressed to 270 psig before entering the Deoxo catalyst reactor. The Deoxo catalyst reactor shall be designed to produce 4,150 SCFM of purified nitrogen.

The effluents from the Deoxo reactor and Methanation reactor will be combined so that a hydrogen to nitrogen molar ratio of 2.7 +/- 1% on a molar basis, is maintained by varying the amount of nitrogen. This combined Ammonia Feed stream will be cooled and fed to a Knockout Drum to remove the majority of the water in the stream. The final water content will then be reduced to a maximum of 10 ppm by using a Coalescing Filter followed by parallel Mole Sieve Beds. A slipstream of the Ammonia Feed stream will be heated and recycled through the fouled Mole Sieve Bed to regenerate it.

When fed to the Ammonia process, these raw material streams should generate 380 STPD of Ammonia. Equipment design is based on a Plant Life

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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of 20 years and 8,000 hours operation per year. All processes will be designed so that there is no continuous flaring or continuous venting of any priority pollutants.					
REGULATORY REQUIREMENTS	R	ES			A
Compliance with applicable codes and permits on maximum values for emissions, effluents and noise shall be conducted by TEC					
DESIGN CRITERIA	CI/ SI	PD/ ES	PR	DR /Ch	A
Aspen-Plus Model OSBL equipment shall be designed with process data from an Aspen-Plus model heat and material balances generated from the WGCU Aspen-Plus model updated with information from Clariant for the LTS and Methanation processes and BASF for the Deoxo process using Aspen-Plus simulator. This model will be a Normal Operating Case heat and material balance model based on the SOR catalyst performance for each individual process. ISBL equipment designs will be provided by the technology vendor but will not be included in the overall Aspen-Plus Model. Aspen-Plus heat and material balance models will also be developed for a Design Case and a Maximum Turndown Case. The Design Case heat and material balance model will be based on the maximum flowrate derived from individual equipment sizes after sizing safety factors have been applied. The Maximum Turndown Case heat and material balance model will be based on the minimum flowrate derived from individual equipment being operated at their maximum turndown. Both of these cases will be based on the pieces of equipment which drive the overall plant capacity due to the interdependency of the various pieces of equipment in the process. An End of Run (EOR) Normal Operating Case heat and material balance will also be developed based on the EOR catalyst performance for each individual process.					

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Project Title:	**RTI Ammonia Plant FEED Study**					
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Pressure Vessel Design

- Code: ASME Sec. VIII
- Design Pressure: Operating pressure plus 25 psi or plus 25% whichever is greater.
- Design Temperature: Operating temperature plus 50 °F or minimum 300°F. Minimum design temperature of 25°F, 20°F for safety critical equipment.
- Additional Design Features Reference: AMEC Equipment Specifications for ASME Coded Vessels 168745-110-213
- Vessel sizing criteria:
    - LTS and Methanation provided by Clariant
    - Guard Bed provided by Clariant based on 12 month life and <0.1 H_2S ppm leakage
    - Guard Bed provided by Clariant based on 12 month life and <0.1 COS/As ppm leakage
    - Deoxo provided by PSB Industries/BASF

Heat Exchangers

- Code: ASME Sec. VIII, TEMA "B"
- Design Pressure and Temperature: Same as guidelines above for pressure vessel design.
- References:
    - AMEC Equipment Specifications for Shell and Tube Heat Exchangers 168745-110-203
    - AMEC Equipment Specifications for Air Cooled Exchangers 168745-110-216
- Sizing safety factors: 1.2 x area – see individual heat exchanger specification.
- Fouling factors, ft^2-hr-°F/Btu:

Sour Syngas	0.001
Desulfurized Syngas	0.001
Cooling Water	0.002
Steam Generation	0.001
Steam Condensation	0.0005

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
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Pumps

Sizing Safety Factors:

- Flow: design with no sizing safety factor. However, require large enough casing to accommodate one impeller size larger.
- Head: add 1.15 x friction losses to total head

Compressors

Electrically driven

Sizing Safety Factors: Compressors shall be designed for largest flow rate required:

- From material balance governing case or
- Start-up/stand-by requirements – see design parameters considered in the section Other Design Criteria
- No sparing of compressors
- Design margin target: 120% of max flow unless this flow forces us to a larger compressor frame size
- Driver: Motor

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Line Sizing

- Liquids:
  Piping velocities maximum values listed below; shall be used as a guideline, lower velocities may be considered to reduce pump or compressor horsepower particularly for long and large size lines.
  - Pump suction lines: based on adequate NPSH (9 ft/sec max)
  - Pump discharge lines:

Nominal pipe size	Maximum velocity, ft/sec
3' and less	7.5
4"	10.0
6"	12.5
8"	15.0
10"	17.0
12"	19.0
14"	20.0
16"	21.0
18"	22.0
20"	23.0
24"	24.0

  - Gas or vapor lines (other than steam): 125 ft/sec
  - Liquid-gas (liquid-vapor)mixture lines: 75 ft/sec
  - Steam lines:

Steam Pressure	Pressure drop
30 - 74 psig	0.25 psi/100 ft
100 - 200 psig	0.5 psi/100 ft
425 - 600 psig	1.0 psi/100 ft
900 - 1200 psig	2.0 psi /100 ft

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Control Valves

Sizing Safety Factors:

Control valves shall not be more than 80% open at normal operating conditions and not less than 20% open at maximum turndown conditions.

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Equipment Summary	CI/ SI	PD/ ES	PR	DR /Ch	A

The plant will consist of the following processing units:

- **Low Temperature Shift (LTS)**
  - Heat Exchanger(s)
  - H2S Guard Bed
  - COS/As Guard Bed
  - LTS Catalyst Bed
- **Methanation**
  - Heat Exchanger
  - Methanation Catalyst Bed
- **DGAN Nitrogen**
  - Compressor
  - Deoxo Catalyst Bed
- **Ammonia Feed**
  - Heat Exchangers
  - Water Knockout Drum
  - Coalescing Filter
  - Mole Sieve Bed
    - Regeneration Compressor
    - Regeneration Heat Exchanger
- **mm a Process**
  - Vendor provided Basic Engineering Design Basis and Battery Limits
- **Cooling Tower**
- **Air Compressor for existing TEC Air Separation Unit**

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Discipline:	**Process**					
Document Owner:	Bruce Stevens					
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Revision No.:	F					
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	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Ammonia Plant Feedstock Requirements	MD				A

Ammonia Feed Stream Composition:

Description	Specification
H2	73.2 mol%
N2	24.4 mol%
NH3	0.0 mol%
CH4	1.6 mol%
Ar	0.8 mol%
Total S	≤ 0.1 ppm vol
Total Oxygen Compounds	< 10 ppm vol as atomic oxygen (CO+2CO2+2O2+H2O)
Other Catalyst poisons (Cl, As, etc.)	0 (NIL)
H2/N2 Ratio	2.7 +/- 1% molar
Temperature	122°F
Pressure	250 psig

Utility Consumption Requirements:

Description	Specification
Electrical Power	TBD
Cooling Water Consumption	TBD
Cooling Water Pressure	TBD
Cooling Water Temperature	TBD
Boiler Feed Water	TBD
Boiler Feed Water Pressure	TBD
BFW Temperature	TBD
Natural Gas	TBD
Steam	TBD
Steam Pressure	TBD
Steam Temperature	TBD

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Ammonia Plant Products	MD				A

Liquid Ammonia Product specification:

Description	Specification
Production	380 STPD
Purity	99.9 %wt
Hydrogen	NIL
Nitrogen	≤2 ppmwt
Methane	≤171 ppmwt
Argon	≤7 ppmwt
Water	≤632 ppmwt
Oil	≤100 ppmwt
Iron	≤10 ppmwt
Copper	≤5 ppmwt
Nickel	≤5 ppmwt
Molybdenum	≤5 ppmwt
Chromium	≤5 ppmwt
Pressure	290 psig
Temperature	60°F

Project No.:	**176858**	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project Title:	**RTI Ammonia Plant FEED Study**					
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Cooling Tower	CI	PD	PR	DR	A
Sizing Safety Factor: Cooling Tower will be designed for 110% of the WGCU and Ammonia Plant demand. (Currently based on Polk 2 Combined Cycle 15651 Mechanical Draft Cooling Tower Design Package, to be verified with AMEC vendor.)					
Equipment Design – Others					
Flare Backpressure The normal backpressure of the existing flare system is 2 psig. The maximum backpressure of the existing flare system is 5 psig. The flare system shall be capable of collecting all PSV discharges including Syngas and Pure Ammonia streams. In addition, to prevent flare system misoperation all streams containing NH3 shall be diverted to a separate flare header.					

Cooling tower parameters (within the Cooling Tower row):

Cooling water temperature Delta T, °F	20.0
Outlet water temperature, °F (Maximum cold water temperature)	≤89.4
Ambient wet-bulb temperature, °F	80.0
Inlet wet-bulb temperature, °F	82.0
Ambient dry-bulb temperature, °F	87.8
Drift, maximum percent of inlet water flow	0.0005%
Maximum drift rate (gpm)	0.076
Maximum evaporation rate (gpm)	265.76 (1.76%)
Piping Design Temperature, °F	200
Piping Design Pressure, psig	170
Preliminary Makeup Water Needs (gpm)	1360

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

Utility Specifications from TEC at B.L.

Electrical

See AMEC 176858-141-DCVP Electrical Rev A

Atmospheric Air

Air	Design
Composition	mol%
Carbon Dioxide, CO_2	0.03
Nitrogen, N_2	78.09
Argon, Ar	0.93
Oxygen, O_2	20.95

Battery Limit Conditions

			BATTERY LIMITS PROCESS CONDITIONS			MECHANICAL DESIGN		
SERVICE	**FROM**	**TO**	**Press psig**	**Temp °F**	**Phase**	**Press Psig**	**Temp °F**	**Remarks**
Syngas	RTI SG 501	LTS	343	640	Gas	480	750	
Lean Syngas	RTI aMDEA	Methanation	293	122	Gas	400	250	
NBS (DGAN Nitrogen)	TEC	Compressor	30	100	Gas	150	300	

Notes:

A. Pressures are at grade elevation. Design Temperatures are at TEC Battery Limit.

Onsite Utilities Design Conditions

	BATTERY LIMITS CONDITION (1)		CONDITION AT EQUIPMENT		MECHANICAL DESIGN		
	Press (psig)	**Temp (°F)**	**Press (psig)**	**Temp (°F)**	**Press (psig)**	**Temp (°F)**	**Commodity Code**
BFW							
HP BFW	2,250	550			2685	650	HOH
MP BFW	750	310			1075	650	HOM
Cooling Water(2, 3)							
Supply (new Cooling Tower)	67 (2)	89.4			170	200	CCL
Return	17 (2)	109			170	200	CCL
LP Condensate (4)	NA	NA			120	390	CNL
Fuel							
Natural Gas		Ambient					FGS
Fuel Oil (7)	140-180	Ambient			250	135	FOY
Instrument Air (9)	108	Ambient			150	200	IAS
Steam							

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
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HPS	1645	610	1620	Sat (608)	1885	629	SHP
MPS	395	592	365	582 Sat (440)	500	650	SMP
LPS	48	309	65 (Gen)	335 Sat (312)	120	390	SLP

Notes:
(1) All pressure at grade elevation
(2) Typical steam condensate conductivity is 35 µmohs. Steam condensate can be returned to TEC with acceptable conductivity measurement. The limit to dump to ditch would be 50 µmohs – 75 µmohs.
(3) Boiler Feed Water quality shall be compliant with VGB Guidelines 2nd Edition (VGB-R-450L).
(4) Chlorides in Boiler Blowdown shall be lower than 500 ppbwt.
(5) Instrument air dew point is -40°F.

Additional Cooling Water Information

Primary Raw Water source is reclaimed water. Secondary Raw Water source is well water.

Local Meteorological Conditions

See AMEC 176858-RTI Ammonia FEED Study Site Conditions Rev A

Control Philosophy

See AMEC 92127-K-DCVP-0002 Instrument & Controls Rev A

Design Input: CI/SI | Design Output: LD/ES | Discipline: In | Verification Method: DR

Existing Facility Modifications

No modifications are required for this project. Integration with the WGCU, DGAN nitrogen, steam, cooling water, and supporting utilities will be accomplished with suitable piping tie-points.

Design Input: CI | Design Output: EL | Discipline: PR | Verification Method: DR

Plant Layout

The LTS unit will be located adjacent to the west end of RTI's existing WGS unit. The DGAN Nitrogen Deoxo unit will be located at the TEC DGAN Nitrogen source. The rest of the equipment will be located west of RTI's existing WGCU.

Permitting Requirements

- Modification to the conditions of certification (process and pipeline, may be one or two applications)
- Air construction permit
- Construction stormwater plan
- NPDES modification
- Update to the PSM plan
- Risk management plan
- Possibly DHS permitting / filings

Project No.:	**176858**	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

- ERP permit for the pipeline
- Hazardous waste
- FDOT / USDOT
- CSX

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Plant FEED Study**					
Major Area:	TEC Plant, Polk County, Florida					
Discipline:	**Process**					
Document Owner:	Bruce Stevens					
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Unit of Measurements

Dimension	English System Unit	Abbreviation
Temperature	Degrees Fahrenheit	°F
Pressure	Pound Force per Square Inch Absolute Pound Force per Square Inch Gauge	psia psig
Mass	Pounds Short Tons	lb sT
Volume	Cubic Feet	ft^3
Mass Flowrate	Pound per Hour	lb/h
Molar Flow	Pound Mole per Hour	lbmol/h
Volumetric Flowrate	Standard Cubic Feet per Hour At 14.7 psia and 60 F	SCFH
Density	Pound per Cubic Foot	lb/ft^3
Viscosity	Centipoise	cP
Energy, heat, work, enthalpy	British Thermal Unit	Btu
Power	Watts (electric heaters) Horsepower (for electric Motors)	W hp

Definition of Standard Conditions
14.7 psig and 60°F

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
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Discipline:	**Process**					
Document Owner:	Bruce Stevens					
Project Document No.:	176858-110-DCVP Process					
Revision No.:	F					
Revision Date:	October 20, 2014					

APPROVED BY:

Customer ______________

Project Manager Gary Messer
Project Engineer

Department Manager		Area or Discipline Leader	
Civil		Civil	
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical		Electrical	
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced.

DESIGN CRITERIA AND VERIFICATION PLAN
PIPING

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**Ammonia Feed**					
Major Area:						
Discipline:	**Piping**					
Document Owner:	Eric Hammon					
Project Document No.:	176858-A-0100					
Revision No.:	0					
Revision Date:	12 Sept 2014					

PROJECT SUMMARY

This project consists a FEED study to develop a +/- 10% cost estimate of producing Ammonia by utilizing the hydrogen stream from RTI's 1.5 MM SCFH Warm Syngas Cleanup (WGCU) demonstration facility at the TEC Polk Power Station located in Polk County, Florida. The Phase 1 Pre-FEED Study concluded that the Phase 2 FEED study will incorporate:

- Clariant's Low Temperature Shift (LTS) and Methanation catalyst processes to enrich hydrogen from RTI's WGCU Steam Generator 501,
- BASF's Deoxo Catalyst process to purify TEC's existing DGAN nitrogen,
- Ammonia Plant technology with Hydrogen Recovery Unit (HRU) to recycle hydrogen and nitrogen after inerts separation.
- A Carbonyl Sulfide (COS) and Arsenic (As) guard bed utilizing Clariant technology will also be added upstream of the LTS catalyst process.

The WGC project is also adding a Hydrogen Sulfide (H2S) guard bed utilizing Clariant technology upstream of the WGCU Water Gas Shift reactor. This bed will be designed to prevent poisoning of the LTS catalyst.

DESIGN AND VERIFICATION CODES

Design Input
CI = Customer Input
SI = AMEC Input
R = Regulatory Requirement
G = Geotechnical Consultants Input
MD = Manufacturers' Data

Principal Design Output
DS = Design & Material Standard/Specfctn
PD = P&ID/P&C/flowsheet
OL = One Line Diagram
LD = Logic Description
PS = Process Functional Specification
SP = Site Plan & Facility Layout
EL = Equipment Layout
ES = Equipment Specification

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

Discipline
Ci = Civil
St = Structural
Ar = Architectural
Me = Mechanical
Pi = Piping
Pr = Process
El = Electrical
In = Instrument & Controls
He = HVAC

Verification Method
Ch = Checking
DR = Design Review
AC = Alternate Calculation
CR = Constructability Review
HA = HAZOP Study
CE = Compare to existing
LT = Lab Testing

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**Ammonia Feed**					
Major Area:						
Discipline:	**Piping**					
Document Owner:	Eric Hammon					
Project Document No.:	176858-A-0100					
Revision No.:	0					
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CODES & STANDARDS	R	DS	Pi	Ch	
The Piping Systems shall be fabricated and erected in accordance with the following codes: · ASME B31.1 - Power Piping · ASME B31.3 - Process Piping · Applicable Federal, State & Local Codes					
GENERAL LAYOUT REQUIREMENTS					
Elevation of Site					
The site elevation in the plant is 144 ft. +/- 1 ft.	R	DS	Pi	Dh	
Wind Loads					
Governing Code ASCE 7-10 Basic Wind Speed, V 145 mph (3-second gust at 33 ft above ground) Risk Category III Exposure Category C					
Seismic Loads					
Governing Code ASCE 7-10 Site Class E Risk Category III					

S_s	0.082g (mapped spectral response acceleration at short periods)
S_1	0.032g (mapped spectral response acceleration at a period of 1 second)
S_{DS}	0.137g (design spectral response acceleration at short periods)
S_{D1}	0.075g (design spectral response acceleration at a period of 1 second)

Seismic Design Category A					
Plant Layout					
The LTS unit will be located adjacent to the west end of RTI's existing WGS unit. The DGAN Nitrogen Deoxo unit will be located at the TEC DGAN Nitrogen source. The rest of the equipment will be located west of RTI's existing WGCU.					
Pipe Racks	SI	OT	Pi	Ch	
All process and utility piping shall be located on the lower utility bridge level. All electrical and instrumentation tray shall be located on the top level of the utility bridge. Road clearance will be 15'-6" minimum to BOS.					

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Project No.:	**176858**					
Project Title:	**Ammonia Feed**					
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Project Document No.:	176858-A-0100					
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Revision Date:	12 Sept 2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Utility Stations	CI	OT	Pi	Ch	
Utility Stations consisting of plant air and water shall be located at grade and all elevated floors. Hoses for the utility stations shall be provided by the client. Safety showers/eyewash stations shall be OSHA approved combination eyewash and emergency shower located near hazardous services or materials					
Vents/Drains	CI	SP	Pi	Ch	
Piping design will include high point vents with valves and low point drains with valves where process conditions and/or the piping configuration indicate the need for them on drawings. The piping contractor will be responsible for the addition of any additional vents and/or drains deemed necessary for the flushing and/or start-up of the various piping systems.					
ACCESS & MAINTENANCE CLEARANCE					
The access and maintenance clearance requirements shall be as defined in OSHA standards, but not less than the following: · Maintenance: 2'-6" Minimum · Bottom Of Pipe or Steel Member: 7'-0" Minimum	SI	OT	Pi	Ch	
PIPING SPECIFICATIONS					
Piping & Valving material specifications for the plant tie-in services shall be per the TECO supplied specifications. The remaining process and utility services will be per AMEC pipe specs to match the requirements of the new ammonia feed process.	CI	OT	Pi	Ch	

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Discipline:	**Piping**					
Document Owner:	Eric Hammon					
Project Document No.:	176858-A-0100					
Revision No.:	0					
Revision Date:	12 Sept 2014					

APPROVED BY:

Customer			
Project Manager			
Department Manager		Area or Discipline Leader	
Civil		Civil	
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping	Mike Tatum	Piping	Eric Hammon
Process		Process	
Electrical		Electrical	
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced.

DESIGN CRITERIA AND VERIFICATION PLAN
ELECTRICAL

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI TECO POLK - Ammonia Integration**					
Major Area:	280, 290					
Discipline:	**Electrical**					
Document Owner:	Stephen Santilian					
Project Document No.:	176858-141-DCVP					
Revision No.:	A – Issued for Review					
Revision Date:	18Sep2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
PROJECT SPECIFIC REQUIREMENTS					
The electrical energy for this project will be furnished by an existing station service transformer, XXX-#X, 230kV-13.8kV, rated for ##/## MVA. The tie-in will be accomplished by tapping the existing ####A bus duct to feed a new 15kV metal-clad switchgear. The existing load on XXX-#X is currently ##MVA.					
PROJECT SUMMARY					
A new 15kV metal-clad switchgear will feed two outdoor 13.8kV-4.16kV, 5000/6650 kVA, dry-type MV transformers. These MV transformers will incorporate load break switches with loop feed provisions to serve outdoor 13.8kV-480Y/277V, 2000/2660 kVA, dry-type LV transformers. All four transformers will each feed a new switchgear line-up. The two LV switchgear lineups will each feed a new 480V MCC.					
DESIGN AND VERIFICATION CODES	R		EI		
The design, electrical equipment, materials and details of installation shall comply with the requirements of the latest revisions of the following standards and codes: • National Electrical Code (NEC) • National Electrical Safety Code (NESC) • Institute Of Electrical and Electronic Engineers (IEEE) • National Electrical Manufacturers Association (NEMA) • National Fire Protection Association (NFPA) • American National Standards Institute (ANSI) • Occupational Safety and Health Administration (OSHA) • Applicable State and Local Codes					

DESIGN AND VERIFICATION CODES

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Major Area:	280, 290					
Discipline:	**Electrical**					
Document Owner:	Stephen Santilian					
Project Document No.:	176858 - 141 - DCVP					
Revision No.:	A					
Revision Date:	10Sep2014					

POWER SUPPLY AND DISTRIBUTION					
In general, the following equipment and stated utilization and supply voltages shall be used as the basis for electrical design.					
Primary Supply & Distribution Volts: 13.8 kV Phase: 3 Frequency: 60 HZ	CI	DS	EI	Ch	
Design Loading Capacities (running load as a percentage of capacity) Nominal load factor (running load/connected load) : 70% Unit Substations 80% of base KVA rating Medium voltage MCC's 80% of bus rating Spare Starters 10% Spare Space 10% Low voltage MCC's 80% of bus rating Spare Starters 10% Spare Space 10% Panelboards 70% of bus rating Spare Breakers 10% Spare Space 20%	SI	DS	EI	Ch	
Power Factor Correction Capacitors ( ) Yes (X) No Locations ( ) Medium Voltage Bus ( ) As part of harmonic filter ( ) Banks on secondary side of unit substations Individual motors rated ____________hp and larger ( ) In MCC ( ) On top of MCC ( ) At Motor			EI		
Station Battery (X) New ( ) Existing (X) 125 volts dc ( ) 250 volts dc	CI	DS	EI	Ch	
Unit Substations: Primary Disconnecting Device ( ) Fused Switch (X) Non-Fused Switch ( ) Circuit breaker ( ) Close-coupled ( ) Separately-mounted line-up Location: ( ) Indoors (X) Outdoors	CI	DS	EI	Ch	

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Document Owner:	Stephen Santilian					
Project Document No.:	176858 - 141 - DCVP					
Revision No.:	A					
Revision Date:	10Sep2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Transformer:	CI	DS	EI	Ch	

Location: ( ) Indoors (X) Outdoors

Primary Voltage
Primary Unit Sub: 13.8 kV
Secondary Unit Sub: 13.8 kV

Secondary Voltage
Primary Unit Sub: 4.16 kV
Secondary Unit Sub: 480V

Primary Connections
Primary Unit Sub: (X) Delta ( ) Wye
Secondary Unit Sub: (X) Delta ( ) Wye

Secondary Connections
Primary Unit Sub: ( ) Delta (X) Wye
Secondary Unit Sub: ( ) Delta (X) Wye
( ) Alternate for transformers feeding drives

Impedance
Primary Unit Sub: 5.75%
Secondary Unit Sub: 5.75%

Fan Cooling
Primary Unit Sub: (X) Future ( ) Installed
Secondary Unit Sub: (X) Future ( ) Installed

Efficiency
Primary Unit Sub: ( ) Standard (X) High
Secondary Unit Sub: ( ) Standard (X) High

Cooling System
(X) Conventional Dry Type ( ) Cast coil ( ) Oil
( ) Silicone fluid ( ) Other

Primary Subs. System Grounding, Feeding:	MCC's	Drive Systems
(X) Low resistance (400 A, 10 seconds):	(X)	( )
( ) High resistance (___ A, ___ seconds):	( )	( )

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Criteria	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Secondary Subs. System Grounding, Feeding: MCC's / Drive Systems ( ) Ungrounded — MCC's ( ) — Drive Systems ( ) • ( ) Ground Detection Lights • ( ) Alarm ( ) PLC Input (X) Solidly grounded — MCC's ( ) — Drive Systems ( ) • (X) Neutral Overcurrent Relay ( ) High resistance • ( ) Ground Detection System: — MCC's ( ) — Drive Systems ( ) * Pulsing Type — MCC's ( ) — Drive Systems ( ) * Non-Pulsing Type — MCC's ( ) — Drive Systems ( ) • ( ) Alarm ( ) PLC Input	SI	DS	EI	Ch	
Secondary-Side Switchgear Location: ( ) Indoors ( ) Outdoors Close-Coupled ( ) Yes (X) No	CI	DS	EI	Ch	
Medium Voltage Switchgear: Construction: ( ) Drawout ( ) Stationary Bus Material: ( ) Copper ( ) Aluminum Breakers: ( ) Fused ( ) Non Fused Main Breaker: ( ) Yes (X) No Feeder Breaker Ratings: Nominal MVA Rating (X) 250 MVA ( ) 350 MVA Continuous Current <u>1200A</u> Feeder Breaker Relaying (X) Solid-State ( ) Electro-Mechanical • ( ) Self-powered • (X) 125 VDC ( ) Single-Phase Relays ( ) Three-Phase Relays Feeder Breaker Metering ( ) Solid-State ( ) Electro-Mechanical ( ) Discrete Meters ( ) Multi-Meter Control voltages: • Close circuit: ( ) 230 VAC ( ) 125 VDC • Trip circuit: ( ) 230 VAC ( ) 125 VDC Control power source: ( ) Capacitor trip device (X) Station battery ( )UPS					

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Document Owner:	Stephen Santilian					
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<u>Low Voltage Switchgear</u>

Type: ( ) Switchboard (X) Metal-enclosed switchgear

Short-circuit rating:	(X) 65 kA	( ) 85 kA	( ) 100 kA
Construction:	(X) Drawout	( ) Stationary	
Bus Material:	(X) Copper		( ) Aluminum
Breakers:	( ) Fused		( ) Non Fused
Main Breaker:	( ) Yes		(X) No

Feeder Breakers:

• Type:	(X) Air-break		( ) Insulated case	( ) Molded case
• Frame size:	( ) 800 A			( ) 1600 A
• Current Sensor:	( ) 800 A		( ) 1200 A	( ) 1600 A
• Trip Unit:	(X) LS	(X) I^2t function	(X) G	( ) Targets
• Detection:	(X) Solid State		( ) Thermal Magnetic	

<u>Installation</u>

Primary Switch	( ) Indoors	(X) Outdoors
Transformers	( ) Indoors	(X) Outdoors
Switchgear	(X) Indoors	( ) Outdoors
Transformer Rooms:	( ) Ventilated	( ) Air Conditioned
Electric rooms:	(X) Air Conditioned	(X) Humidity control

Low Voltage Motor Control Centers	CI	DS	EI	Ch	

NEMA Enclosure

(X) 1A	( ) 7	( ) 12
( ) 3R	( ) 9	

NEMA Class

( ) I (X) II ( ) III

NEMA Type

( ) A (X) B ( ) C

Main Disconnect

(X) None ( ) Circuit Breaker ( ) Fused Switch

Main Bus continuous current rating::

( ) 600 A ( ) 800 A (X) 1200 A ( ) 1600 A ( ) 2000 A

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Revision No.:	A					
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Vertical Bus continuous current rating: ( ) 300 A (X) 600 A					
Ground Bus Locations: ( ) Top (X) Bottom ( ) Vertical ( )Unit					
Interrupting current rating: ( ) 22 kA ( ) 42 kA (X) 65 kA ( ) 100 kA					
Bus Material: (X) Copper ( ) Aluminum ( ) Tin-plated ( ) Silver-plated					
Control Voltage: (X) 120 VAC ( ) Separate Source ( ) From PLC cabinet (X) Individual Transformers ( ) Main MCC Control Transformer					
Starter Disconnect: ( ) Thermal-Magnetic C.B's for starter sizes _5 (X) Magnetic Only C.B's for starter sizes 1 thru 4 ( ) Fused Switch					
Feeder Disconnects: (X) Thermal-Magnetic C.B's ( ) Fused Switch					
Overload Relays: (X) Solid-state ( ) Electro-mechanical					
Arrangement: (X) Front Only ( ) Front and Rear					
Current Signals (X) CT's ( ) Transducers ( ) Riley Current Sensors					
Miscellaneous Motor Control Information a. Individual controllers ( ) Permitted for single-phase applications only ( ) For three-phase applications in remote location ( ) In the following areas b. Pushbuttons and other control devices locations ( ) Local ( ) Panel (X) Starter compartment door					
Special Requirements (list): Off/On pilot lights on starter doors					
General Motor Control Philosophy Hardwired DCS I/O					

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Medium Voltage Motor Control Centers	CI	DS	EI	Ch	
Construction: ( ) 1 High (X) 2 High ( ) 3 High					
NEMA Enclosure (X) 1A ( ) 3R ( ) 12					
Power Bus continuous current rating: ( ) 1200 A (X) 2000 A ( ) 3000 A Power Bus bracing: <u>40 kA</u> Minimum contactor rating: ( ) 200 A (X) 400 A					
Control Power (X) 120 V (X) Individual Transformers ( ) From PLC cabinet					
(X) Solid-State Motor Protection					
Synchronous Motor Excitation ( ) Static Excitation - Mounted Remote ( ) Static Excitation - MCC Mounted ( ) Common Excitation Bus ( ) Brushless Excitation					

Motors-Low Voltage	CI	DS	EI	Ch	
Below ½ H.P. (X) 120 Volts AC, Single-Phase					
From 1/2 H.P. to 200 H.P. (X) 460 VAC ( ) 575 VAC					
Efficiency: ( ) Standard (X) Premium					
Enclosure: ( ) TENV ( ) Standard Open ( ) Explosion Proof (X) TEFC ( ) TEAO					
Insulation: (X) Class B ( ) Class F					
Temperature Rise: ( ) Class B (X) Class F					
Service Factor: ( ) 1.0 (X) 1.15					
Heater: ( ) Space ( ) Winding (X) None					

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Above 200 H.P. ( ) 2300 VAC (X) 4160 VAC ( ) Other					
Efficiency: ( ) Standard (X) High					
Enclosures (X) TEFC ( ) Open Drip-Proof Sealed ( ) Weather Protected Type 1 (X) Weather Protected Type II ( ) Explosion Proof Application notes: ____________________	BC	BC	EL		
Insulation: (X) Class B ( ) Other					
Temperature Rise: ( ) Class B (X) Class F					
Service Factor: (X) 1.0 ( ) 1.15					
RTD's: (X) Stator windings (X) Bearings Application notes: For motors 500 HP and above.					

AC Variable Frequency Drives	CI	DS	EI	Ch	
Input Voltage (VAC, 3Ø) ( ) 208 or 240 (X) 480 ( ) 600 ( ) 2400 ( ) 4160 ( ) 13,800					
NEMA Enclosure (X) 1A ( ) 3R ( ) 7 ( ) 9 ( ) 12					
Control Features (X) Single Motor ( ) Multi Motor ( ) Isolation Transformer ( ) Dynamic Braking (X) Output Filters (X) 120 V control (X) Analog input (X) Analog output ( ) Control voltage from PLC cabinet					

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Major Area:	280, 290					
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Document Owner:	Stephen Santilian					
Project Document No.:	176858 - 141 - DCVP					
Revision No.:	A					
Revision Date:	10Sep2014					

ELECTRICAL INSTALLATION	CI	DS	EI	Ch	
Wiring Methods	CI	DS	EI	Ch	
Medium Voltage Feeders (X) Armored cable in tray ( ) Bus duct ( ) Single conductors in conduit ( ) Multi-conductor cable in tray ( ) Preassembled aerial cable					
Medium Voltage Motor Feeders (X) Armored cable in tray (X) Multi-conductor cable in tray ( ) Single conductors in conduit					
Low Voltage Feeders ( ) Armored cable in tray ( ) Cable in conduit (X) Nonarmored cable in tray ( ) Single conductors in conduit					
Low Voltage Motor Feeders ( ) Armored cable in tray (X) Cable in conduit (X) Nonarmored cable in tray ( ) Single conductors in conduit Application notes: ________________________________					
Control Wiring ( ) Armored cable in tray ( ) Cable in conduit (X) Nonarmored cable in tray ( ) Single conductors in conduit					
Instrument Signal Wiring (Analog) ( ) Armored cable in tray ( ) Cable in conduit (X) Nonarmored cable in tray ( ) Other					

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI TECO Polk - Ammonia Integration**					
Major Area:	280, 290					
Discipline:	**Electrical**					
Document Owner:	Stephen Santilian					
Project Document No.:	176858 - 141 - DCVP					
Revision No.:	A					
Revision Date:	10Sep2014					

Electrical Raceway and Cable Tray	CI	DS	EI	Ch	
Rigid Conduit (X) Galvanized Rigid Steel ( ) Aluminum ( ) Electrical Metallic Tubing (EMT) ( ) PVC Coated Galvanized (X) Minimum Size: 3/4"					
Underground Conduit - Direct Buried (X) Rigid PVC - Schedule 40 ( ) Rigid PVC - Schedule 80 ( ) Galvanized Rigid Steel (X) Minimum Size: 2"					
Cable Trays ( ) PVC Coated ( ) Fiber Glass (X) Aluminum ( ) 4" Side rail (X) 6" Side rail ( ) Galvanized Steel ( ) Stainless Steel Power cables: Ladder with 9 inch rung spacing Control cables: Ladder with 9 inch rung spacing Instrument cables: • ( ) Ladder with ___ inch rung spacing • ( ) Ventilated trough with ___ inch rung spacing Tray covers: ( ) Outdoors ( ) Indoors where exposed to falling debris					

Wire and Cable	CI	DS	EI	Ch	
15kV Cable Insulation Type: ( ) Cross-linked Polyethylene (X) Ethylene Propylene Armoring: (X) IAC ( ) CLX (X) Aluminum Armor ( ) Galv. Armor Jacket: (X) PVC (X) Red ( ) Other Conductors: (X) Copper ( ) Aluminum Construction: ( ) Single-conductor (X) Multi-conductor					
5 KV Cable Insulation Type: ( ) Cross-linked Polyethylene (X) Ethylene Propylene Armoring: (X) IAC ( ) CLX (X) Aluminum Armor ( ) Galv. Armor Jacket: (X) PVC (X) Yellow Conductors: (X) Copper ( ) Aluminum					

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Revision No.:	A					
Revision Date:	10Sep2014					

Construction: ( ) Single-conductor (X) Multi-conductor ( ) Nonshielded (X) Shielded					
600 Volt Multi-conductor Cable Type: (X) TC ( )MC ( )Other Insulation type: ( )RHH-RHW-2 (X) XHHW-2 ( )THHN-THWN-2 Insulation Material: (X) Cross-linked Polyethylene ( ) Ethylene Propylene (X) Polyvinyl Chloride w/Nylon jacket Armoring: (X) IAC ( ) CLX ( ) Aluminum Armor ( ) Galv. Armor Jacket: (X) PVC (X) Black ( ) Other Conductors: (X) Copper ( ) Aluminum Application Notes:					
600 Volt Single-Conductor Cable Insulation type: ( )RHH-RHW-2 (X) XHHW-2 ( )THHN-THWN-2 Insulation Material: (X) Cross-linked Polyethylene ( ) Ethylene Propylene (X) Polyvinyl Chloride w/Nylon jacket Conductors: (X) Copper ( ) Aluminum 600 Volt Multi-conductor Control Cable Insulation type: ( ) RHH-RHW-2 (X) XHHW-2 ( )THHN-THWN-2 Insulation type: (X) Cross-linked Polyethylene ( ) PVC w/Nylon jacket (X) PVC ( ) Other Overall Jacket: (X) PVC ( ) CPE ( ) ________________					
Multi-conductor Shielded Signal Cable NEC Type: ( ) TC (X) PLTC ( ) ITC Jacket Material: (X) PVC ( ) CPE					

LIGHTING	CI	DS	EI	Ch	
High Bay (X) Metal Halid ( ) High Pressure Sodium ( ) Other					
Low Bay ( ) High Pressure Sodium (X) Metal Halide (X) Fluorescent ( ) Other					
Emergency (X) Battery Pack Units ( ) Gas Generator System ( ) Central Battery Unit ( ) Diesel Generator ( ) UPS					

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Revision Date:	10Sep2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
Voltage (X) 480Y/277 Volts (X) 208Y/120 Volts ( ) Other					
Lighting Panelboards (X) Circuit Breaker Type 3 pH, 4W, 480/277V (X) Bolt On ( ) Plug In (X) Circuit Breaker Type 3 pH, 4W, 208/120V (X) Bolt On ( ) Plug In ( ) Circuit Breaker Type 1 pH, 3W, 120/240V ( ) Bolt On ( ) Plug In ( ) Other (X) Main Breaker (X) In Panel ( ) Remote					
Distribution Panelboards (X) Circuit Breaker Type 3 pH, 4W, 480/277V (X) Bolt On ( ) Plug In (X) Circuit Breaker Type 3 pH, 4W, 208/120V (X) Bolt On ( ) Plug In ( ) Circuit Breaker Type 1 pH, 3W, 120/240V ( ) Bolt On ( ) Plug In ( ) Other (X) Main Breaker (X) In Panel ( ) Remote					
Lighting Panelboard Feeder From: (X) MCC ( ) Load Center					
Distribution Panelboards Feeder From (X) Three Phase Dry Type Transformers ( ) Utility Supply ( ) Motor Control Center ( ) Other					
Lighting Foot Candle Levels Operating Areas __3__ Offices _________ Basement Areas _________ Electrical Rooms __50__ Control Room _________ Storage Rooms _________ Transformer rooms ________					
Plug and Receptacle For Fixtures: (X) Yes ( ) No					

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GROUNDING AND LIGHTNING PROTECTION	CI	DS	EI	Ch	
Method (X) Concrete Footings, Pilings and Rebar (X) Copper Ground Mat (X) Copper Clad Steel Rods					
Grounding Conductor ( ) Insulated Copper (X) Bare copper					
Connection Type ( ) Bolted (X) Compression -above ground (X) Welded -below ground					
Maximum Allowable Ground Resistance <u>25 ohms</u>					
Lightning Protection: (X) Yes ( ) No Application notes: <u>New structures will be protected via traditional lightning rods and down comer cables.</u>					

MISCELLANEOUS	CI	DS	EI	Ch	
In-Plant Communication Systems ( ) Bell System Telephone ( ) Closed Circuit TV ( ) Plant Owner Telephone (X) Fire Alarm System ( ) FM Radio ( ) Other (X) Paging/Intercom					
Heat Tracing System ( ) Steam (X) Electric					
HAZARDOUS (CLASSIFIED) AREAS					
Are any areas hazardous (classified) due to the possible presence of flammable vapors, liquids or dust? (X) Yes ( ) No					
Class 1, Division 2, Groups B, C, and D.					

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Discipline:	**Electrical**					
Document Owner:	Stephen Santilian					
Project Document No.:	176858 - 141 - DCVP					
Revision No.:	A					
Revision Date:	10Sep2014					

APPROVED BY:

Customer	RTI
Project Manager Project Engineer	Gary Messer

	Department Manager		Area or Discipline Leader
Civil		Civil	
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical	Bruce Cantrell	Electrical	Stephen Santilian
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced

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		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI/TEC Ammonia FEED Study**					
Major Area:	Syngas					
Discipline:	**Instrument & Controls**					
Document Owner:	Neal Fedak					
Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

PROJECT SPECIFIC REQUIREMENTS					
Provide I&C Design Engineering and Documentation to support the addition of Ammonia production to the current Syngas production facility. Revise the existing ABB DCS by adding I/O modules and other devices as required to facilitate the control of the Ammonia system.					
PROJECT SUMMARY					
The Syngas plant will be revised by the addition of necessary equipment to produce, store and transport Ammonia. A completely integrated control system based on an ABB Symphony DCS will be provided for data acquisition, regulatory control, discrete logic processing, alarms, current trends, historical trends, event logs, reports and historical data archiving. Ethernet communications interfaces shall be provided that will support communications between the process controller and the ammonia production vessels and compressors furnished as vendor packages. AMEC I&C design responsibilities include supplying Instrument Index, Instrument Specifications, Loop Diagrams, Installation Details, Location Drawings and Cable Schedule. Additionally, Operation Narratives and Complex Loop Narratives will be provided as necessary to assist in DCS Configuration. The ammonia production portion of the plant will utilize the existing ABB DCS by adding required I/O modules and other items as required. Configuration services will be provided by PASS, as in the current facility. The Triconix system will be expanded as required to incorporate the Ammonia system.					

DESIGN AND VERIFICATION CODES

Design Input
CI = Customer Input
AI = AMEC Input
R = Regulatory Requirement
G = Geotechnical Consultants Input
MD = Manufacturers' Data

Principal Design Output
DS = Design & Material Standard/Specfctn
PD = P&ID/P&C/flowsheet
OL = One Line Diagram
LD = Logic Description
PS = Process Functional Specification
SP = Site Plan & Facility Layout
EL = Equipment Layout
ES = Equipment Specification

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

Discipline
Ci = Civil
St = Structural
Ar = Architectural
Me = Mechanical
Pi = Piping
Pr = Process
El = Electrical
In = Instrument & Controls
He = HVAC

Verification Method
Ch = Checking
DR = Design Review
AC = Alternate Calculation
CR = Constructability Review
HA = HAZOP Study
CE = Compare to existing
LT = Lab Testing

All staff members are responsible for ensuring that they are using the correct revision of this document.

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI/TEC Ammonia FEED Study**					
Major Area:	Syngas					
Discipline:	**Instrument & Controls**					
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Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

	Design Input	Design Output	Discipline	Verification Method	Rev. No.
DESIGN AND VERIFICATION CODES	R	DS	IN	CH	
The design, equipment, materials and details of installation shall comply with the requirements of the latest revisions of the following standards and codes: • National Electrical Code (NEC) • International Society of Automation (ISA) • Institute Of Electrical and Electronic Engineers (IEEE) • National Electrical Manufacturers Association (NEMA) • National Fire Protection Association (NFPA) • American National Standards Institute (ANSI) • Occupational Safety and Health Administration (OSHA) • Local Codes					
CONTROL SYSTEMS	CI	DS	IN	CH	
DCS System • Manufacturer — ABB • System Name — Symphony • Existing System — ABB • How Long Installed — TBD • System Architecture Dwg — Revised • System Updates — TBD • System Configuration Printout — Design documents • Other Equipment Interfaces — Invensys Triconix • Control Room — Existing • Control Room Computer Floor — TBD • Rack Room — In Electrical Building • Rack Room Computer Floor — No • Computer Floor Access — TBD					

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• Operator Stations Required	Yes, (use existing)					
• Operator Station Display	Operating Graphics					
• Quantity Of Operator Displays	Use existing					
• Data Highway	ModBus/Ethernet, TBD					
• Controller Type	Processor BRC410					
• How many controllers required	TBD					
• Redundancy Required	Standard					
• DCS Rack Locations	Electric Building					
• DCS Rack Type	Processor frt, I/O frt/bk					
• How many racks	4					
• I/O Redundancy Required	No					
• Engineering Station	(1) - One in Control Room					
• Prints, Loggers, Videos, Copiers	1 B&W, 1 Color, 1 logging					
• DCS System Data Loggers	Yes, TBD					
• DCS Furniture for others	Existing					

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		Design Input	Design Output	Discipline	Verification Method	Rev. No.
ESD System		CI	DS	IN	CH	
• Manufacturer	Invensys					
• System Type/Series	Triconix					
• How many required	One					
• Existing System	Triconix ESD					
• How Long Installed	TBD					
• System Architecture Drawing	Later					
• System Updates	TBD					
• Other Equipment Interfaces	DCS					
• PLC CPU Location	Electrical Building					
• I/O Types (1771, SLC, etc.)	TBD					
• I/O Mounting Method	Cabinet					
• I/O Racks	Yes, 2					
• I/O Rack Location	Electrical Building					
• HMI Interface Software	Included					
Application Notes:						
DCS/ESD POWER SYSTEM		MD	DS	IN	CH	
DCS System						
• DC Power Supply	Mfg Std					
• Redundant Power Supply	Yes					
• Battery Back-Up	UPS					
• Battery Back-Up Location	Electrical Building					

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Project No.:	**176858**					
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• Uninterruptible Power Supply	TBD					
• If UPS is used, what is on UPS?	CPUs, I/O racks					
ESD System						
• DC Power Supply	Mfg Std					
• Redundant Power Supply	Yes					
• Battery Back-Up	UPS					
• Battery Back-Up Location	Electrical Building					
• Uninterruptible Power Supply	TBD					
SYMBOLOGY/NUMBER SYSTEM		CI	DS	IN	CH	
Instrument Symbols	ISA					
Loop Numbering System	TEC Specification					
Instrument Tag Order	Plant, Area, Function, Seq					
Field Instrument Tagging	Stainless Steel					
Engineering Units	English					
MEASUREMENT/DISPLAY STANDARDS		CI	DS	IN	CH	
LOCAL MEASUREMENT INDICATION (Indicating Xmtr, Not Req'd., Special-example)	On Transmitter					
FLOW						
• Air	SCFM					
• Natural Gas	SCFM					
• Syngas	SCFH					

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Project No.:	**176858**					
Project Title:	**RTI/TEC Ammonia FEED Study**					
Major Area:	Syngas					
Discipline:	**Instrument & Controls**					
Document Owner:	Neal Fedak					
Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
• Other (specify) • Press/Temp Compensation	 Yes					
LIQUIDS • Acid • Condensate • Water • Other (specify)	 GPM GPM GPM, LBS/HR					
STEAM Press /Temp Compensation	LB/HR Yes					
LEVEL	0-100%					
PRESSURE	PSIG					
TEMPERATURE	DEG F					
VACUUM	IN HG, PSIA					

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Project No.:	**176858**					
Project Title:	**RTI/TEC Ammonia FEED Study**					
Major Area:	Syngas					
Discipline:	**Instrument & Controls**					
Document Owner:	Neal Fedak					
Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

DOCUMENTATION						
A. Instrument Index	Yes	MD	DS	IN	CH	
B. Loop Sheets	Yes	MD	DS	IN	CH	
C. Instrument Specifications	Yes	MD	DS	IN	CH	
D. Logic Diagrams	No	CI	DS	IN	CH	
E. SAMA Diagrams	No	CI	DS	IN	CH	
F. Interlock Descriptions or Loop Functional Descriptions	Yes	MD	DS	IN	DR	
F. ESD/DCS I/O Connections	Yes	MD	DS	IN	CH	
G. DCS Architecture Drawings	Vendor	MD	DS	IN	CH	
H. ESD Architecture Drawings	Vendor	MD	DS	IN	CH	
I. DCS Equip Pwr, Gnd., Comm Cabling	Yes	MD	DS	IN	CH	
J. ESD Communication Cabling	Yes	MD	DS	IN	CH	
K. Panel/Cabinet Drawings	Vendor	CI	DS	IN	DR	
L. Control/Rack Room Layouts	No	CI	DS	IN	CH	
M. Construction Specifications	No	CI	DS	IN	CH	
N. Installation Details	Yes	CI	DS	IN	CH	
O. Special Documentation (Give Types)	N/A					
FINAL CONTROL ELEMENTS - SIZING CALCULATIONS W/SPEC. SHEETS PREFERRED.		AI	DS	IN	CH	
Flow Control Valve	Fisher					
I/P Converter, Positioners	Fisher / Hart					
Electric Valve Actuator	EIM, On valve					
E-H Actuator	EIM					
Pneumatic ¼ turn Actuator	El-o-Matic					

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Revision Date:	9/19/2014					

Control Valve Type vs. Service Application Gases • Air • Natural Gas • Others (specify) Liquids • Acid • Water • Others (specify)	 V-Ball Globe, V-Ball Globe, V-Ball V-Ball Globe, Butterfly, V-Ball TBD					
Available Air Pressure (Maximum/Minimum)	 120/80 psig					
Available Instrument Air Pressure (Maximum/Minimum)	 120/80 psig					
INSTRUMENTS						
ANALYZERS Conductivity • Model No. • Type pH/ORP (Manufacturer) Model No. • Type Other (Manufacturer) • Model No. • Type	 Rosmount TBD TBD TBD Yokogawa TBD TBD TBD Yokogawa					

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PH (Manufacturer) • Model No. • Type	Yokogawa					
CAPACITANCE LEVEL DEVICES • Model No.	TBD					
CONTROL PANEL/RACKS	Vendor specific					
FILTER REGULATORS Model No. Type Purchased Pre-piped, loose, etc.	TBD					
FLOW ELEMENTS, ORIFICES/NOZZLES (Manufacturer) Model No. Type Nozzles	TBD Daniel					

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FLOW ELEMENTS, MAG. FLOWMETERS	Rosemount					
Model No.						
Type						
Electrode Material	As Req'd					
Cable	With Meter					
Mounting	Remote					
Accessories	As Req'd					
Other features	Hart					
FLOW ELEMENTS, THERMAL MASS	Rosemount					
FLOW ELEMENTS, ROTAMETER	ABB					
LIMIT SWITCHES (Valves)	TBD					
(Manufacturer)	Topworx GO					
Model No.						
Type						
Purchased	With Valve					
Voltage (120 VAC, 24 VDC, etc.)						
MANIFOLDS	TBD					
(Manufacturer)						
Model No.						
Purchased						
PRESSURE GAUGES	Ashcroft					
Model No.						
Type	4 in					
FLOW						
Magnetic	Rosemount					
Thermal	Rosemount					
Model No.	TBD					

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Document Owner:	Neal Fedak					
Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

SIGNAL CONDITIONERS	TBD					
Model No.						
Type	Rack/DIN Rail					
SOLENOID VALVES	ASCO					
Model No.						
Materials	As required by process					
Purchased	With Valve					
Voltage						
SPEED SWITCHES / TRANSMITTERS	TBD					
Model No.						
Type	Pulse Pick-Up					
SWITCHES						
Pressure	SOR					
Model No.						
Mounting						
Level						
	Drexelbrook					
Model No.						
Temperature	TBD					
Model No.						
Type						
LEVEL						
Ultrasonic	Omartvega, Rosemount					

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Discipline:	**Instrument & Controls**					
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Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

Capacitance Float Submersible Radar Model No.	Do not use KARI Rosemount Omartvega, Rosemount TBD					
CCTV SYSTEM Model No.	TBD					
TEMPERATURE Switch. Indicator. RTD Model No.	 Ashcroft Ashcroft Ashcroft TBD					
THERMOMETERS Model No. Type	Ashcroft 5" Every Angle					
PRESSURE Differential and Gauge Switch Gauge	 Rosemount SOR Aschroft					
VORTEX FLOWMETERS Model No. Smart, FFb, Hart, etc.	Rosemount Hart					
Installation						
IMPULSE LINES	304SS	CI	DS	IN	CH	

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		Design Input	Design Output	Discipline	Verification Method	Rev. No.
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Discipline:	**Instrument & Controls**					
Document Owner:	Neal Fedak					
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TUBE FITTINGS						
Manufacturer	Parker					
Type	Compression					
HEAT TRACING	Electric					
Limits						
H/T Enclosures						
Manufacturer	TBD					
INDIVIDUAL AIR SUPPLIES	304 SS					
INSTRUMENT AIR BRANCH HEADERS	304 SS					
CONTROL PANELS						
PANEL TERMINAL BLOCKS						
Fused	TBD					
Non Fused	TBD					
PUSHBUTTONS	TBD					
RELAYS	TBD					
FUSES	TBD					

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Project Title:	**RTI/TEC Ammonia FEED Study**					
Major Area:	Syngas					
Discipline:	**Instrument & Controls**					
Document Owner:	Neal Fedak					
Project Document No.:	92127-K-DCVP-0002					
Revision No.:	A					
Revision Date:	9/19/2014					

APPROVED BY:

Customer	RTI/TEC		
Project Manager	Gary Messer		
Department Manager		Area or Discipline Leader	
Civil		Civil	
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical		Electrical	
Control Systems	Mike Norris MN	Control Systems	Neal Fedak NF
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced.

DESIGN CRITERIA AND VERIFICATION PLAN
STRUCTURAL

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		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Integration FEED**					
Major Area:						
Discipline:	**Structural**					
Document Owner:	Marlon Will					
Project Document No.:	176858-S-DCVP					
Revision No.:	A (for Approval)					
Revision Date:	30-September-2014					

PROJECT DESCRIPTION This project consists of a FEED study to develop a +/- 10% cost estimate for producing ammonia by utilizing the hydrogen stream from RTI's 1.5 MM SCFH Warm Syngas Cleanup (WGCU) demonstration facility at the TEC Polk Power Station located in Polk County, Florida. **STRUCTURAL SCOPE** **OUTSIDE BATTERY LIMITS (OBL):** LOW TEMPERATURE SHIFT (LTS) COOLING TOWER METHANATION AREA AMMONIA STORAGE AREA PIPE BRIDGE **INSIDE BATTERY LIMITS (IBL):** AMMONIA PLANT (AMMONIA SYNTHESIS AREA) COMPRESSOR BUILDING (INCLUDING EXTERNAL COOLERS)	CI	SA	St	Ch	

DESIGN AND VERIFICATION CODES

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G = Geotechnical Consultants Input
MD = Manufacturers' Data

Principal Design Output
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PS = Process Functional Specification
SP = Site Plan & Facility Layout
EL = Equipment Layout
ES = Equipment Specification

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

Discipline
Ci = Civil
St = Structural
Ar = Architectural
Me = Mechanical
Pi = Piping
Pr = Process
El = Electrical
In = Instrument & Controls
He = HVAC

Verification Method
Ch = Checking
DR = Design Review
AC = Alternate Calculation
CR = Constructability Review
HA = HAZOP Study
CE = Compare to existing
LT = Lab Testing

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Integration FEED**					
Major Area:						
Discipline:	**Structural**					
Document Owner:	Marlon Will					
Project Document No.:	176858-S-DCVP					
Revision No.:	A					
Revision Date:	30-September-2014					

PROJECT SPECIFIC REQUIREMENTS					
Future Expansion • No future expansion is considered.	CI		St	Ch	
Fire Rating • Fire Rating is not within the Structural scope of work for the project.	CI		St	Ch	
Constructability • Pipe bridges will be designed to include a splice between the first and second tiers to facilitate installation of the piping and cable trays on the ground and then erected into place as a single lift.	CI		St	CR	
CODES, STANDARDS, AND DESIGN GUIDELINES					
General • 2010 Florida Building Code • ASCE 7-10, as referenced by the Florida Building Code • OSHA 29 CFR Part 1910, latest edition • TECO Design Criteria, Section 200, Civil/Structural/Architectural/Geotechnical	R/ CI	SA/ CS	St	Ch	
Concrete • 2010 Florida Building Code, Chapter 19 • ACI 318-08, "Building Code Requirements For Structural Concrete", as referenced by the Florida Building Code • ACI 350-06, "Code Requirements For Environmental Engineering Concrete Structures and Commentary" (for water retention structures)	R	SA/ CS	St	Ch	
Metals • AISC 360-05, "Specification for Structural Steel Buildings" (ASD Provisions) • RCSC-04, "Specification for Structural Joints using ASTM A325 or A490 Bolts" • AWS D1.1-04 "Structural Welding Code - Steel"	R	SA/ CS	St	Ch	
Geotechnical • Foundation design will be based on the Geotechnical Report, "Tampa Electric Facility Development, East of SR 37 North of CR 674, Polk County, Florida" by Professional Service Industries, Inc, PSI Project No. 0775-1248 dated January 31, 2012.	G	SA	St	Ch	
Design Guidelines • ACI 318-08, Anchoring to Concrete, for Anchor Bolt Design • Factory Mutual Global - Property Loss Prevention Data Sheet 1-28, "Wind Design" (as it pertains to roof systems and roof fastening requirements) • Factory Mutual Global - Loss Prevention Data Sheet 1-29, "Roof Deck Securement and Above-Deck Roof Components" • Factory Mutual Global - Property Loss Prevention Data Sheet 1-28R/1-29R, "Roof Systems" • Factory Mutual Global - Loss Prevention Data Sheet 1-31, "Metal Roof Systems" • Factory Mutual Global - Loss Prevention Data Sheet 1-54, "Roof Loads for New Construction"	SI/ CI	SA	St	Ch	

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Revision Date:	30-September-2014					

Drawings • Structural drawing size shall be 34" x 44"	CI	SA	St	Ch	
MATERIALS OF CONSTRUCTION					
Foundations • Shallow (bearing 12 inches or more below finished grade) foundations utilizing spread footings, mats, and slab-on-grade construction will be provided as recommended in the Geotechnical Report.	SI	SA	St	Ch	
Cast-In-Place Concrete • Type II Portland Cement (with fly ash or slag) moderate sulfate resistant • # 57 stone maximum coarse aggregate size (one inch) • Reinforcing shall conform to the requirements of Section 3 of ACI 301-08 • Reinforcing bars shall be uncoated ASTM A615 Grade 60 bars • Reinforcing bars shall not be welded • Welded plain wire reinforcement shall be uncoated ASTM A185, 65 ksi min; minimum size should be WWF 6x6-W6xW6 sheets (no rolls) • Any admixtures proposed by the concrete supplier should be reviewed by the Engineer • Waterstop – PVC resin in dumbbell configuration, or approved equal. • Slabs on grade should have construction or control joints at 15'maximum spacing and a minimum thickness of 6 inches. • Structural concrete shall have a specified compressive strength, f'c, of 4000 psi (includes foundations, grade slabs, elevated slab, beams, girders and columns) • Floor slabs shall be specified to have a soft-textured broom finish (rough textured broom finish in a continuously wet process area).	SI	CS	St	Ch	
Grout • Non-shrink cement-based grout shall comply with ASTM C 1107, be suitable for placing at a flowable consistency at temperatures between 45 and 90 degrees, have a 7 day compressive strength of 4000 psi, and exhibit no shrinkage (per ASTM C 1107); and 28 day strength of 6000 psi. • Epoxy grout should be suitable for placing at a self levelling consistency at temperatures between 60 and 90 degrees, have a 7 day compressive strength of 10,000 psi, and withstand elevated temperatures up to 150 F.	SI	CS	St	Ch	
Structural Steel • Wide flanges, WT shapes – ASTM A992, Grade 50 • S Shapes & Channels – ASTM A36 • Angles- ASTM A36 or ASTM A529 Grade 50 • Structural Plates & Bars – ASTM A36 or ASTM A572 Grade 50 • HSS Sections (Square, Rectangular & Round) – ASTM A500 Grade B • Structural Pipe – ASTM A53 Grade B • High Strength Bolts – ASTM A325N, Type 1 (Galvanized) • Nuts – ASTM A563, Grade C, Heavy Hex (Galvanized) • Washers – ASTM F436 (Galvanized) • Welding Electrodes - per Section 4 of AWS D1.1 (E70XX are generally required	SI	CS	St	Ch	

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	Design Input	Design Output	Discipline	Verification Method	Rev. No.
for shielded metal arc welding) • Bolted connections shall be considered bearing type with threads included in the shear plane. • Field connections shall be bolted using ¾" diameter (minimum) high strength bolts • All high strength bolts shall be fully pretensioned • Connections loaded in direct tension, monorail members, and for members subject to vibration or fatigue**,** or as noted on drawings, shall be designed as slip-critical using a slip coefficient of 0.35, Class C, galvanized faying surfaces (see Specification for Structural Joints using ASTM A325 or A490 Bolts" – June 2004). • Minimum thickness of exposed exterior steel members is ¼ inch.					
Miscellaneous Metal • Steel grating shall be galvanized 1-1/4" deep with 3/16" thick serrated bearing bars at 1-3/16" spacing, attached with galvanized G-Clips. • Checkered plate shall be skid-resistant, raised pattern floor plate of commercial quality, ASTM A786 steel, galvanized. • Anchor bolt material shall be ASTM F1554 Grade 36, unless a higher strength material is required. For these situations ASTM F1554 Grade 55 or 105 shall be used. Grades 36 and 55 shall be galvanized. Grade 105 shall be field touch-up painted after steel erection. • Guardrails and handrails shall have two rails and comply with the 2010 Florida Building Code and OSHA. Top of rail height measured from finish floor or stair tread nosing shall be uniform at 42". • Guardrail and handrail material shall be ASTM A53 Grade B, 1-1/2" diameter, Schedule 40 for rails and Schedule 40 for posts (galvanized).	SI	SA	St	Ch	
Painting, Structural and Miscellaneous Steel • Structural Steel shall be galvanized. • Pre-engineered building: ○ Cold-formed primary and secondary members shall be galvanized. ○ Rolled structural steel shall be primed with an inorganic zinc primer.	CI	SA	St	Ch	
Roof & Siding • Metal siding and standing seam roof will be used for pre-engineered buildings. • Siding and roofing panels shall be approved by Underwriters Laboratories Inc., as non-combustible.	SI/ CI	SA	St	Ch	
DESIGN LOADS					
Dead Load Member self weight Equipment weight	CI	SA	St	Ch	
Snow Load • Ground snow load = 0 psf	R	SA	St	Ch	
Wind Loads • Governing Code: ASCE 7-10, Chapters 26 & 29 (2010 Florida Building Code	R	SA	St	Ch	

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Revision Date:	30-September-2014					

refers to ASCE for wind) • Basic Wind Speed, V: 145 mph (3-second gust at 33 ft above ground) • Risk Category: III • Exposure Category: C • Enclosure Classification: Open					
Roof Loads • Dead load: Based on Roofing and Structural components. • Live load: 20 psf. • Allowance for suspended utilities (Collateral): 25 psf for roofs.	SI	SA	St	Ch	
Floor Live Loads • Concrete floors on grade: 350 psf UNO • Elevated concrete floors: 175 psf (including 50 psf for suspended loads) UNO • Grating floors: 100 psf (including 50 psf for suspended loads) UNO • Grating walkways & elevated platforms (other than exit ways): 60 psf (including 10 psf for suspended loads) • Control rooms: 150 psf (including 25 psf for suspended loads) UNO • Electrical Equipment Rooms: 200 psf UNO	SI	SA	St	Ch	
Fork Lift Truck Loads • Not Applicable	SI		St	Ch	
Special Loading • Dynamic analysis shall be provided for foundations or support structures for equipment if required.	SI		St	Ch	
Seismic Loads • Seismic Code: ASCE 7-10 • Site Class: E (based on avg shear wave velocity of 590 ft/sec per Geotechnical Report) • Risk Category: III • Importance Factor: 1.25 • Plant Site Latitude 27° 42' 18" Plant Site Longitude 82° 03' 34" • S_S: 0.063g (per USGS website, ASCE 7-10 Standard, utilizing USGS hazard data available in 2008) • S_1: 0.031g (per USGS website, ASCE 7-10 Standard, utilizing USGS hazard data available in 2008) • F_a: 2.5 • F_v: 3.5 • S_{MS}: 0.157g • S_{M1}: 0.109g • S_{DS}: 0.105g • S_{D1}: 0.073g • Seismic Design Category: A (per ASCE 7-10 Section 11.4.1)	R	SA	St	Ch	

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Load Combinations • Buildings and other structures in accordance with the 2010 Florida Building Code Chapter 16, Section 1605.	R	SA	St	Ch	0
Thermal Effects • Buildings and structures over 300 feet long shall be designed for movements resulting from a change in temperature. Outdoor ambient dry bulb temperature extremes shall be a maximum of 95° F and a minimum of 25° F. Thermal movements will be calculated based on the assumption that the ambient dry bulb temperature during construction is 70° F. • Design temperature range (Extremes) o Summer High = 99° F per National Climatic Data Center (NCDC) o Winter Low = 18° F per NCDC	CI	SA	St	Ch	
GEOTECHNICAL REPORT AND RECOMMENDATIONS Geotechnical Report, "Tampa Electric Facility Development, East of SR 37 North of CR 674, Polk County, Florida" by Professional Service Industries, Inc, PSI Project No. 0775-1248 dated January 31, 2012 will be used.					
Shallow Foundations • Allowable net soil bearing pressure is 4000 psf. • Minimum embedment below finished grade is 12 inches. • "Total settlement should not exceed 1 inch. Differential settlement is estimated to be on the order of 50 percent of the total settlement." • The depth of the frost line is zero inches below grade.	G	SA	St	Ch	
Slab on Grade • Slabs on grade will be designed as reinforced concrete floating slabs and shall be cast directly on the bottom of foundation excavations after compaction or compacted backfill. Modulus of Subgrade reaction, k, ranges from 50 to 200 pci. • Interior ground floor slabs shall have a steel trowel finish. • Exterior ground floor slabs shall have a soft-textured broom finish (rough textured in a continuously wet process area). • Equipment pads shall be a minimum of 6 inches above finish slab elevation.	G	SA	St	Ch	
Deep Foundations • All foundations will be shallow, soil bearing foundations.	G		St	Ch	
Mat Foundations • Allowable net soil bearing pressure is 4000 psf. • Minimum embedment below finished grade is 12 inches. • Modulus of Subgrade reaction, k, ranges from 50 to 200 pci.	G	SA	St	Ch	
Ground Water Level • The anticipated ground water level is EL (*later*), based on 100 year flood level.	G	SA	St	Ch	
Soil parameters for computing Lateral Earth Pressure of Compacted Fill • K_o (at-rest) = 0.50 • K_A (active) = 0.33 • K_p (passive) = 3.00	G	SA	St	Ch	

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• Allowable coefficient of friction for sliding = 0.25 (Includes a FS = 2.0) • "Foundations and below grade structures shall be designed for applicable earth/water pressure plus an appropriate surcharge load (which shall not be less than a construction surcharge load of 250 psf)."					
Soil Weight • 110 pound per cu ft (moist unit weight for clean sand backfill)	G	SA	St	Ch	
ADDITIONAL CONSIDERATIONS					
Utility Bridge Minimum Clearances (*confirm following values with Plant*) • 22 feet over main plant roads • 15'-6" over secondary plant roads • 22 feet over plant railroads • 7 feet over other plant areas • 5 feet horizontal clearance between roadway edges and support bents.	SI/ CI	SA	St	DR /Ch	
Floor Slopes and Levels • Floor for ordinary wash-up; minimum 1/8 inch per foot. • Wet floor areas slope ¾ inch per foot max., to 3/16 inch per foot min.	SI	SA	St	Ch	
U-Drains • None	SI		St	Ch	
Floor Drains • None	SI		St	Ch	

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Discipline:	**Structural**					
Document Owner:	Marlon Will					
Project Document No.:	176858-S-DCVP					
Revision No.:	A					
Revision Date:	30-September-2014					

APPROVED BY:

Customer	
Project Manager	Gary Messer

Department Manager		Area or Discipline Leader	
Civil		Civil	
Structural	Dan Elmore	Structural	Marlon Will
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical		Electrical	
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced

		Design Input	Design Output	Discipline	Verification Method	Rev. No.
Project No.:	**176858**					
Project Title:	**RTI Ammonia Integration FEED**					
Major Area:						
Discipline:	**Civil**					
Document Owner:	Randy Reynolds					
Project Document No.:	176858-C-DCVP					
Revision No.:	A (for Approval)					
Revision Date:	06-January-2015					

PROJECT DESCRIPTION This project consists of a FEED study to develop a +/- 10% cost estimate for producing ammonia by utilizing the hydrogen stream from RTI's 1.5 MM SCFH Warm Syngas Cleanup (WGCU) demonstration facility at the TEC Polk Power Station located in Polk County, Florida.					
SITE INFORMATION	CI	SP	Ci	Ch	
LOCATION					
• The site is located in Polk County, Florida, approximately 33 miles east of Tampa and 10 miles south of Mulberry, Florida. • The address is 9995 State Road 37 S, Mulberry, Florida 33860. • The approximately four (4) acre site is within the property boundary of the Polk Power Station, which occupies 4,300 acres on Florida State Road 37					
SITE UTILIZATION					
• Building Layout Consideration: There are no inhabited buildings. • Equipment Layout is by AMEC, with approval by RTI and TEC (Tampa Electric Company).					
Traffic Control Consideration:					
• None required.					

DESIGN AND VERIFICATION CODES

Design Input
CI = Customer Input
SI = AMEC Input
R = Regulatory Requirement
G = Geotechnical Consultants Input
MD = Manufacturers' Data

Principal Design Output
DS = Design & Material Standard/Specfctn
PD = P&ID/P&C/flowsheet
OL = One Line Diagram
LD = Logic Description
PS = Process Functional Specification
SP = Site Plan & Facility Layout
EL = Equipment Layout
ES = Equipment Specification

Other Design Outputs
SA = Structural & Arch. Dwg.
OT = Other Drawings
CS = Construction Specifications

Discipline
Ci = Civil
St = Structural
Ar = Architectural
Me = Mechanical
Pi = Piping
Pr = Process
El = Electrical
In = Instrument & Controls
He = HVAC

Verification Method
Ch = Checking
DR = Design Review
AC = Alternate Calculation
CR = Constructability Review
HA = HAZOP Study
CE = Compare to existing
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Project No.:	**168745**					
Project Title:	**RTI Ammonia Integration FEED**					
Major Area:						
Discipline:	**Civil**					
Document Owner:	Randy Reynolds					
Project Document No.:						
Revision No.:	0 Issued for Design					
Revision Date:	29-AUG-2012					

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Future Expansion Consideration					
• None					
SURVEY INFORMATION	CI	SP	Ci	Ch	
Benchmark-Vertical Control					
• As shown on Tampa Electric drawing Number 379-EY-2X, "Construction Marker Location". • Plant Datum Elevation 100.0000 = Elevation 143.5000 NGVD 29.					
Topographic					
• Survey has not been completed at this time					
Boundary:					
• Not required. Site is inside of the property boundary of the TEC Polk Power Station.					
Restrictions:					
• None known					
Rights-of-Way and Easements:					
• None					
Flood Plain Investigation					
• No FEMA maps are available					
Grid Systems:					
• Polk Power Station Plant Grid • Plant Coordinate N00.00, E00.00 = Florida State Plane (NAD '83, West Zone) Coordinate N1,230,000.00, E656,000.00					
ZONING RESTRICTIONS	R	SP	Ci	Ch	
• None					

DESIGN CRITERIA AND VERIFICATION PLAN

Civil (Cont'd.)

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Project No.:	**168745**					
Project Title:	**RTI Ammonia Integration FEED**					
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Discipline:	**Civil**					
Document Owner:	Randy Reynolds					
Project Document No.:						
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SOILS INFORMATION	G	SP	Ci	Ch	
See "Geotechnical" section under "Project Specific Requirements" in the STRUCTURAL DESIGN CRITERIA AND VERIFICATION PLAN					
RAILROADS					
Not Applicable					
ROADWAYS AND PARKING	CI	SP	Ci	Ch	
Design Traffic:					
• Light trucks (pickups), fork lifts and ammonia tanker trucks.					
Access Road Paving (to ammonia loadout area)					
• Per geotechnical recommendation. (Not completed at this time). Pavement will be designed for load and frequency of the ammonia tanker trucks.					
Curb And Gutter Requirements					
• None					
Parking Spaces					
• None					
Lighting, Outside Requirements					
• See Electrical discipline design criteria verification plan.					
UNDERGROUND UTILITIES REQUIREMENTS	CI	SP	Ci	Ch	
Fire Protection Underground					
• All project fire protection will be by others (fire protection specialist).					
Sanitary Sewer Underground					
• None required					
Process Sewer Underground					
• None required					

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Fuel Gas Piping Underground					
• None required					
Potable Water Underground					
• None required underground. Will be routed overhead on pipe bridges					
Oily Water Drains					
• Will be routed by gravity from equipment/pumps to the Water-Oily Waste (WOW) sewer					
UTILITY BURIAL DEPTH All pipes except storm drains will have minimum 3 feet cover for mechanical protection.	SI	SP	Ci	Ch	
• All underground piping shall be designed for bury to withstand an HS-20 truck loading or a 40 kip single axle load, whichever controls. • Minimum cover yard area: 3 feet. • Minimum cover beneath roads: 3 feet. • Frost depth: Less than one foot.					
• Beneath structures: 3 feet minimum, but at least 12 inches clear beneath concrete slabs or grade beams or wall footings.					
SITE GRADING AND DRAINAGE REQUIREMENTS	CI	SP	Ci	Ch	
Demolition Requirements					
• None					
Earthwork Description					
Site will be cleared, proofrolled with a heavy vibratory roller and compacted to a minimum depth of one foot below stripped grade to a dry density of at least 95% of the modified Proctor maximum dry density within the limits of the proposed structures and paved areas. Structural fill will be used to bring levels up to finished grade as necessary, and compacted to 95% of the modified Proctor maximum dry density.					

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Document Owner:	Randy Reynolds					
Project Document No.:						
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Revision Date:	29-AUG-2012					

Dewatering					
• If necessary, dewatering system shall be designed by a qualified dewatering professional.					
Borrow Material					
• On-site soils acceptable as structural fill are fine sand, slightly silty fine sand and clayey fine sand (SP, SP-SM and SP-SC) provided it is free of rocks larger than ½ inch, significant clay, organics or other deleterious material.					
Clearing And Grubbing					
• Area is presently grassed and only needs clearing.					
Stockpile Materials					
• Topsoil and structural fill.					
Materials Disposal					
• Any and all suitable or unsuitable material and earthwork debris will become the property of the owner, to be disposed of or stockpiled as directed by same.					
Potentially contaminated storm water					
• Storm water which could possibly become contaminated will be collected within a paved and curbed area and pumped to primary treatment (WOW sewer).					
Non-contaminated storm water					
• Storm water which is not likely to be contaminated will sheet flow over graded areas to the perimeter storm water ditches.					
Detention/Retention Pond Requirements					
• None. (Storm water drainage from the equipment island shall be routed to the existing north detention pond.					
Lowest Finish Floor Elevation					
• No inhabited buildings-Curbed containment slabs low elevation=plant elevation 99.0+/-.					

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Document Owner:	Randy Reynolds					
Project Document No.:						
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	Design Input	Design Output	Discipline	Verification Method	Rev. No.
LANDSCAPING AND PLANTING	SI	SP	Ci	Ch	
Grassing					
• All areas not surfaced with gravel or pavement, outside the limits of any buildings, shall be grassed. No landscaping plantings.					
Abrupt Changes In Elevation					
• None					
Civil Related Equipment					
• Stormwater pumps which will send the potentially contaminated storm water to the WOW sewer.					
Fencing					
• None					
SPECIFIC DESIGN REQUIREMENT FOR FUTURE					
• None					
APPLICABLE CODES, STANDARDS, REGULATIONS (See also Basic Facility Information)	R	SP/ CS	Ci	Ch	
Fire Protection					
• National Fire Protection Association (NFPA) • 2010 Florida Fire Prevention Code					
Highway Agencies					
• Florida DOT 2010 Standard Specifications for Road and Bridge Construction • American Association of State Highway and Transportation Officials (AASHTO)					
Storm Water and Erosion and Sediment Control Standards/Regulations					
• Florida Department of Environmental Protection (FDEP)					
Note: A 25 year-24 hr. design storm will be used unless otherwise noted.					
Testing and Materials					
• American Society for Testing and Materials (ASTM)					

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Document Owner:	Randy Reynolds					
Project Document No.:						
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Revision Date:	29-AUG-2012					

Other					
• American Water Works Association (AWWA)					

APPROVED BY:

Customer	RTI Ammonia Integration FEED		
Project Manager	Gary Messer		
	Department Manager		Area or Discipline Leader
Civil	Dan Elmore	Civil	Randy Reynolds
Structural		Structural	
Architectural		Architectural	
Mechanical		Mechanical	
Piping		Piping	
Process		Process	
Electrical		Electrical	
Instrument & Controls		Instrument & Controls	
HVAC		HVAC	

NOTE: Department Manager and Area or Discipline Leader signatures are only required for those disciplines referenced

Appendix Ammonia Pipeline Study & Routing Drawing

TAMPA ELECTRIC COMPANY

POLK POWER STATION

AMMONIA PIPELINE FEASIBILITY STUDY

FINAL 12/3/2014

Prepared by

AECOM Technical Services, Inc.

September 2014

TAMPA ELECTRIC COMPANY
POLK POWER STATION
AMMONIA PIPELINE FEASIBILITY STUDY

Introduction

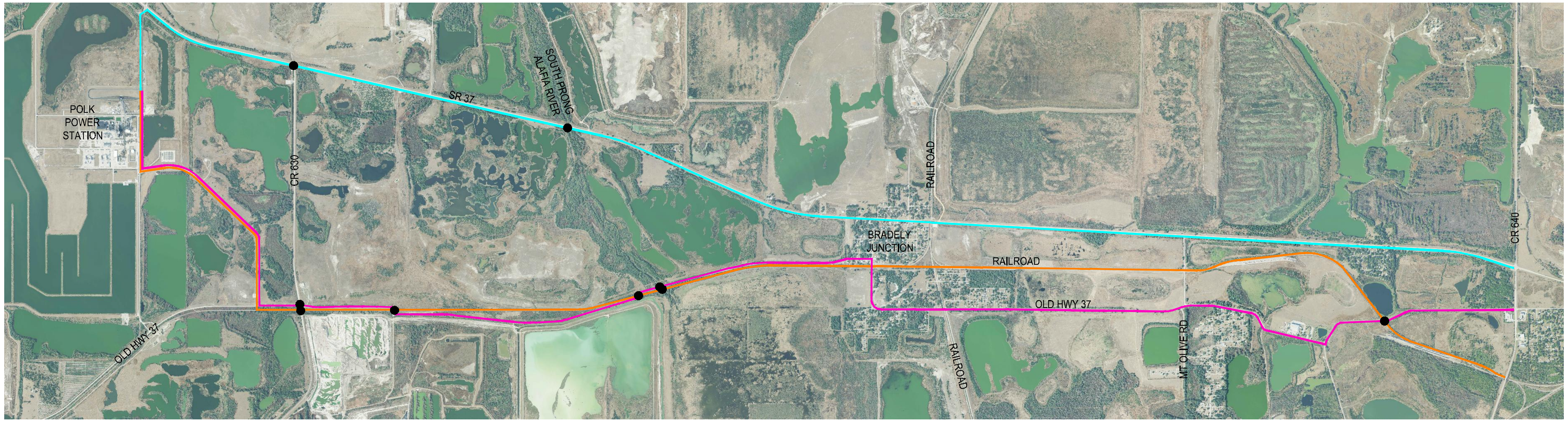
Tampa Electric Company (TEC) retained AECOM Technical Services, Inc. (AECOM) to perform a limited feasibility study of constructing a new pipeline from the Polk Power Station (PPS) to a point of connection with an existing ammonia pipeline located within the right-of-way of CR 640. This new pipeline will be used to convey liquid ammonia produced at PPS. The normal operating pressure for the new pipeline is expected exceed 500 psig.

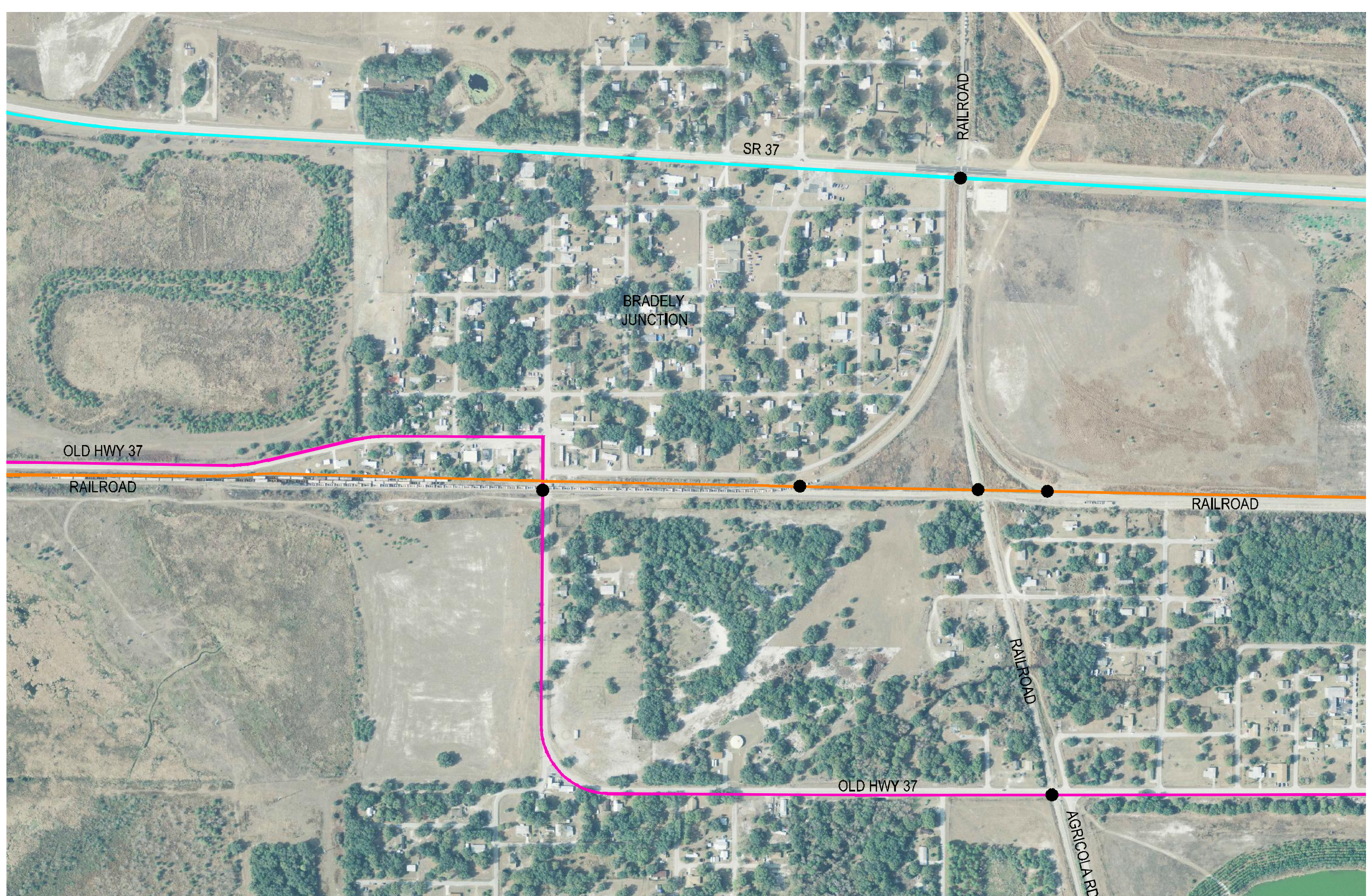
Two general pipeline routes were identified by AMEC E&C Services (AMEC). Both routes originate at PPS and terminate in a new connection to an existing pipeline, located at the intersection of SR 37 and CR 640/Pinecrest Road. One route assumed the pipeline will be constructed within the SR 37 right-of-way while the other route assumed the pipeline will be constructed in a combination of Old Highway 37 right-of-way, CSX Railroad right-of-way, and SR 37 right-of-way. The total length of the pipeline in either configuration is approximately 9 miles.

AECOM's scope of work included:

1. Reviewing information provided by TEC, AMEC, and others.
2. Developing approximately scaled maps of the two alternative routes. Maps will be based on GIS applications, no survey will be performed.
3. To the extent possible, walking or riding the two routes to identify possible design or construction issues.
4. Preparing a Class III construction cost estimate for each alternative pipeline route, conforming to the attached TEC Summary Classification Schedule table (**Appendix A**).
5. The mechanical basis of design for the ammonia pipeline was provided by AMEC. This basis of design included selection of pipe materials, valves and appurtenances suitable for construction and operation of a liquid ammonia pipeline.
6. Providing permitting support to TEC. TEC provided expected durations for obtaining environmental and other required permits. AECOM summarized the permitting requirements for the alternate routes, based on information provided by various agencies and TEC. Additionally, AECOM obtained information from FDOT regarding permitting and construction of liquid ammonia pipelines in road rights-of-way.
7. Preparing a preliminary project schedule for design, permitting and construction of each of the alternative ammonia pipelines.
8. Evaluating the estimated construction cost, permitting requirements, and project schedule for each of the two alternative pipeline routes, and recommending one alternative route for use.
9. Preparing and delivering a technical memorandum summarizing the information reviewed, field observations, construction cost estimates, permitting requirements, preliminary construction schedule, pipeline route evaluation and recommendations.

During field investigations with TEC it was determined that a third route option should be considered. This option consists of constructing the pipeline completely within the right-of-way of Old SR 37. Therefore, the three alternate routes evaluated in this feasibility study consist of the SR 37 route, a route primarily located within CSX Right-of-way, and a route primarily located within the right-of-way of Old Highway 37. The three routes are shown on **Figure 1**.





PIPELINE WITHIN SR 37 R.O.W.
- 47,850 FT
- 1 RR CROSSING
- 1 CROSSING OF S. PRONG ALAFIA RIVER
- 1 JACK AND BORE CROSSING

PIPELINE WITHIN OLD HWY 37 R.O.W.
- 52,500 FT
- 5 RR CROSSINGS
- 1 CROSSING OF S. PRONG ALAFIA RIVER
- 1 JACK AND BORE CROSSING

PIPELINE WITHIN RR R.O.W.
- 51,200 FT
- 2 OR 3 RR CROSSINGS
- 1 CROSSING OF S. PRONG ALAFIA RIVER
- 1 JACK AND BORE CROSSING

● CRITICAL CROSSING POINT

AECOM
AECOM TECHNICAL SERVICES, INC.
150 NORTH ORANGE AVE, SUITE 200
ORLANDO, FLORIDA 32801
PHONE (407) 843-6552
CERTIFICATE OF AUTHORIZATION NO. EB-8115

TAMPA ELECTRIC COMPANY
POLK POWER STATION

AMMONIA PIPELINE FEASIBILITY STUDY

FIGURE
1

Summary of Existing Information

Information was provided by TEC and AMEC. The engineering design of a TEC reclaimed water pipeline performed by AECOM was also reviewed. Additional information was obtained from the Florida Department of Transportation (FDOT), the United States Department of Transportation (USDOT), and CSX Railroad (CSX).

Information Summary

Provider	Description	Summary	Included As
TEC	Summary Classification Schedule	Construction Cost Estimating Criteria	Appendix A
TEC	Real Estate Maps	Showing property owners along the alternate routes	Appendix B
TEC	Project Schedules for the Reclaimed Water Pipeline Project	Permitting schedule information.	Reference only
AMEC	Alternate Route Maps	Base and one alternate route	Figure 1
AMEC	Mechanical Basis of Design	Basic ammonia pipeline design information.	Figure 2
FDOT	Utility Accommodation Manual, August 2010 Edition	Standard FDOT design and permitting requirements.	Reference only
CSX	Permitting Requirements	Design and permitting requirements to construct pipelines within CSX ROW	Reference only
USDOT	Design standards for materials conveying hazardous materials	Technical standards for pipelines conveying hazardous materials	Reference only

Existing Conditions and Observed Constraints

The three alternate pipeline routes are located generally within a narrow corridor in southwest Polk County. Soil conditions, the size and number of wetlands, and the number of major road crossings are generally equivalent for the three routes.

As shown on **Figure 3** the number of rail crossings varies between the alternate routes.

- One rail crossing will be required for the SR 37 route
- Five rail crossings will be required for the Old Highway 37 route
- Two or three rail crossings will be required for the CSX railroad route, depending upon which side of the tracks the pipeline were to be installed.

Although all three routes extend through the residential community of Bradley Junction, Old Highway 37 appears to have narrower right-of-way than does SR 37. Additionally, some of the residences are close to the edge of the right-of-way of Old Highway 37, with the edge of the buildings within approximately 30 feet of the edge of the right-of-way.

TEC provided aerial plat maps identifying property owners abutting the alternate routes. These maps are included in **Appendix B.** This information will be valuable when negotiating property values with CSX or with property owners along the Old Highway 37 route, if those routes are chosen. This information was used to confirm that easements will not be required from private property owners, other than CSX, for any of the routes.

Based on previous pipeline work performed within the SR 37 corridor, experience with construction and permitting of pipelines within road rights-of-way in general, and discussions with CSX railroad, it appears all three routes may be considered to be "constructible", that is, the proposed pipeline could be expected to be permitted and constructed within any of the routes. However, the degree of difficulty in obtaining a permit to construct a pipeline of this type parallel to and within the CSX right-of-way should not be underestimated, and in the end, CSX may not grant such a permit. It is not possible to confirm CSX's position without actually submitting a permit application.

Relative Risk Assessment

The following primary risks to TEC due to construction and operation of the pipeline were identified and qualitatively assessed.

Activity	Risk Parameter	Criteria	Relative Severity of Risk		
			SR 37	**CSX**	**Old Hwy 37**
Construction of the pipeline	Noise and general construction activities	Proximity to residential properties and constructed structures, including rail lines.	Moderate through Bradley Junction due to medium proximity to residences	Moderate through Bradley Junction due to medium proximity to residences	High through Bradley Junction due to close proximity to residences
Construction of the pipeline	Permitting required for crossing Wetlands, Road Crossings, and RR Crossings	Number and extent of crossings	Moderate 1 wetland crossing (S. Prong Alafia River), 1 road crossing (CR 630), 1 RR crossing	High 1 wetland (S. Prong Alafia River), 1 road crossing (CR 631), min. 2 RR crossings, entire pipe length is on CSX ROW	Moderate 1 wetland crossing (S. Prong Alafia River), 1 road crossing (CR 630), 5 RR crossings
Operation of the pipeline	Pipeline Failure, release of ammonia	Proximity to residential properties and constructed structures, including rail lines.	Moderate through Bradley Junction due to medium proximity to residences, potential damage to road and RR crossings	High due to proximity to rail lines, and proximity to residence through Bradley Junction, potential damage to road and RR lines and crossings	High through Bradley Junction due to close proximity to residences, potential damage to road and RR crossings

Summary of Permitting Requirements

In general each of the alternate routes will require the following permits, which are common to all three routes:

1. Conditions of Certification Modification (COC)
2. Environmental Resource Permit (Florida Department of Environmental Protection and U.S. Army Corps of Engineers)
3. CSX Railroad permit
4. U.S. Department of Transportation Utility permit (PHMSA compliance)

Two routes require additional permits not common to all the routes:

- The SR 37 route requires permitting from the Florida Department of Transportation.
- The Old Highway 37 route requires permitting from Polk County.

Each of these permits is commonly required for construction of utility pipelines of this type. The above permits were recently obtained for construction of a reclaimed water main within the SR 37 corridor. This past experience confirms that the SR 37 route can be permitted. The permitting effort was significant, although standard permits were required and obtained.

It should be noted that the number of rail crossings along the Old Highway 37 route will increase the permitting effort with CSX. Also, obtaining a permit to construct the pipeline within and parallel to the CSX rail lines is expected to be difficult and expensive, and there is no guarantee CSX will grant this permit.

Based on recent experience constructing the TEC reclaimed water transmission main within the SR 37 corridor, and the historical level of effort required to obtain CSX permits, the following relative order of permitting effort is assigned to the three route options.

Permits Required	Route and Expected Degree of Effort		
	SR 37	Old Highway 37	CSX RR
COC	Yes/standard	Yes/standard	Yes/standard
ERP	Yes/standard	Yes/standard	Yes/standard
CSX	Yes/standard	**Yes/moderate**	**Yes/extensive**
USDOT	Yes/standard	Yes/standard	Yes/standard
FDOT	Yes/standard	Not required	Not required
Polk County	Not required	Yes/standard	Not required
Permitability Ranking	Lowest	Second Lowest	Highest

Preliminary Project Schedule

A milestone schedule was developed for each alternate route and is shown in **Figure 4**. Activities that are expected to occur in sequence and comprise the “critical-path activities” are shown in red, while non-critical path activities are shown in blue.

Permitting durations are based on TEC and AECOM experience.

Construction durations were based on the contractor being able to weld, inspect, and install 10 sections of steel pipe (200 feet) daily, under normal conditions, using open cut construction methodology. For a nominal 50,000 LF pipeline length the resulting construction duration would be 250 working days, or one calendar year, for the pipeline construction. Added to this duration would be time for ordering and fabricating pipeline, valves, fittings, and pigging stations, testing and restoration. It is assumed that one jack-and-bore crossing of CR 630 and one jack-and-bore crossing of CSX railroad, and the directional drill crossing of the Alafia River would be performed concurrently with construction of the open cut installation.

This schedule makes no allowance for weather delays or other frequently encountered construction delays. This schedule is for construction only, and does not include activities the contractor would be required to complete prior to and post construction.

Construction in areas having limited right-of-way width and increased obstructions was expected to have slower production. Similarly, construction parallel to and within the CSX RR right-of-way was expected to slow production due to increased oversight by CSX and occasional work stoppages due to train traffic.

Summary:

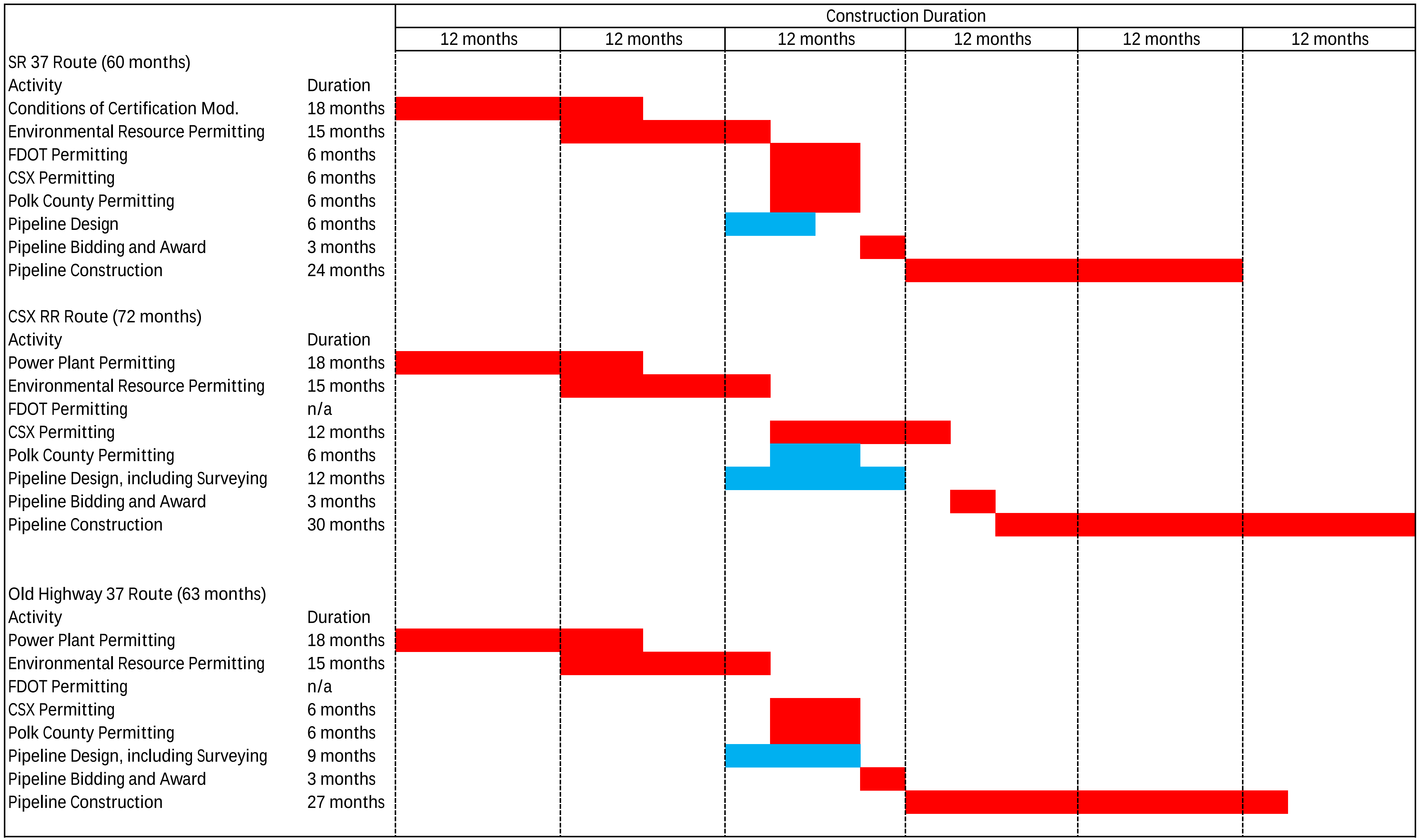
As shown in **Figure 2** an estimated total project duration was developed for each route alternate. The total project duration for each route includes permitting, design and construction.

The SR 37 route is expected to have the shortest total project duration (60 months). This route has the least obstructed right of way and the least number of CSX RR crossings.

The CSX RR Route is expected to have the longest total project duration (72 months). In this route the majority length of pipeline is located parallel to and in relatively close proximity to the railroad tracks, which is expected to increase the construction duration. In addition, this route alternate is expected to require significantly more time for permitting and negotiations with CSX RR than either of the other two alternate routes. Similarly, the duration of design for this route option was expected to be longer due to resolution of technical issues with CSX.

The Old Highway 37 route is expected to have an intermediate total project duration (63 months). This route has tight, potentially obstructed right-of-way within the Bradley Junction area, and has five CSX RR crossings, in addition to the jack-and-bore crossing of CR 630 and the directional drill crossing of the South Prong of the Alafia River. It is estimated that these seven special construction locations will add approximately three months to the construction duration.

Tampa Electric Company
Preliminary Construction Schedule
Ammonia Pipeline Feasibility Study
Figure 2



Construction Cost Estimate

A Preliminary Opinion of Probable Construction Cost (OPCC) was prepared for each of the alternate routes. A summary is presented below. Details of the construction cost estimate are included in **Appendix C**.

SUMMARY OF OPCC			
Item	Pipe Within SR 37 ROW	Pipe Within Old HWY 37 ROW	Pipe Within Railroad ROW
Estimated Construction Cost	$10,411,100	$11,334,300	$11,323,700
Special Construction Fees for pipe constructed within and parallel to CSX ROW (1)			
Utility Occupancy Review (permit review fee)	NA	NA	$15,000
Licensing Fee (Property)(2)	NA	NA	$88,361
CSX Flagman (3)	NA	NA	$375,000
Contract Inspector (4)	NA	NA	$562,500
Total	$10,411,100	$11,334,300	$12,364,561
Total (rounded)	$10,411,100	$11,334,300	$12,364,561

(1) Standard CSX permitting fees and design fees are not included in this comparative feasibility study.
(2) Licensing fee is based on a cost of $3,000 per acre for an area of 29.5 acres. The acreage is based on the length of pipe route with a width of 25 feet.
(3) Flagman cost is based on a cost of $1,000 per day for a duration of 375 days.
(4) Contract Inspector cost is based on a cost of $1,500 per day for a duration of 375 days.

The OPCC is based on material cost supplied by vendors, typical construction cost from similar and recent projects, and Means published construction cost estimating.

For this OPCC the pipe material was assumed to be steel, welded joints, meeting the requirements of API5L-X42. For this OPCC some assumptions were made including the length of direction drill required to pass under the Alafia River and the length of Jack and Bores under the road and railroads. The chosen lengths are based on expected typical value and installation means. However the actual installation length will need to be confirmed following the soil and survey analysis from the Geotechnical Engineer.

As a preliminary OPCC there is an assumed level of accuracy and detail that is necessary for calculating the cost. Given that the design status for this project is less than 30% complete, and, given that construction prices may not be obtained for two or more years, the actual construction cost should be expected to vary by up to -10% to +30% before contingency. Therefore, this OPCC is a Class III estimate.

For this project the steel pipe is welded steel pipe and installed in an open cut excavation that provides for a minimum of 3-feet of cover except where the pipe is routed under the road, railroad, or the river. At the locations where open cut is not feasible the piping is assumed to be 10 feet under the road, 15-feet under the railroad and 15 feet under the lowest river bed level in the river.

The Jack and Bore installation requires a carrier pipe in this installation. The carrier pipe is assumed to be a 12-inch restrained joint ductile iron pipe with pipe spacers and end caps. An alternative approach could be the filling of the pipe with cement slurry. However, this option was not considered at this time.

Additional costs were assumed for the installation of pigging stations and isolation valves. No material specifications were provided for these items.

As with all projects, bonding, indemnification and insurance are requirements that need to be obtained prior to performing any construction activity. The costs for bonding, indemnification and insurance coverage were assigned a value of 5% of the construction cost, which is a typical value. Costs to mobilize and demobilize from the project were also assigned a value of 5% of the construction cost, which is a typical value. These costs are captured in the **Appendix C**.

Additionally the proposed overhead and profit were assumed to be within the industry standard of 15%.

The above summary assumes that all piping installed within the CSX RR route will be installed via open cut methodology, except for RR and road crossings, which will be installed via jack-and-bore methodology. During discussions with CSX their spokesman advised that some or all of the piping installed within the CSX RR route could be required to be cased, depending upon proximity to the tracks and other factors. If the entire length of pipeline is required to be cased, then the total OPCC for the CSX RR route is estimated to be $26,100,000.

Alternative Route Comparison

The objective of this limited feasibility study was to compare the feasibility of alternate routes for a new liquid ammonia pipeline, and develop a recommendation for one route to be selected for further consideration. The following factors were considered when performing the route comparison:

- Basic Feasibility – can the pipeline be physically constructed?
- Permitting Requirements
- Relative Risk Assessment
- Existing Conditions and Observed Constraints
- Project Duration
- Cost (OPCC)

The following table summarizes the feasibility comparison for the three alternate routes

Criteria	SR 37 Route	Old Highway 37 Route	CSX RR ROW Route
General Feasibility	Constructible	Constructible	Constructible (1)
Anticipated Permitting Requirements	Least	Second lowest	Most, may not be permitable
Relative Risk Assessment	Lowest	Highest	Second Lowest
Anticipated Permitting Requirements	Least	Second lowest	Most, may not be permitable
Project Duration	Shortest (60 months)	Second shortest (63 months)	Longest (72 months)
Cost	Least ($10.4 Million)	Second lowest ($11.3 million)	Most ($12.4 million)
Assessment	Best Choice		

(1) It is technically feasible to construct the pipeline within the CSX ROW, but CSX may not issue a permit the construction.

Recommendation

On the basis of the data and information provided by AMEC, TEC and others, the field conditions and constraints observed, and the experience of AECOM in linear utility design and construction it is recommended that the SR 37 route alternate be considered for further action, including design and construction of the proposed pipeline.

This recommendation is based upon the demonstrated constructability and permitability of a pipeline within the SR 37 corridor, as evidenced by the recently constructed reclaimed water transmission main, the estimated project duration, and the comparative project cost.

This feasibility study was expressly limited to comparing alternative pipeline routes. Other methods of conveying liquid ammonia, such as trucking, were not evaluated.

TAMPA ELECTRIC COMPANY
POLK POWER STATION
AMMONIA PIPELINE FEASIBILTY STUDY

APPENDIX A

TEC Summary Classification Schedule

Tampa Electric Standard
Summary Estimate Classification Table

TYPE	ESTIMATE DESCRIPTION (Phase of estimating cycle - and typical estimate headings)	EXPECTED ACCURACY RANGE (Typical accuracy range and contingency - 90% confident that actual $ will fall within)	PROJECT DEFINITION **(Percent Complete)** (Engineering, bill of materials, quotes, contracts)
CLASS I	FINAL DESIGN ESTIMATE (also full detail, release, fallout, tender, bottoms-up, detailed)	-5% TO +5% before contingency. Typical Contingency = 3-5%	65 to 100%
CLASS II	DEFINITIVE ESTIMATE (also detailed, control, construction or definitive)	-10% to +15% before contingency. Typical Contingency = 5-15%	30 to 75%
CLASS III	PRELIMINARY ESTIMATE (also, budget, scope, design, sanction, semi-detailed, authorization, office)	-10% to +20% before contingency. Typical Contingency = 8-20%	10 to 40%
CLASS IV	CONCEPTUAL ESTIMATE (also, factored, top-down, evaluation, study, favored, predesign study)	-20% TO +30% before contingency. Typical Contingency = 10-25%	1 to 15%
CLASS V	ORDER OF MAGNITUDE ESTIMATE (also, ROM, ball-park, rule-of-thumb)	-30% TO +50% before contingency. Typical Contingency = 15-40%	0 to 2%

Qualifications:

The above table is a guideline intended to provide a common basis for communicating estimate quality and contingency.

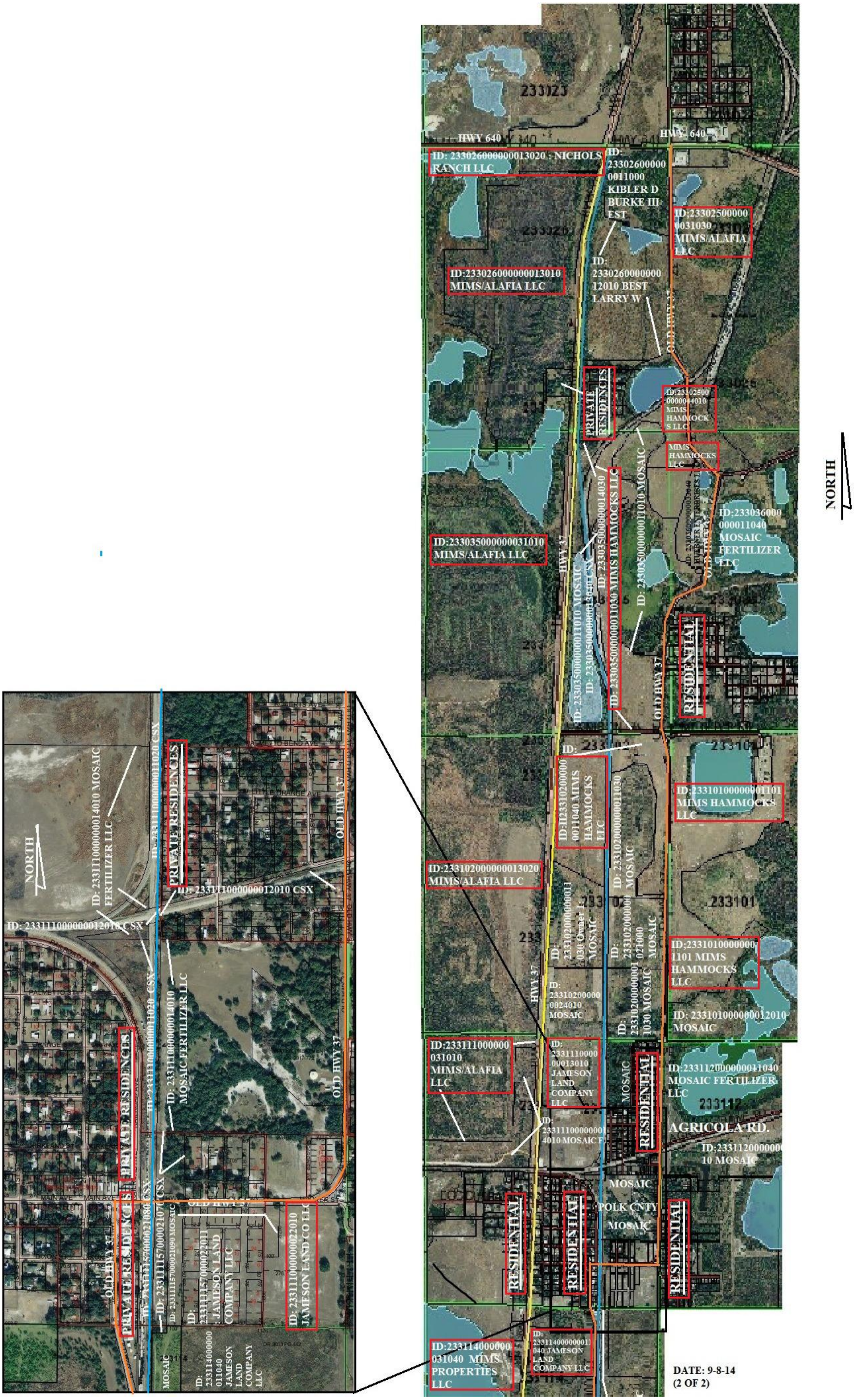
The table presents typical contingency ranges for estimate quality. Contingencies for specific risks are not included in these ranges. It is expected that project managers, estimators and other project team members will apply sound judgment based on specific project circumstances. In doing so, some projects will include contingencies which fall outside the typical ranges.

TAMPA ELECTRIC COMPANY
POLK POWER STATION
AMMONIA PIPELINE FEASIBILTY STUDY

APPENDIX B

Property Maps

DATE: 9-8-14 (SHEET 1 OF 2)



DATE: 9-8-14
(2 OF 2)

TAMPA ELECTRIC COMPANY
POLK POWER STATION
AMMONIA PIPELINE FEASIBILTY STUDY

APPENDIX C

Opinion of Probable Construction Cost

PROJECT COST SUMMARY			
	Pipe Within SR 37 ROW	Pipe Within Old HWY 37 ROW	Pipe Within Railroad ROW (5)
Estimated Construction Cost	$10,411,100	$11,334,300	$11,323,700
Special Construction Fees associated with CSX (1)			
Utility Occupancy Review	NA	NA	$15,000
Licensing Fee (Property)(2)	NA	NA	$88,361
CSX Flagman (3)	NA	NA	$375,000
Contract Inspector (4)	NA	NA	$562,500
Total Construction Cost	$10,411,100	$11,334,300	$12,364,561

(1) Standard CSX permitting fees and design fees common to the three alternatives are not included in this comparative feasibility study

(2) Licensing fee is based on a cost of $3,000 per acre for an area of 29.5 acres. The acreage is based on the length of pipe route with a width of 25 feet.

(3) Flagman cost is based on a cost of $1,000 per day for a duration of 375 days.

(4) Special Inspector cost is based on a cost of $1,500 per day for a duration of 375 days.

(5) CSX may require casing of the entire length of pipeline within their ROW. If so, then the construction cost for this option will be significantly more.

SCHEDULE OF BID PRICES Option 1 Pipeline within SR 37 ROW					
PAY ITEM #	QTY	UNIT	ITEM DESCRIPTION	UNIT PRICE	EXTENDED PRICE
1	1	LS	PAYMENT AND PERFORMANCE BONDS, INDEMNIFICATION, INSURANCE	$338,017	$338,017
2	1	LS	MOBILIZATION AND DEMOBILIZATION	$338,017	$338,017
3	47310	FT	Open Cut Pipe Installation	$124	$5,868,510
4	120	FT	Jack and Bore Under the Roadway	$677	$81,214
5	120	FT	Jack and Bore Under the Railroad	$677	$81,214
6	300	FT	Directional Drill under Alafia River	$698	$209,400
7	27	EA	Pressure Testing	$0	$0
8	2370	EA	X-ray Testing	$0	$0
9	2	EA	Pigging Port	$200,000	$400,000
10	10	EA	Valves	$12,000	$120,000
				Sum of Cost Items	$7,436,400
				15% Overhead	$1,115,500
				15% Profit	$1,115,500
				10% Contingency	$743,700
				Total Cost	$10,411,100

SCHEDULE OF BID PRICES Option 2 Pipeline within Old HWY 37 ROW					
PAY ITEM #	QTY	UNIT	ITEM DESCRIPTION	UNIT PRICE	EXTENDED PRICE
1	1	LS	PAYMENT AND PERFORMANCE BONDS, INDEMNIFICATION, INSURANCE	$379,979	$379,979
2	1	LS	MOBILIZATION AND DEMOBILIZATION	$379,979	$379,979
3	51360	FT	Open Cut Pipe Installation	$124	$6,370,887
4	120	FT	Jack and Bore Under the Roadway	$677	$81,214
5	120	FT	Jack and Bore Under the Railroad	$677	$81,214
6	120	FT	Jack and Bore Under the Railroad	$677	$81,214
7	120	FT	Jack and Bore Under the Railroad	$677	$81,214
8	120	FT	Jack and Bore Under the Railroad	$677	$81,214
9	120	FT	Jack and Bore Under the Railroad	$677	$81,214
10	300	FT	Directional Drill under Alafia River	$698	$209,400
11	33	EA	Pressure Testing	$0	$0
12	2620	EA	X-ray Testing	$0	$0
13	2	EA	Pigging Port	$200,000	$400,000
14	11	EA	Valves	$12,000	$132,000
				Sum of Cost Items	$8,359,600
				15 %Overhead	$1,115,500
				15% Profit	$1,115,500
				10% Contingency	$743,700
				Total Cost	$11,334,300

SCHEDULE OF BID PRICES Option 3 Pipeline within Railroad ROW					
PAY ITEM #	QTY	UNIT	ITEM DESCRIPTION	UNIT PRICE	EXTENDED PRICE
1	1	LS	PAYMENT AND PERFORMANCE BONDS, INDEMNIFICATION, INSURANCE	$360,771	$360,771
2	1	LS	MOBILIZATION AND DEMOBILIZATION	$360,771	$360,771
3	50540	FT	Open Cut Pipe Installation	$124	$6,269,171
4		FT	Open Cut Pipe Casing	$179	$0
5	120	FT	Jack and Bore Under the Roadway	$677	$81,214
6	120	FT	Jack and Bore Under the Railroad	$677	$81,214
7	120	FT	Jack and Bore Under the Railroad	$677	$81,214
8	120	FT	Jack and Bore Under the Railroad	$677	$81,214
9	300	FT	Directional Drill under Alafia River	$698	$209,400
10	31	EA	Pressure Testing	$0	$0
11	2570	EA	X-ray Testing	$0	$0
12	2	EA	Pigging Port	$200,000	$400,000
13	1	EA	Valves	$12,000	$12,000
				Sum of Cost Items	$7,937,000
				15 %Overhead	$1,115,500
				15% Profit	$1,115,500
				10% Contingency	$743,700
				Total Cost	$11,323,700

Activity	Cost per Unit Noted	Description
Open Cut Pipe Construction		
Material and assembly of piping, including welding, handling, x-ray, and testing.	98	Cost from AMEC, 158.18/LF. Adjusted to reduce labor by $60 ($125 to $65, rounded to 98)
Excavation cost	10.14	for digging and backfilling to set the pipe, per Means.
Welding	0.00	included
Handling	0	included
Dewatering	10	Estimate based on previous reclaimed water pipeline construction, adjusted for diameter.
Subtotal	118.14	
Fittings	5.91	Estimated to be 5% of subtotal pipe cost, based on previous reclaimed water pipeline construction.
cost per foot	124	total unit price
Directional Drill under Alafia River		
material cost	98	estimated cost for material, welding, and multiple handling.
Drilling cost	600	Estimate based on previous reclaimed water pipeline construction, adjusted for diameter.
Mob and Set up cost	50	This is a summation of the lump sum setup cost divided by the length of directional drill operation
cost per foot	698	total unit price
Jack and Bore Under the Roadway		
Pipe material cost	98	material cost for the pipe
Casing Material cost	78.78	material cost for the casing
Installation cost	500	Estimate includes jacking and receiving pits, dewatering,
cost per foot	677	total unit price
Jack and Bore Under the Railroad		
Pipe material cost	98	material cost for the pipe
Casing Material cost	78.78	material cost for the casing
Installation cost	500	Estimate includes jacking and receiving pits, dewatering,
cost per foot	677	total unit price
Testing		
Weld test	125	Weld testing is a unit cost per weld test
Pigging port	200000	Estimate based on previous pipeline job. No technical specs or details were provided to AECOM.
Valves	12000	materil cost from Tampa Bay Pipeline, estimated installation cost.
Open Cut Pipe Casing		
Material	78.78	material cost for the pipe

Installation	100	Handling, Assembly and Installation
Cost per foot	179	total unit price

This sheet is used to compile the material and excavation cost to be used in the cost evaluation.

Description	Unit cost	Unit	total	
6-inch Steel	16.94	1	16.94	material cost estimate provided by Consolidated pipe
welding	150	0.05	7.5	assume $150 per weld and coating repair following the weld expand cost over 20 foot length of pipe
Jack and Bore Casing under the road and railway	57.45	1	57.95	12-inch Steel pipe at $57.95 per foot from Means
spacers	2000	120	16.67	Estimated
end cap	500	120	4.17	Estimated
			78.78	total unit cost
Pigging port	200000	1	200000	Estimated, includes all associated valves, fittings and appurtenances
high pressure service Valves	12000	1	12000	Material pricing from Tampa Bay Pipeline, estimated installation cost, includes all associated fittings and appurtenances

Description	Unit cost	Units	CY/Foot of Excavation	Total Cost/Foot of Trench/Pipe
Open cut				
Trench: 3' wide x 5' deep = 15 CF/FT of trench = 1.67 CY/foot of trench				
Assume 4.5 ' of cover on nominal 6" pipe				
Estimated Cost	6.07	CY	1.67	10.14

Activity	Unit Cost	Units	Source
Excavation	2.90	CY	Means 31.23.16.13 0620
Backfill	3.17	CY	Meams 31.23.23.17 0170
Compaction	2.41	CY	Means 31.23.23.23 7020
Total Unit Cost	6.07	CY	

This sheet is used to compile the labor and equipment cost associated with the testing of the installed material used in the cost evaluation.

Description	Unit cost	
Pressure testing	1000	test every 2,000 feet plus at J&B and HDD
Joint / weld x-ray	125	

pressure testing is an estimated cost based on the length of pipe, equipment to pressurize the system and work duration for the test.
Joint / weld X-ray testing is a cost obtained from Welding Testing Laboratories Inc. and is based on 10 tests per day.

Appendix Equipment List

EQUIPMENT LIST

PROJECT TITLE:	RTI Ammonia	REVISION:	H
PROJECT NUMBER:	176858	ISSUED FOR :	INFORMATION
CLIENT DOCUMENT NO.	N/A		
DOCUMENT NO.	176858-110-EQLIST-01		

Equipment Number	Description / Title	REF. DWG PFD / P&ID	Price	Notes
280-AMA-C-711	REGENERATION COMPRESSOR	92127-PID-280-12K	$1,200,000.00	
280-AMA-D-705	AMMONIA FEED KO DRUM	92127-PID-280-12F	$93,028.00	
280-AMA-D-710	REGENERATION KO POT	92127-PID-280-12J	$52,664.00	
280-AMA-DRY-707A	AMMONIA FEED DEHYDRATION MOLE SIEVE A	92127-PID-280-12G	$193,498.00	
280-AMA-DRY-707B	AMMONIA FEED DEHYDRATION MOLE SIEVE B	92127-PID-280-12G	$0.00	included in DRY-707A
	Mole Sieve		$148,818.08	
280-AMA-E-601	METHANATION HEATER	92127-PID-280-11A	$23,675.00	
280-AMA-E-704	AMMONIA FEED COOLER 3	92127-PID-280-12E	$41,650.00	
280-AMA-E-708	MOLE SIEVE HEATER	92127-PID-280-12H	$59,475.00	
280-AMA-E-709	REGENERATION COOLER	92127-PID-280-12J	$36,825.00	
280-AMA-E-710	REGENERATION INTERCHANGER	92127-PID-280-12H	$27,400.00	
280-AMA-FLT-706	AMMONIA FEED COALESCING FILTER	92127-PID-280-12F	$97,993.00	
280-AMA-FLT-712	MOLECULAR SIEVE FILTER	92127-PID-280-12G	$20,838.00	
280-AMA-M-711	REGENERATION COMPRESSOR MOTOR	92127-PID-280-12K	$0.00	
	Methanation Catalyst		$178,679.00	
280-AMA-REV-601	METHANATION REACTOR	92127-PID-280-12C	$168,013.00	
280-AMA-SG-703	AMMONIA FEED STEAM GENERATOR	92127-PID-280-12D	$55,400.00	
280-AMF-M-902	AMMONIIA STORAGE PUMP MOTOR	92127-PID-280-13J	$0.00	
280-AMF-P-902	AMMONIA STORAGE PUMP	92127-PID-280-13J	$70,937.00	
	AMMONIA TRUCK LOADOUT SCALE		$75,000.00	
280-AMF-M-902A	AMMONIA STORAGE PUMP NO.1 MOTOR	92127-PID-280-13F	$0.00	
280-AMF-M-902B	AMMONIA STORAGE PUMP NO.2 MOTOR	92127-PID-280-13F	$0.00	
280-AMF-P-902A	AMMONIA STORAGE PUMP NO.1	92127-PID-280-13F	$70,937.00	
280-AMF-P-902B	AMMONIA STORAGE PUMP NO.2	92127-PID-280-13F	$70,937.00	Estimated Pricing, Alternate Case Only

EQUIPMENT LIST

PROJECT TITLE:	RTI Ammonia	REVISION:	H
PROJECT NUMBER:	176858	ISSUED FOR :	INFORMATION
CLIENT DOCUMENT NO.	N/A		
DOCUMENT NO.	176858-110-EQLIST-01		

Equipment Number	Description / Title	REF. DWG PFD / P&ID	Price	Notes
280-AMF-PKG-901	AMMONIA METERING STATION	92127-PID-280-13G	$150,000.00	
280-AMF-PP-901	AMMONIA PIG LAUNCHER	92127-PID-280-13G	$100,000.00	
280-AMF-PP-902	AMMONIA PIG RECEIVER	92127-PID-280-13G	$100,000.00	
280-AMF-TK-901	AMMONIA STORAGE BULLET NO.1	92127-PID-280-13B	$381,444.00	
280-AMF-TK-902	AMMONIA STORAGE BULLET NO.2	92127-PID-280-13B	$381,444.00	
280-AMF-TK-903	AMMONIA STORAGE BULLET NO.3	92127-PID-280-13C	$381,444.00	
280-AMF-TK-904	AMMONIA STORAGE BULLET NO.4	92127-PID-280-13C	$381,444.00	
280-AMF-TK-905	AMMONIA STORAGE BULLET NO.5	92127-PID-280-13D	$381,444.00	
280-AMF-TK-906	AMMONIA STORAGE BULLET NO.6	92127-PID-280-13D	$381,444.00	
280-AMF-TK-907	AMMONIA STORAGE BULLET NO.7	92127-PID-280-13E	$381,444.00	
280-AMF-TK-908	AMMONIA STORAGE BULLET NO.8	92127-PID-280-13E	$381,444.00	
280-AML-D-909	AMMONIA BLOWDOWN TANK	92127-PID-280-17F	$50,000.00	
280-ASN-C-701	DGAN NITROGEN COMPRESSOR	92127-PID-280-12A	$2,395,000.00	
280-ASN-E-701A	DGAN COMPRESSOR INTERCOOLER NO.1	92127-PID-280-12A	$23,650.00	
280-ASN-E-701B	DGAN COMPRESSOR INTERCOOLER NO.2	92127-PID-280-12A	$0.00	not required per Sundyne
280-AMA-E-701	DGAN COMPRESSOR AFTERCOOLER		$273,975.00	
280-ASN-M-701	DGAN NITROGEN COMPRESSOR MOTOR	92127-PID-280-12A	$0.00	
	DEOXO Catalyst		$220,201.00	
280-ASN-REV-701	DEOXO REACTOR	92127-PID-280-12B	$126,846.00	
280-ASU-C-907	ASU SECONDARY AIR COMPRESSER NO.1	92127-PID-280-18(A-D)	$1,100,000.00	
280-ASU-D-907A	ASU COMPRESSER KO DRUM NO.1	92127-PID-280-18A	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-D-907B	ASU COMPRESSER KO DRUM NO.2	92127-PID-280-18B	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-D-907C	ASU COMPRESSOR KO DRUM NO. 3	92127-PID-280-18C	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-D-907D	ASU COMPRESSOR KO DRUM NO. 4	92127-PID-280-18D	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1

EQUIPMENT LIST

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CLIENT DOCUMENT NO.	N/A		
DOCUMENT NO.	176858-110-EQLIST-01		

Equipment Number	Description / Title	REF. DWG PFD / P&ID	Price	Notes
280-ASU-E-907A	ASU COMPRESSOR INTERCOOLER NO.1	92127-PID-280-18A	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-E-907B	ASU COMPRESSOR INTERCOOLER NO.2	92127-PID-280-18B	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-E-907C	ASU COMPRESSOR INTERCOOLER NO.3	92127-PID-280-18C	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-E-907C	ASU COMPRESSOR INTERCOOLER NO.4	92127-PID-280-18D	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 1
280-ASU-FLT-906	INLET AIR FILTER NO.1	92127-PID-280-18A	$20,000.00	
280-ASU-M-907	ASU SECONDARY COMPRESSOR MOTOR NO.1	92127-PID-280-18B	$0.00	
280-ASU-C-912	ASU SECONDARY AIR COMPRESSER NO.2	92127-PID-280-18(E-H)	$1,100,000.00	
280-ASU-D-912A	ASU COMPRESSOR KO DRUM NO.5	92127-PID-280-18E	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-D-912B	ASU COMPRESSOR KO DRUM NO.6	92127-PID-280-18F	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-D-912C	ASU COMPRESSOR KO DRUM NO. 7	92127-PID-280-18G	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-D-912D	ASU COMPRESSOR KO DRUM NO. 8	92127-PID-280-18H	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-E-912A	ASU COMPRESSOR INTERCOOLER NO.5	92127-PID-280-18E	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-E-912B	ASU COMPRESSOR INTERCOOLER NO.6	92127-PID-280-18F	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-E-912C	ASU COMPRESSOR INTERCOOLER NO.7	92127-PID-280-18G	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-E-912C	ASU COMPRESSOR INTERCOOLER NO.8	92127-PID-280-18H	$0.00	included in ASU SECONDARY AIR COMPRESSOR NO. 2
280-ASU-FLT-911	INLET AIR FILTER NO.2	92127-PID-280-18E	$20,000.00	
280-ASU-M-912	ASU SECONDARY COMPRESSOR MOTOR NO.2	92127-PID-280-18F	$0.00	
280-CCS-CT-901	COOLING TOWER	92127-PID-280-14A	$1,200,000.00	
280-CCS-D-?1	WATER TREATMENT PACKAGE 1	92127-PID-280-14A	$15,000.00	
280-CCS-D-?2	WATER TREATMENT PACKAGE 2	92127-PID-280-14A	$15,000.00	
280-CCS-FLT-901	COOLING WATER SEPARATOR FILTER	92127-PID-280-14A	$50,000.00	
280-CCS-FN-901A	COOLING TOWER FAN NO.1	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-FN-901B	COOLING TOWER FAN NO.2	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-FN-901C	COOLING TOWER FAN NO.3	92127-PID-280-14A	$0.00	included in COOLING TOWER

EQUIPMENT LIST

PROJECT TITLE:	RTI Ammonia	REVISION:	H
PROJECT NUMBER:	176858	ISSUED FOR :	INFORMATION
CLIENT DOCUMENT NO.	N/A		
DOCUMENT NO.	176858-110-EQLIST-01		

		REF. DWG		
Equipment Number	Description / Title	PFD / P&ID	Price	Notes
280-CCS-M-901A	COOLING TOWER FAN NO.1 MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-M-901B	COOLING TOWER FAN NO.2 MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-M-901C	COOLING TOWER FAN NO.3 MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-M-909A	COOLING WATER SUPPLY PUMP NO.1 MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-M-909B	COOLING WATER SUPPLY PUMP NO.2 MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-M-910	COOLING WATER SEPARATOR PUMP MOTOR	92127-PID-280-14A	$0.00	included in COOLING TOWER
280-CCS-P-909A	COOLING WATER SUPPLY PUMP NO.1	92127-PID-280-14A	$150,000.00	
280-CCS-P-909B	COOLING WATER SUPPLY PUMP NO.2	92127-PID-280-14A	$150,000.00	
280-CCS-P-910	COOLING WATER SEPERATOR PUMP	92127-PID-280-14A	$100,000.00	
280-CCS-PKG-?	RAW WATER TREATMENT	92127-PID-280-14A	$100,000.00	
280-DWS-PKG-902	AMMONIA STORAGE FOGGING SYSTEM	92127-PID-280-13H	$75,000.00	
280-DWS-SSH-901	AMMONIA STORAGE SAFETY SHOWER/EYE WASH NO.1	92127-PID-280-13H	$8,000.00	
280-DWS-SSH-902	AMMONIA STORAGE SAFETY SHOWER/EYE WASH NO.2	92127-PID-280-13H	$8,000.00	
280-DWS-SSH-903	AMMONIA STORAGE SAFETY SHOWER/EYE WASH NO.3	92127-PID-280-13H	$8,000.00	

Appendix D Division of Responsibility Matrix

DIVISION OF RESPONSIBILITY

Legend:
O = Owner (TEC) & Project Manager
E = Engineer & Procurement Assistance
C = Contractor
A = Ammonia Technology Supplier (ISBL)
T = OEM Technology Providers (OSBL)

Owner: TEC
Project: Ammonia Plant
Location: Polk County, FL
Date: 12/3/2014

1 - GENERAL	General	LTS	Methanatio n	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Permits - Environmental	O										
Permits - Construction	O / C										
Taxes/Duties	C / A /T										
Freight	C / A /T										
Insurance - General Liability	C / A / T										
Insurance - Builder's Risk	O										
Insurance - Workmen's Comp	C / A / T										
Owner's Cost Estimate	O										
Technology License Fees	A / T										
Financing Costs	O										
Project Numbering System	O										
Engineering & Equipment Delivery Schedules	E	E / T	E / T	E	E / A	E	E	E			C
Project Schedule	E										

2 - PROCESS	General	LTS	Methanatio n	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Process Heat & Material Balances	E	E	E	E	A	E	E				
P&IDs	E	E	E	E	A	E	E				
Utility Flow Diagrams	E	E	E	E	E	E	E				
Priced Equipment List with Weights and HP	E	E	E	E	E / A	E	E				
Process Equipment Data Sheets	E	E	E	E	E / A	E	E				
Propriatary Equipment (as defined in Equipment List)	E	E	E	E	A	E	E		O		C
Other Process / Mechanical Equipment (as defined in Equipment List)	E	E	E	E	E	E	E		O		C
Equipment Support Steel	C	C	C	C	C	C	C				
Vendor Erection Support Services	E	E /T	E /T	E	A	E	E				
Freight to Jobsite	O	O	O	O	O	O	O				

3 - MECHANICAL & PIPING	General	LTS	Methanatio n	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Plot Plan	E	E	E	E	A	E	E	E			

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Project: Ammonia Plant
Location: Polk County, FL
Date: 12/3/2014

Plant 3D Model	E	E	E	E	E	E	E	E			
Equipment Layout Drawings (GAs)	E	E	E	E	E / A	E	E	E			
Piping Line List	E										
Process Piping	E	E	E	E	E	E	E			C	C
Utility Systems Piping:	E						E				
Steam & Condensate	E						E			C	C
Cooling Water	E						E			C	C
BF Water	E						E			C	C
Potable Water	E						E			C	C
Fire Water	E						E			C	C
Natural Gas Piping	E						E			C	C
Plant Air	E						E			C	C
Nitrogen	E						E			C	C
Oxygen	E						E			C	C
Process Sewer	E						E	E		C	C
Drains	E						E			C	C
Oil - Lube	E						E			C	C
Piping System Components	E	E	E	E	E	E	E			C	C
Pipe Supports	E	E	E	E	E	E	E			C	C
Pipe Bridge	E	E	E	E	E	E	E			C	C
Sprinkler Systems	E							E		C	C
HVAC	E							E		C	C
Radiographic Inspection Testing	E	E	E	E	E	E	E			C	C

4 - CIVIL SITE WORKS	General	LTS	Methanation	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Geotechncial Report	O										
Site Survey	O										
Site Clearance	E										
Demolition	E										
Site Plan	E							E		C	C
Site Grading Plan	E							E		C	C
Storm Water System	E							E		C	C
Roads and Paving	E							E		C	C
Underground Utilities Plan	E						E	E		C	C
Railroad Trackage	N.A.							N.A.		N.A.	N.A.
Raw Water System	E						E			C	C

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Owner: TEC
Project: Ammonia Plant
Location: Polk County, FL
Date: 12/3/2014

Fire Protection Water System	E						E		O	C	C
Water Treatment System	E						E		O	C	C
Sanitary Sewer System	E						E	E		C	C
Natural Gas Reducing Station	N.A.						N.A.			N.A.	N.A.
Site Fencing	E							E		C	C
Soil Testing (Density, Proctors, Sieve Analysis)	O										

5 - CONCRETE & STEEL WORKS	**General**	**LTS**	**Methanatio n**	**DGAN**	**Ammonia Plant**	**Ammonia Storage & Loadout**	**Utility Systems**	**Site / Facilities**	**Equipment Supply**	**Material Supply**	**Erection**
Concrete Foundations	E	E	E	E	E	E	E			C	C
Slabs - On Grade and Elevated	E	E	E	E	E	E	E			C	C
Anchor Bolts	E	E	E	E	E	E	E			C	C
Structural Steel	E	E	E	E	E	E	E			C	C
Platforms / Equipment Access	E	E	E	E	E	E	E			C	C
Utility Pipe Bridges	E						E			C	C
Concrete Testing	O										
Steel Testing	O										

6 - ARCHITECTURAL WORKS	**General**	**LTS**	**Methanatio n**	**DGAN**	**Ammonia Plant**	**Ammonia Storage & Loadout**	**Utility Systems**	**Site / Facilities**	**Equipment Supply**	**Material Supply**	**Erection**
Ammonia Plant Compressor Building	E							E		C	C
Miscellaneous Buildings	E							E		C	C

7 - ELECTRICAL WORK	**General**	**LTS**	**Methanatio n**	**DGAN**	**Ammonia Plant**	**Ammonia Storage & Loadout**	**Utility Systems**	**Site / Facilities**	**Equipment Supply**	**Material Supply**	**Erection**
Electrical Single Line	E										
Area Classification Drawings	E	E	E	E	A	E	E				
Motor List	E	E	E	E	E	E	E				
Cable List	E	E	E	E	E	E	E				
Primary Power Feed	O										
Primary Switchgear / Transformers	E								O	C	C
Secondary Switchgear / Transformers	E								O	C	C
MCC Equipment	E	E	E	E	E	E	E		O	C	C
AC Motors	E	E	E	E	E	E	E		O	C	C
Variable Frequency Drives	E	E	E	E	E	E	E		O	C	C

DIVISION OF RESPONSIBILITY

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Owner: TEC
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Location: Polk County, FL
Date: 12/3/2014

Local Motor Controls	E	E	E	E	E	E	E		O	C	C
Grounding System	E	E	E	E	E	E	E			C	C
Cable, Tray & Conduit	E	E	E	E	E	E	E			C	C
Area Lighting	E	E	E	E	E	E	E			C	C
Site Lighting	E						E	E		C	C
Panelboards	E	E	E	E	E	E	E			C	C
Duplex Receptacles	E	E	E	E	E	E	E			C	C
Weld Outlets	E	E	E	E	E	E	E			C	C
Paging & Comm. System	E									C	C
Telephone Raceway	E									C	C
Smoke / Fire Detector	E									C	C
Central Alarm / Panel	E									C	C
Lightning Protection	E									C	C
UPS System	E	C	C	C	C	C	C			C	C

8 - INSTRUMENTATION & CONTROL SYSTEM WORK	General	LTS	Methanation	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Instrument List	E	E	E	E	A	E	E				
Process Specialty Valves & Instruments (as defined in Equipment List)	E	E	E	E	E / A	E	E		O	C	C
Field, Panel and In-Line Instruments	E	E	E	E	E	E	E		O	C	C
Cable List	E	E	E	E	E	E	E			C	C
Wiring to Terminals	E	E	E	E	E	E	E			C	C
Pneumatic Tubing	E	E	E	E	E	E	E			C	C
Instrument Stands	E	E	E	E	E	E	E			C	C
Plant Control System Narrative	E	E	E	E	A	E	E				
Emergency Shutdown System Description	E	E	E	E	A	E	E				
Interlock System Descriptions	E	E	E	E	A	E	E				
Plant Control System Block Diagram	E										
Plant Contol System Network	E									C	C
Plant Control System Hardware	E								O		
Plant Control System Software	E								O		
Programming & Configuration	E	E	E	E	E	E	E				
I/O Devices	E	E	E	E	E	E	E			C	C

DIVISION OF RESPONSIBILITY

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C = Contractor
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T = OEM Technology Providers (OSBL)

Owner: TEC
Project: Ammonia Plant
Location: Polk County, FL
Date: 12/3/2014

9 - CHECK OUT & START UP	General	LTS	Methanation	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Flush Systems and Water Runs	C	C	C	C	C	C	C				
Electrical Check-Out	C	C	C	C	C	C	C				
Instrumentation Checkout	C	C	C	C	C	C	C				
Loop Checks	C	C	C	C	C	C	C				
Post-Installation Instrument Calibration	C	C	C	C	C	C	C				
Construction Startup Standby Assistance	C	C	C	C	C	C	C				
Erection Advisory Support Services	T	T	T	T	A	T	T				
Licensor Startup Services	T	T	T	T	A	T	T				
Licensor Operating Manuals	T	T	T	T	A	T	T				
Technology Training	T	T	T	T	A	T	T				

10 - TEMPORARY SERVICES	General	LTS	Methanation	DGAN	Ammonia Plant	Ammonia Storage & Loadout	Utility Systems	Site / Facilities	Equipment Supply	Material Supply	Erection
Site Electric Power	O										
Site Power Distribution System	C										
Water - Construction	O										
Water - Potable	C										
Compressed Air	C										
Sanitary Facilities	C										
Receiving	C										
Site Warehousing	O										
Security Service	O										
Fire Extinguishers for Construction Site	C										
First Aid / Safety	C										
Drug Testing	C										
Field Offices	C										
Telephones	C										
Internet Service	C										
Field Office Equipment	C										
Laydown Yard	C										
Rubbish Removal	C										
On-Site Soil and Debris Disposal Area	O										

Appendix E CAPEX Estimate

amec

RTI International
TEC Polk Station Ammonia Feed
FEL3 Estimate

Spreadsheet Level	Takeoff Quantity/Unit	Labor Hours/Unit	Labor Quantity (Hours)	Labor Rate (USD)	Labor Amount (USD)	Material Price (USD)	Material Amount (USD)	Sub Price (USD)	Sub Amount (USD)	Equip Price (USD)	Equip Amount (USD)	Total Amount (USD)
01-ISBL			*75,935.65*		*3,253,931*		*2,587,836*		*1,092,295*		*23,189,091*	*30,123,153*
02-OSBL			*186,760.44*		*7,930,323*		*6,643,216*		*3,444,054*		*13,545,037*	*31,562,630*

Estimate Totals

Description	Amount	Totals	Hours	Rate
Labor	11,184,254		262,696.09 hrs	
Material	9,231,052			
Subcontract	4,536,349			
Equipment-Process	36,734,128			
Subtotal-Direct Costs	61,685,783	61,685,783		
Support Costs	6,146,234			
Site Services & Facilities	585,433			
Equipment, Tools & Supplies	3,286,428			
Fuel & Maintenance	277,892			
Sales Tax(exclude Prcss Equip)	355,785			
General Expenses	130,748			
Construction Project Personnel	2,686,332			
Contractor OH&P	4,751,318			
Subtotal	18,220,170	79,905,953		
TECHNOLOGY FEE	450,000			
ERECTION SUPV(Factor on Equip)	918,353			2.50 %
SALES TAX - MATERIAL	646,174			
SPARE PARTS(Factor on Equip)	734,683			2.00 %
OWNER'S COST(Factor on Direct)	3,701,147			6.00 %
COMMISSION(Factor on Direct)	1,233,716			2.00 %
ENGINEERING	6,560,000			
Subtotal	14,244,073	94,150,026		
CONTINGENCY(Factor on Subtot)	4,707,501			5.00 %
PROJECT ESCALATION (BY TECO)				
	4,707,501	98,857,527		
Total		**98,857,527**		

Spreadsheet Level	Takeoff Quantity/Unit	Labor Hours/Unit	Labor Quantity (Hours)	Labor Rate (USD)	Labor Amount (USD)	Material Price (USD)	Material Amount (USD)	Sub Price (USD)	Sub Amount (USD)	Equip Price (USD)	Equip Amount (USD)	Total Amount (USD)
0100 Sitework			*301.00*		*10,659*		*39,600*		*274,815*			*325,074*
0300 ISBL Civil	*4,046.00 cy*		*8,476.91*		*353,894*		*287,049*		*6,044*			*646,987*
0301-OSBL Civil			*29,883.28*		*1,218,742*		*954,430*		*1,415,028*			*3,588,200*
0400 ISBL Structural	*668.00 tn*		*7,566.92*		*464,079*		*893,681*		*49,316*			*1,407,077*
0401-OSBL Structural			*13,347.34*		*818,592*		*1,523,665*		*48,286*			*2,390,543*
0500-ISBL Equipment			*5,394.00*		*220,764*				*77,535*		*16,419,729*	*16,718,028*
0501-OSBL Equipment			*10,655.00*		*421,623*		*351,000*		*142,425*		*15,745,037*	*16,660,085*
0600-ISBL Piping	*23,224.00 lf*		*35,504.82*		*1,487,297*		*717,986*		*857,200*			*3,062,483*
0601-OSBL Piping	*47,587.00 lf*		*110,900.83*		*4,645,636*		*2,653,279*		*1,563,500*			*8,862,415*
0700-ISBL Electrical			*19,462.00*		*721,456*		*1,055,987*					*1,777,443*
0701-OSBL Electrical			*14,094.00*		*522,465*		*541,971*		*102,200*		*2,539,605*	*3,706,241*
0750-ISBL Instrument			*2,451.00*		*103,089*		*65,255*					*168,344*
0751-OSBL Instrument			*4,659.00*		*195,958*		*147,149*				*2,029,757*	*2,372,864*

Estimate Totals

Description	Amount	Totals	Hours	Rate
Labor	**11,184,254**		**262,696.09 hrs**	
Material	**9,231,052**			
Subcontract	**4,536,349**			
Equipment-Process	**36,734,128**			
Subtotal-Direct Costs	**61,685,783**	**61,685,783**		
Support Costs	**6,146,234**			
Site Services & Facilities	**585,433**			
Equipment, Tools & Supplies	**3,286,428**			
Fuel & Maintenance	**277,892**			
Sales Tax(exclude Prcss Equip)	**355,785**			
General Expenses	**130,748**			
Construction Project Personnel	**2,686,332**			
Contractor OH&P	**4,751,318**			
Subtotal	**18,220,170**	**79,905,953**		
TECHNOLOGY FEE	**450,000**			
ERECTION SUPV(Factor on Equip)	**918,353**			**2.50 %**
SALES TAX - MATERIAL	**646,174**			
SPARE PARTS(Factor on Equip)	**734,683**			**2.00 %**
OWNER'S COST(Factor on Direct)	**3,701,147**			**6.00 %**
COMMISSION(Factor on Direct)	**1,233,716**			**2.00 %**
ENGINEERING	**6,560,000**			
Subtotal	**14,244,073**	**94,150,026**		
CONTINGENCY(Factor on Subtot)	**4,707,501**			**5.00 %**
PROJECT ESCALATION (BY TECO)				
	4,707,501	**98,857,527**		
Total		**98,857,527**		

Appendix F Ammonia Truck Load Out Estimate

Spreadsheet Level	Takeoff Quantity	Labor Productivity	Labor Quantity	Labor Price	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Total Cost/Unit	Total Amount
0100-Sitework													
01-Fencing													
10' Chain Link Fence	475.00 lf		-	-	-	-	-	60.00	28,500	-	-	60.00 /lf	28,500
Chain Link Gate - 12' wide x 10' high (Manual)	2.00 ea		-	-	-	-	-	3,000.00	6,000	-	-	3,000.00 /ea	6,000
01-Fencing									**34,500**				**34,500**
0100-Sitework									***34,500***				***34,500***
0200-Building													
01-Operator Room													
12'x12' Prefab building w/lighting & HVAC	1.00 ea			125.00				50,000.00	50,000	-	-	50,000.00 /ea	50,000
01-Operator Room									**50,000**				**50,000**
0200-Building									***50,000***				***50,000***
0300-Concrete													
01-Footings													
Machine Excavate & Loadout	7.26 cy	0.140	1.02	125.00	127	-	-	-	-	-	-	17.50 /cy	127
Backfill, Spread & Compact (25% waste)	3.56 cy	0.250	0.89	125.00	111	7.00	25			-	-	38.25 /cy	136
Crushed Stone (2.0 TONS/CY)	1.85 cy	0.198	0.37	125.00	46	33.00	122	-	-	-	-	90.75 /cy	168
Fine Grade	100.00 sf	0.007	0.70	125.00	88	-	-	-	-	-	-	0.88 /sf	88
Stockpile Excavated materials (16 cy/load)	7.26 cy	0.080	0.58	125.00	73	-	-	45.00	20	-	-	12.81 /cy	93
Load Excavated materials from Stockpile (16 cy/load)	3.56 cy	0.080	0.28	125.00	36	-	-	45.00	10	-	-	12.81 /cy	46
Grading @ Stockpile	7.26 cy	0.005	0.04	125.00	5	-	-	-	-	-	-	0.63 /cy	5
Form Pile Caps	160.00 sf	0.200	32.00	125.00	4,000	2.50	400	-	-	-	-	27.50 /sf	4,400
Strip Formwork	160.00 sf	0.100	16.00	125.00	2,000					-	-	12.50 /sf	2,000
Supply & Install Rebar Standees (10% waste-mat'l)	0.11 ton	30.000	3.21	125.00	401	980.00	116	-	-	-	-	4,830.75 /ton	517
Supply & Install Rebar (10% waste-mat'l)	0.46 ton	19.000	8.80	125.00	1,100	980.00	499	-	-	-	-	3,452.38 /ton	1,598
Supply & Install Rebar Dowels (10% waste-mat'l)	0.11 ton	40.000	4.24	125.00	530	980.00	115	-	-	-	-	6,081.70 /ton	645
Supply & Install Rebar Ties (10% waste-mat'l)	0.05 ton	20.000	0.94	125.00	118	980.00	51	-	-	-	-	3,584.30 /ton	168
Edge Bars	0.29 ton	19.000	5.47	125.00	684	980.00	282	-	-	-	-	3,355.00 /ton	966
Rebar Accessories	0.72 ton		-	-	-	35.00	25	-	-	-	-	35.00 /ton	25
Pour Pile Caps (5% waste)	3.56 cy	1.000	3.73	125.00	467	100.00	373	-	-	-	-	236.26 /cy	840
Screed & Float Concrete	100.00 sf	0.003	0.30	125.00	38	-	-	-	-	-	-	0.38 /sf	38
Broom Concrete	100.00 sf	0.020	2.00	125.00	250	-	-	-	-	-	-	2.50 /sf	250
Apply Curing Compound	100.00 sf	0.002	0.20	125.00	25	0.10	10	-	-	-	-	0.35 /sf	35
Break Ties & Patch Concrete	160.00 sf	0.020	3.20	125.00	400	0.02	3	-	-	-	-	2.52 /sf	403
01-Footings			**83.97**		**10,496**		**2,021**		**30**				**12,548**
02-Piers													
Roughen Concrete Slab	16.00 sf	0.050	0.80	125.00	100	-	-	-	-	-	-	6.25 /sf	100
Apply Bonding Agent	16.00 sf	0.025	0.40	125.00	50	0.10	2	-	-	-	-	3.23 /sf	52
Form Small Piers/pedestals	64.00 sf	0.200	12.80	125.00	1,600	2.50	160	-	-	-	-	27.50 /sf	1,760
Strip Formwork	64.00 sf	0.100	6.40	125.00	800					-	-	12.50 /sf	800
3/4" Anchor Bolts	32.00 ea	1.000	32.00	125.00	4,000	10.00	320	-	-	-	-	135.00 /ea	4,320
Rebar Accessories	0.05 ton		-	-	-	35.00	2	-	-	-	-	35.00 /ton	2
Pour Regular Columns/Piers (5% waste)	0.59 cy	1.000	0.62	125.00	78	100.00	62	-	-	-	-	236.39 /cy	140
Screed & Float Concrete	16.00 sf	0.003	0.05	125.00	6	-	-	-	-	-	-	0.38 /sf	6
Broom Concrete	16.00 sf	0.020	0.32	125.00	40	-	-	-	-	-	-	2.50 /sf	40
Apply Curing Compound	80.00 sf	0.002	0.16	125.00	20	0.10	8	-	-	-	-	0.35 /sf	28

Spreadsheet Level	Takeoff Quantity	Labor Productivity	Labor Quantity	Labor Price	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Total Cost/Unit	Total Amount
02-Piers													
Break Ties & Patch Concrete	64.00 sf	0.020	1.28	125.00	160	0.02	1	-	-	-	-	2.52 /sf	161
Rub Concrete	64.00 sf	0.040	2.56	125.00	320	0.06	4	-	-	-	-	5.06 /sf	324
Supply & Install Grout (CF)	2.67 cf	6.000	16.00	125.00	2,000	75.00	200	-	-	-	-	825.00 /cf	2,200
02-Piers			**73.39**		**9,174**		**759**						**9,933**
03-Slab on grade													
Machine Excavate & Loadout	126.00 cy	0.140	17.64	125.00	2,205	-	-	-	-	-	-	17.50 /cy	2,205
Backfill, Spread & Compact (25% waste)	1.65 cy	0.250	0.41	125.00	51	7.00	12			-	-	38.25 /cy	63
Crushed Stone (2.0 TONS/CY)	59.26 cy	0.198	11.73	125.00	1,467	33.00	3,911	-	-	-	-	90.75 /cy	5,378
Fine Grade	3,200.00 sf	0.007	22.40	125.00	2,800	-	-	-	-	-	-	0.88 /sf	2,800
4 mil Vapor Barrier	3,520.00 sf	0.002	7.74	125.00	968	0.03	92	-	-	-	-	0.30 /sf	1,060
Stockpile Excavated materials (16 cy/load)	126.00 cy	0.080	10.08	125.00	1,260	-	-	45.00	354	-	-	12.81 /cy	1,614
Load Excavated materials from Stockpile (16 cy/load)	1.65 cy	0.080	0.13	125.00	16	-	-	45.00	5	-	-	12.81 /cy	21
Grading @ Stockpile	126.00 cy	0.005	0.63	125.00	79	-	-	-	-	-	-	0.63 /cy	79
Form Slab On Grade	400.00 sf	0.200	80.00	125.00	10,000	2.50	1,000			-	-	27.50 /sf	11,000
Strip Formwork	400.00 sf	0.100	40.00	125.00	5,000					-	-	12.50 /sf	5,000
Supply & Install Rebar (10% waste-mat'l)	4.85 ton	19.000	92.15	125.00	11,519	980.00	5,228	-	-	-	-	3,453.00 /ton	16,747
Supply & Install Rebar Dowels (10% waste-mat'l)	0.29 ton	40.000	11.76	125.00	1,470	980.00	317	-	-	-	-	6,076.67 /ton	1,787
Rebar Accessories	5.14 ton		-	-	-	35.00	180	-	-	-	-	35.00 /ton	180
Pour Slabs On Grade (5% waste included on materials)	82.30 cy	1.000	86.42	125.00	10,802	100.00	8,642	-	-	-	-	236.25 /cy	19,444
Screed & Float Concrete	3,200.00 sf	0.003	9.60	125.00	1,200	-	-	-	-	-	-	0.38 /sf	1,200
Broom Concrete	3,200.00 sf	0.020	64.00	125.00	8,000	-	-	-	-	-	-	2.50 /sf	8,000
Apply Curing Compound	3,200.00 sf	0.002	6.40	125.00	800	0.10	320	-	-	-	-	0.35 /sf	1,120
Break Ties & Patch Concrete	400.00 sf	0.020	8.00	125.00	1,000	0.02	8	-	-	-	-	2.52 /sf	1,008
03-Slab on grade			**469.10**		**58,637**		**19,710**		**359**				**78,706**
04-Containment wall													
Form Regular Walls	400.00 sf	0.200	80.00	125.00	10,000	2.50	1,000			-	-	27.50 /sf	11,000
Strip Formwork	400.00 sf	0.100	40.00	125.00	5,000					-	-	12.50 /sf	5,000
Pour Walls (5% waste)	4.96 cy	1.000	4.96	125.00	620	100.00	496	-	-	-	-	225.00 /cy	1,117
Screed & Float Concrete	134.00 sf	0.003	0.40	125.00	50	-	-	-	-	-	-	0.38 /sf	50
Apply Curing Compound	400.00 sf	0.002	0.80	125.00	100	0.10	40	-	-	-	-	0.35 /sf	140
Break Ties & Patch Concrete	400.00 sf	0.020	8.00	125.00	1,000	0.02	8	-	-	-	-	2.52 /sf	1,008
Rub Concrete	400.00 sf	0.040	16.00	125.00	2,000	0.06	24	-	-	-	-	5.06 /sf	2,024
04-Containment wall			**150.17**		**18,771**		**1,568**						**20,339**
05-Approach slab													
Machine Excavate & Loadout	17.11 cy	0.140	2.40	125.00	299	-	-	-	-	-	-	17.50 /cy	299
Backfill, Spread & Compact (25% waste)	1.98 cy	0.250	0.49	125.00	62	7.00	14			-	-	38.25 /cy	76
Crushed Stone (2.0 TONS/CY)	7.41 cy	0.198	1.47	125.00	183	33.00	489	-	-	-	-	90.75 /cy	672
Fine Grade	400.00 sf	0.007	2.80	125.00	350	-	-	-	-	-	-	0.88 /sf	350
4 mil Vapor Barrier	440.00 sf	0.002	0.97	125.00	121	0.03	12	-	-	-	-	0.30 /sf	133
Stockpile Excavated materials (16 cy/load)	17.11 cy	0.080	1.37	125.00	171	-	-	45.00	48	-	-	12.81 /cy	219
Load Excavated materials from Stockpile (16 cy/load)	1.98 cy	0.080	0.16	125.00	20	-	-	45.00	6	-	-	12.81 /cy	25
Grading @ Stockpile	17.11 cy	0.005	0.09	125.00	11	-	-	-	-	-	-	0.63 /cy	11
Supply & Install Rebar (10% waste-mat'l)	0.63 ton	19.000	12.01	125.00	1,501	980.00	681	-	-	-	-	3,452.69 /ton	2,182
Rebar Accessories	0.63 ton		-	-	-	35.00	22	-	-	-	-	35.00 /ton	22
Pour Slabs On Grade (5% waste included on materials)	9.88 cy	1.000	10.37	125.00	1,296	100.00	1,037	-	-	-	-	236.25 /cy	2,333
Screed & Float Concrete	400.00 sf	0.003	1.20	125.00	150	-	-	-	-	-	-	0.38 /sf	150

Spreadsheet Level	Takeoff Quantity	Labor Productivity	Labor Quantity	Labor Price	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Total Cost/Unit	Total Amount
05-Approach slab													
Broom Concrete	400.00 sf	0.020	8.00	125.00	1,000	-	-	-	-	-	-	2.50 /sf	1,000
Apply Curing Compound	400.00 sf	0.002	0.80	125.00	100	0.10	40	-	-	-	-	0.35 /sf	140
05-Approach slab			**42.12**		**5,264**		**2,295**		**54**				**7,613**
06-Building fdn													
Machine Excavate & Loadout	6.26 cy	0.140	0.88	125.00	110	-	-	-	-	-	-	17.50 /cy	110
Backfill, Spread & Compact (25% waste)	0.79 cy	0.250	0.20	125.00	25	7.00	6			-	-	38.25 /cy	30
Crushed Stone (2.0 TONS/CY)	2.67 cy	0.198	0.53	125.00	66	33.00	176	-	-	-	-	90.75 /cy	242
Fine Grade	144.00 sf	0.007	1.01	125.00	126	-	-	-	-	-	-	0.88 /sf	126
4 mil Vapor Barrier	158.40 sf	0.002	0.35	125.00	44	0.03	4	-	-	-	-	0.30 /sf	48
Stockpile Excavated materials (16 cy/load)	6.26 cy	0.080	0.50	125.00	63	-	-	45.00	18	-	-	12.81 /cy	80
Load Excavated materials from Stockpile (16 cy/load)	0.79 cy	0.080	0.06	125.00	8	-	-	45.00	2	-	-	12.81 /cy	10
Grading @ Stockpile	6.26 cy	0.005	0.03	125.00	4	-	-	-	-	-	-	0.63 /cy	4
1/2" Anchor Bolts	8.00 ea	0.500	4.00	125.00	500	5.00	40	-	-	-	-	67.50 /ea	540
Supply & Install Rebar (10% waste-mat'l)	0.12 ton	19.000	2.19	125.00	273	980.00	124	-	-	-	-	3,457.30 /ton	398
Rebar Accessories	0.12 ton		-	-	-	35.00	4	-	-	-	-	35.00 /ton	4
Pour Slabs On Grade (5% waste included on materials)	3.56 cy	1.000	3.73	125.00	467	100.00	373	-	-	-	-	236.26 /cy	840
Screed & Float Concrete	144.00 sf	0.003	0.43	125.00	54	-	-	-	-	-	-	0.38 /sf	54
Steel Trowel Concrete	144.00 sf	0.020	2.88	125.00	360	-	-	-	-	-	-	2.50 /sf	360
Apply Curing Compound	144.00 sf	0.002	0.29	125.00	36	0.10	14	-	-	-	-	0.35 /sf	50
06-Building fdn			**17.07**		**2,134**		**742**		**20**				**2,896**
07-Other concrete													
MIsc concrete	20.00 cy	20.000	400.00	125.00	50,000	400.00	8,000	-	-	-	-	2,900.00 /cy	58,000
07-Other concrete			**400.00**		**50,000**		**8,000**						**58,000**
0300-Concrete			***1,235.81***		***154,477***		***35,095***		***463***				***190,034***
0400-Structural													
01-Tee poles													
Tee Pole Supports	20.00 ea	5.000	100.00	125.00	12,500	750.00	15,000	-	-	-	-	1,375.00 /ea	27,500
01-Tee poles			**100.00**		**12,500**		**15,000**						**27,500**
0400-Structural			***100.00***		***12,500***		***15,000***						***27,500***
0500-Equipment													
*** unassigned ***													
Truck scale and supports	1.00 ea	200.000	200.00	125.00	25,000			-	-	100,000.00	100,000	125,000.00 /ea	125,000
Fogging system	1.00 ea	40.000	40.00	125.00	5,000			-	-	3,000.00	3,000	8,000.00 /ea	8,000
Safety shower	1.00 ea	20.000	20.00	125.00	2,500			-	-	1,000.00	1,000	3,500.00 /ea	3,500
Relief valve	1.00 ea	10.000	10.00	125.00	1,250			-	-	5,000.00	5,000	6,250.00 /ea	6,250
Booster pump	1.00 ea	30.000	30.00	125.00	3,750			-	-	3,000.00	3,000	6,750.00 /ea	6,750
Backflow preventer	1.00 ea	40.000	40.00	125.00	5,000			-	-	750.00	750	5,750.00 /ea	5,750
*** unassigned ***			**340.00**		**42,500**						**112,750**		**155,250**
0500-Equipment			***340.00***		***42,500***						***112,750***		***155,250***
0600-Piping													
01-Pipe													
1" Composite Piping - A53 CS	1,150.00 lf	0.975	1,121.25	125.00	140,156	7.66	8,809	-	-	-	-	129.54 /lf	148,965
1 1/2" Composite Piping - A53 CS	200.00 lf	1.305	261.00	125.00	32,625	9.96	1,992	-	-	-	-	173.09 /lf	34,617

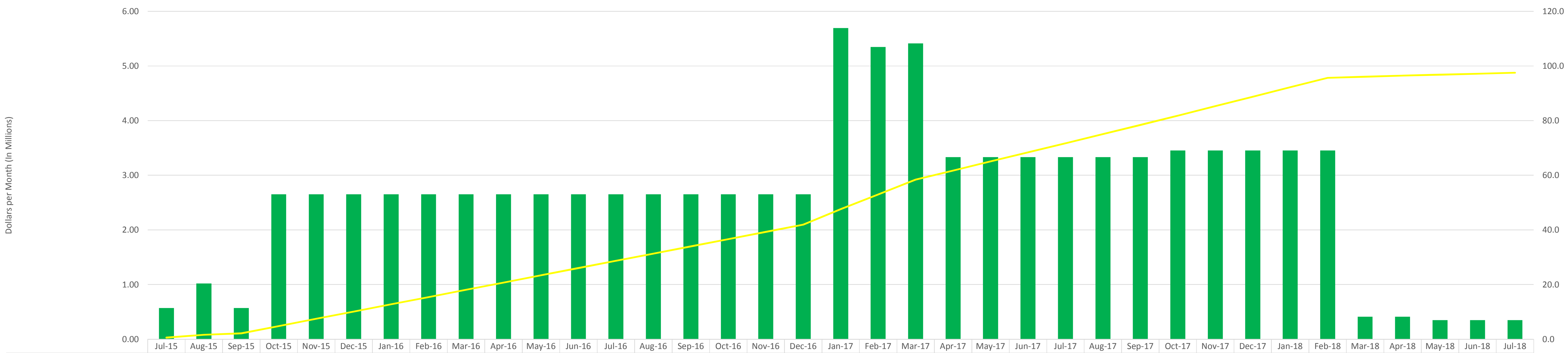
Spreadsheet Level	Takeoff Quantity	Labor Productivity	Labor Quantity	Labor Price	Labor Amount	Material Price	Material Amount	Sub Price	Sub Amount	Equip Price	Equip Amount	Total Cost/Unit	Total Amount
01-Pipe													
3" Composite Piping - A53 CS	200.00 lf	1.875	375.00	125.00	46,875	11.70	2,340	-	-	-	-	246.08 /lf	49,215
6" Composite Piping - A53 CS	150.00 lf	2.670	400.50	125.00	50,063	32.22	4,833	-	-	-	-	365.97 /lf	54,896
01-Pipe			**2,157.75**		**269,719**		**17,974**						**287,693**
02-Valves													
Gate Valve 1" - 150#	8.00 ea	0.480	3.84	125.00	480	40.00	320	-	-	-	-	100.00 /ea	800
Gate Valve 1-1/2" - 150#	4.00 ea	0.675	2.70	125.00	338	70.00	280	-	-	-	-	154.38 /ea	618
Gate Valve 6" - 150#	2.00 ea	4.800	9.60	125.00	1,200	600.00	1,200	-	-	-	-	1,200.00 /ea	2,400
02-Valves			**16.14**		**2,018**		**1,800**						**3,818**
0600-Piping			***2,173.89***		***271,736***		***19,774***						***291,510***
0700*Electrical													
01-Power Feeders													
Power to equipment/lights	1.00 ls	300.000	300.00	125.00	37,500	6,000.00	6,000	-	-	8,000.00	8,000	51,500.00 /ls	51,500
01-Power Feeders			**300.00**		**37,500**		**6,000**				**8,000**		**51,500**
02-Lighting													
Pole lights	4.00 ea	10.000	40.00	125.00	5,000	800.00	3,200	-	-	-	-	2,050.00 /ea	8,200
02-Lighting			**40.00**		**5,000**		**3,200**						**8,200**
03-Grounding													
Grounding	1.00 ls	50.000	50.00	125.00	6,250	1,000.00	1,000	-	-	-	-	7,250.00 / ls	7,250
03-Grounding			**50.00**		**6,250**		**1,000**						**7,250**
0700*Electrical			***390.00***		***48,750***		***10,200***				***8,000***		***66,950***
0750-Instrumentation													
01-Instruments													
Blending and loadout skid	1.00 ea	40.000	40.00	125.00	5,000					100,000.00	100,000	105,000.00 /ea	105,000
Monitors/alarms	1.00 ls	40.000	40.00	125.00	5,000	500.00	500			13,000.00	13,000	18,500.00 /ls	18,500
Cabling	1.00 ls	40.000	40.00	125.00	5,000	2,500.00	2,500					7,500.00 /ls	7,500
01-Instruments			**120.00**		**15,000**		**3,000**				**113,000**		**131,000**
0750-Instrumentation			***120.00***		***15,000***		***3,000***				***113,000***		***131,000***

Estimate Totals

	Description	Amount	Totals	Hours	Rate	Cost Basis
Labor		**544,963**		**4,359.70 hrs**		
Material		**83,069**				
Subcontract		**84,963**				
Equipment		**233,750**				
		946,745	**946,745**			
ENGINEERING		**50,000**				**L**
OWNER'S COSTS		**28,402**			**3.00 %**	**T**
CONTINGENCY		**47,337**			**5.00 %**	**T**
PROJECT ESCALATION		**32,175**			**3.00 %**	**T**
	Total		**1,104,659**			

Appendix G Cash Flow Curve

RTI Ammonia FEED EPCM Cash Flow Curve



	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16
Dollars / Month (In Millions)	0.57	1.02	0.57	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Cumulative Dollars (In Millions)	0.6	1.6	2.2	4.8	7.5	10.1	12.8	15.4	18.1	20.7	23.4	26.0	28.7

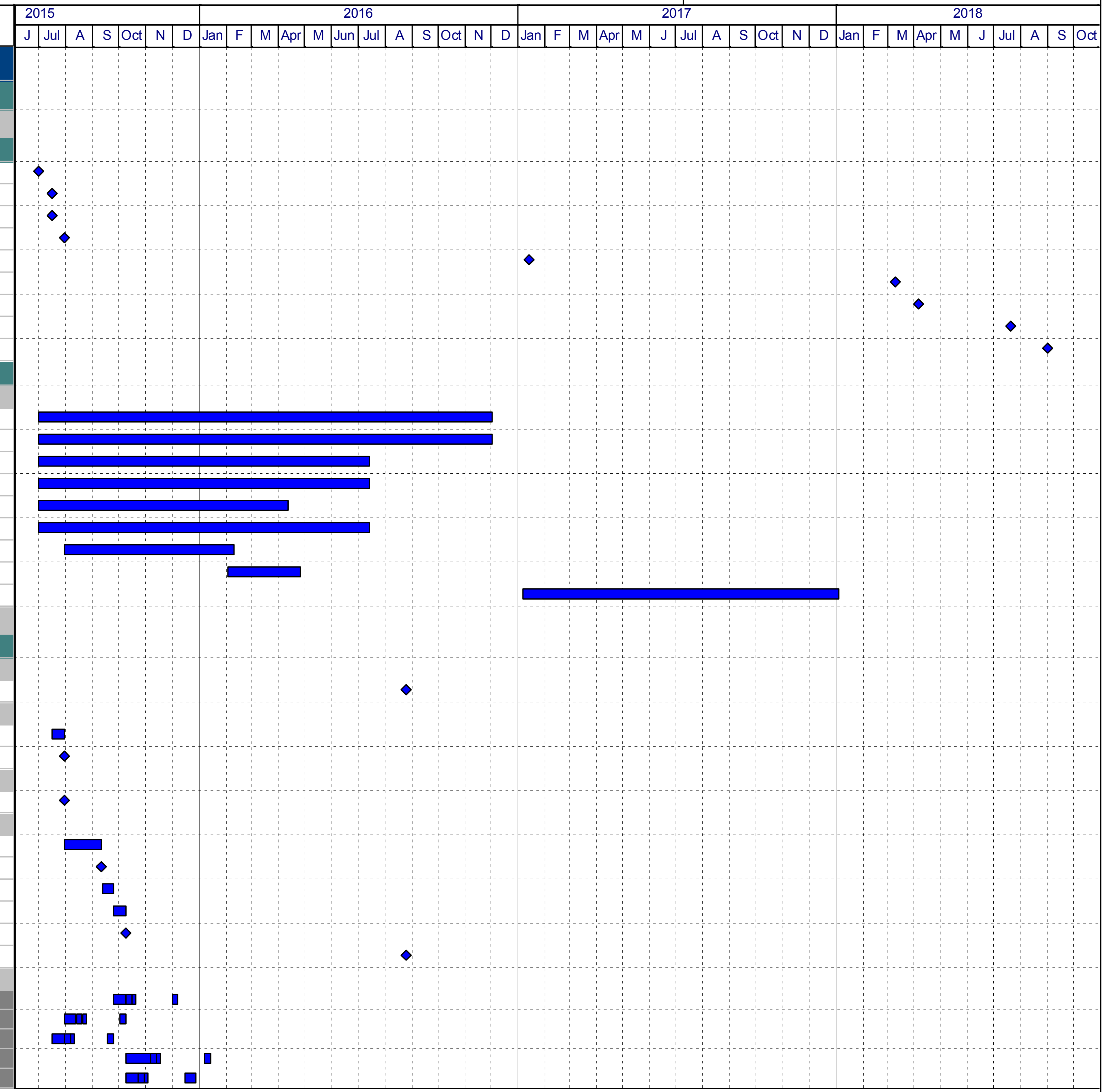
	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17
Dollars / Month (In Millions)	2.65	2.65	2.65	2.65	2.65	5.69	5.35	5.41	3.33	3.33	3.33	3.33
Cumulative Dollars (In Millions)	31.3	34.0	36.6	39.3	41.9	47.6	53.0	58.4	61.7	65.1	68.4	71.7

	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18
Dollars / Month (In Millions)	3.33	3.33	3.46	3.46	3.46	3.46	3.46	0.41	0.41	0.35	0.35	0.35
Cumulative Dollars (In Millions)	75.1	78.4	81.8	85.3	88.8	92.2	95.7	96.1	96.5	96.8	97.2	97.5

Appendix H Project Schedule

Data Date: 28-Dec-14
Run Date: 22-Jan-15 09:27
TASK filters: (Untitled Filter)_14, Level of Effort.

Activity ID	Activity Name	Days	Start	Finish
RTI / TEC Ammonia Integration FEED Study		828	01-Jul-15	31-Aug-18
RTI Ammonia Integration EPCM		828	01-Jul-15	31-Aug-18
Project Administration		816	01-Jul-15	31-Aug-18
Overall Project Milestones		816	01-Jul-15	31-Aug-18
M-1540	Receive TEC Board Approval	0		01-Jul-15*
M-0000	Award Detailed Engineering Contract	0		15-Jul-15
M-0001	Award Ammonia Process Detailed Engineering Contract	0		15-Jul-15
M-0002	Ammonia Integration Project KickOff Date	0		29-Jul-15
M-1020	Mobilize Date	0		13-Jan-17
M-1450	Mechanical Completion	0		09-Mar-18
M-1480	Substantial Completion	0		06-Apr-18
M-1530	Final Completion	0		20-Jul-18
M-000020	Plant In-service Date	0		31-Aug-18
Permitting		645	01-Jul-15	04-Jan-18
Permits Obtained by TEC		645	01-Jul-15	04-Jan-18
PERM-1000	Modification to the Conditions of Certification	360	01-Jul-15	01-Dec-16
PERM-1020	Air Construction Permit	360	01-Jul-15	01-Dec-16
PERM-1070	NPDES Modification	260	01-Jul-15	14-Jul-16
PERM-1080	DHS Permitting	260	01-Jul-15	14-Jul-16
PERM-1100	Hazardous Waste Permit	194	01-Jul-15	12-Apr-16
PERM-1110	Raw Water Permit for Cooling Tower	260	01-Jul-15	14-Jul-16
PERM-1130	Risk Management Plan	130	30-Jul-15	10-Feb-16
PERM-1040	Construction Stormwater Plan	60	03-Feb-16	26-Apr-16
PERM-1120	Update to the PSM Plan	260	06-Jan-17	04-Jan-18
mmmonia a t Detailed Engineering		280	16-Jul-15	25-Aug-16
Process Engineering		280	16-Jul-15	25-Aug-16
General		0	25-Aug-16	25-Aug-16
E-27480	Ammonia Process Engineering Discipline Complete	0		25-Aug-16
Design Criteria		10	16-Jul-15	29-Jul-15
E-26710	Develop & /Submit ISBL Design Criteria - Process	10	16-Jul-15	29-Jul-15
E-26720	ISBL Design Criteria - Process - IFD	0		29-Jul-15
Piping Service Index		0	29-Jul-15	29-Jul-15
E-26810	ISBL Piping Service Index - Process - IFD	0		29-Jul-15
ISBL P&ID's		270	30-Jul-15	25-Aug-16
E-26640	Develop/Submit IFA ISBL P&IDs & Preliminary Line Sizing	30	30-Jul-15	10-Sep-15
E-26750	ISBL P&IDs & Preliminary Line Sizing - IFA	0		10-Sep-15
E-26650	Owner Review/Approve IISBL P&IDs & Preliminary Line Sizing	10	11-Sep-15	24-Sep-15
E-26770	ISBL P&IDs & Preliminary Line Sizing - Incorporate Client Comments	10	25-Sep-15	08-Oct-15
E-26760	ISBL P&IDs & Line Sizing - IFD with Holds	0		08-Oct-15
E-26660	ISBL P&ID Drawings - IFD Without Holds	0		25-Aug-16
Specifications		120	16-Jul-15	13-Jan-16
Shell & Tube Heat Exchangers		50	25-Sep-15	07-Dec-15
Vessels		50	30-Jul-15	08-Oct-15
Compressors		50	16-Jul-15	24-Sep-15
Centrifugal Pumps		60	09-Oct-15	13-Jan-16
Ammonia Feed Steam Generators		50	09-Oct-15	28-Dec-15



Current
Milestone
Milestone Actual

RTI International, TEC Polk Station

Ammonia FEED Study Project Schedule

Date	Revision	Checked	Approved
22-Jan-15	Ammonia FEED Estimate Submission	MM	GM

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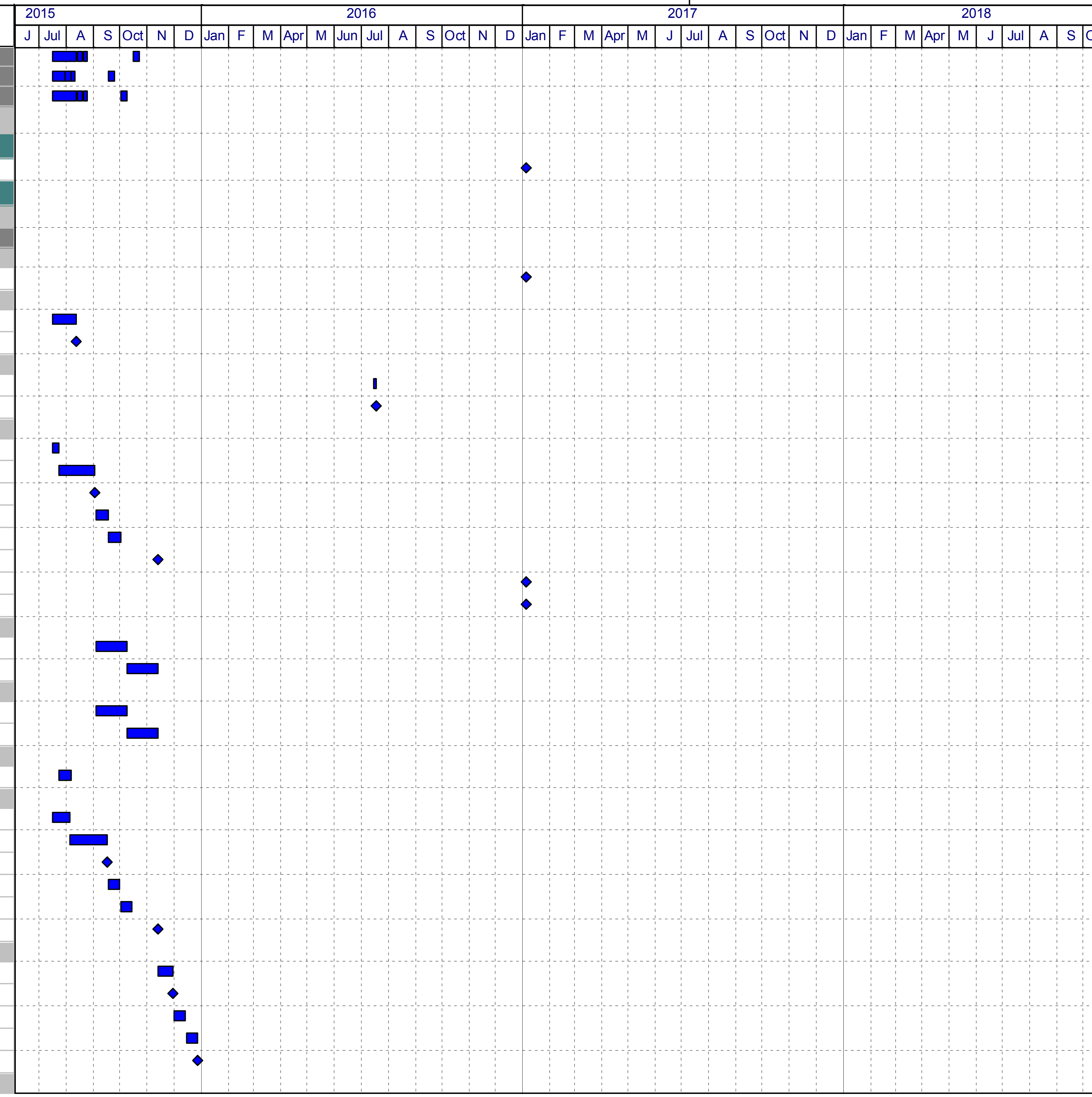
Data Date: 28-Dec-14
Run Date: 22-Jan-15 09:27
TASK filters: (Untitled Filter)_14, Level of Effort.

Activity ID	Activity Name	Days	Start	Finish
Syngas & Ammonia Compressors		70	16-Jul-15	22-Oct-15
Syngas Compressor Intercooler		50	16-Jul-15	24-Sep-15
Hydrogen Recovery Unit		60	16-Jul-15	08-Oct-15
AMEC Engineering / Design		787	16-Jul-15	20-Jul-18
General		0	05-Jan-17	05-Jan-17
IND-1790	AMEC Engineering / Design Complete	0		05-Jan-17
Engineering		787	16-Jul-15	20-Jul-18
All Areas		787	16-Jul-15	20-Jul-18
Process Engineering		375	16-Jul-15	05-Jan-17
General		0	05-Jan-17	05-Jan-17
E-1700	Process Engineering Discipline Complete	0		05-Jan-17
Design Criteria		20	16-Jul-15	12-Aug-15
E-3910	Develop & /Submit Design Criteria - Process	20	16-Jul-15	12-Aug-15
E-3930	Design Criteria - Process - IFD	0		12-Aug-15
Piping Service Index		2	15-Jul-16	18-Jul-16
E-10260	Develop/Submit IFA Piping Service Index - Process	2	15-Jul-16	18-Jul-16
E-10460	Piping Service Index - Process - IFD	0		18-Jul-16
P&ID's		375	16-Jul-15	05-Jan-17
E-10290	AVEVA P&ID Set Up	5	16-Jul-15	22-Jul-15
E-3130	Develop/Submit IFA P&IDs & Preliminary Line Sizing	30	23-Jul-15	02-Sep-15
E-10300	P&IDs & Preliminary Line Sizing - IFA	0		02-Sep-15
E-3140	Owner Review/Approve P&IDs & Preliminary Line Sizing	10	03-Sep-15	17-Sep-15
E-10320	P&IDs & Preliminary Line Sizing - Incorporate Client Comments	10	18-Sep-15	01-Oct-15
E-10310	P&IDs & Line Sizing - IFD with Holds	0		12-Nov-15
E-3150	P&ID Drawings - IFD Without Holds	0		05-Jan-17
E-3590	Receive Final Vendor Documents	0		05-Jan-17
Relief Valve Sizing Calculations & Checking		50	03-Sep-15	12-Nov-15
E-10330	Develop Preliminary Relief Valve Sizing Calculations & Checking	25	03-Sep-15	08-Oct-15
E-11490	Develop Final Relief Valve Sizing Calculations & Checking	25	09-Oct-15	12-Nov-15
Line Sizing Calculations & Checking		50	03-Sep-15	12-Nov-15
E-10360	Develop Preliminary Line Sizing Calculations & Checking	25	03-Sep-15	08-Oct-15
E-11500	Develop Final Line Sizing Calculations & Checking	25	09-Oct-15	12-Nov-15
Pump Calculations & Checking		10	23-Jul-15	05-Aug-15
E-10390	Develop/Submit IFA Pump Calculations & Checking	10	23-Jul-15	05-Aug-15
Equipment List		85	16-Jul-15	12-Nov-15
E-19180	Develop/Submit Preliminary Issue of Equipment List	14	16-Jul-15	04-Aug-15
E-1580	Develop/Submit Draft Issue of Equipment List	30	05-Aug-15	16-Sep-15
E-16430	Draft Issue of Equipment List - IFR	0		16-Sep-15
E-1590	Owner Review/Comment Draft Issue of Equipment List	10	17-Sep-15	30-Sep-15
E-3740	Incorporate Comments & Reissue Equipment List	10	01-Oct-15	14-Oct-15
E-1600	Equipment List to IFD	0		12-Nov-15
Piping Line List		25	13-Nov-15	28-Dec-15
E-14350	Develop/Submit IFR Piping Line List	10	13-Nov-15	30-Nov-15
E-14380	Piping Line List - IFR	0		30-Nov-15
E-14360	Owner Review / Comment IFR Piping Line List	10	01-Dec-15	14-Dec-15
E-14390	Piping Line List - Incorporate Comments from Owner's Review	5	15-Dec-15	28-Dec-15
E-14370	Piping Line List - IFC	0		28-Dec-15
Manual Valve List		25	13-Nov-15	28-Dec-15



Current
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RTI International, TEC Polk Station

Ammonia FEED Study Project Schedule

Date	Revision	Checked	Approved
22-Jan-15	Ammonia FEED Estimate Submission	MM	GM

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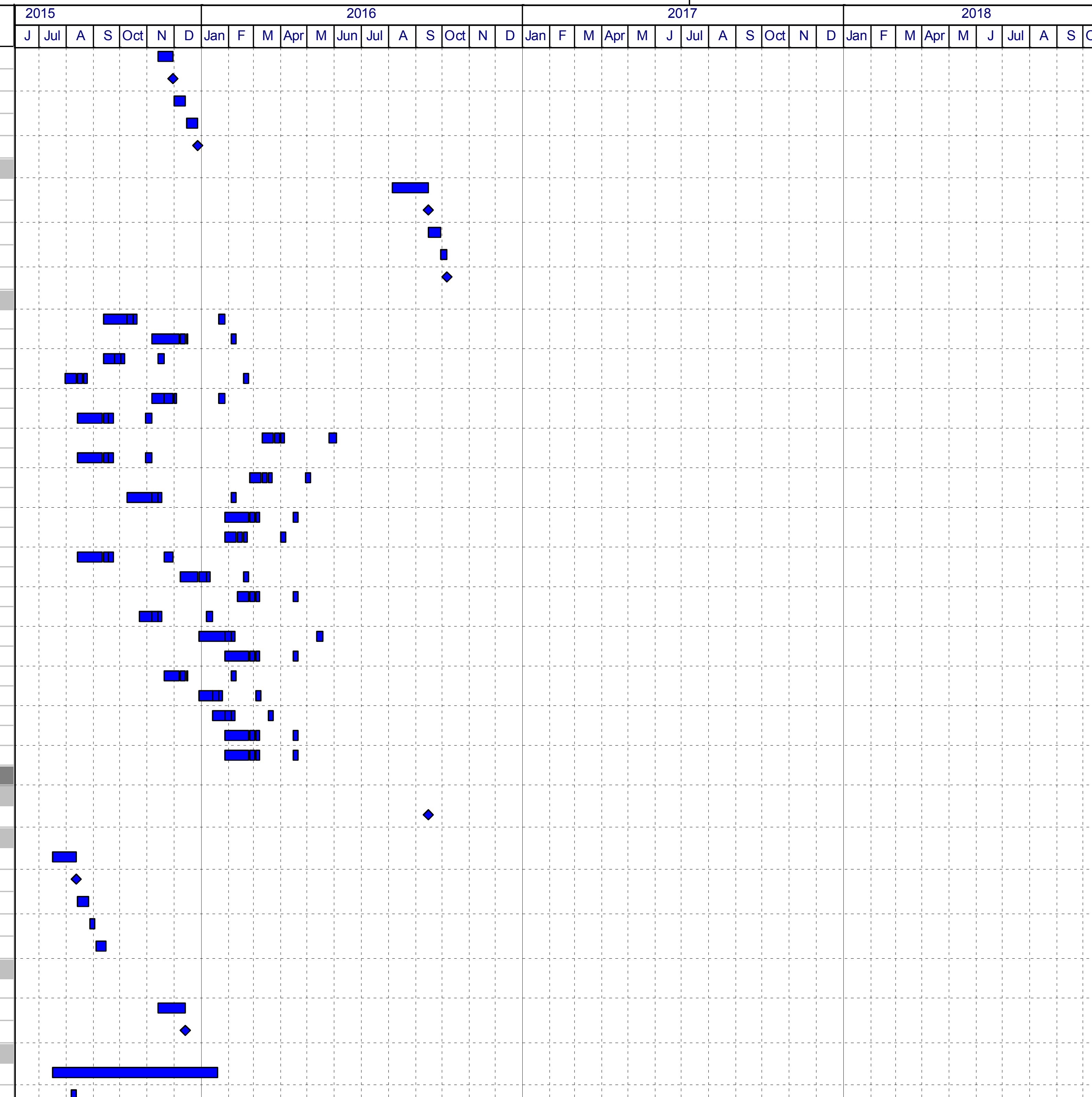
Data Date: 28-Dec-14
Run Date: 22-Jan-15 09:27
TASK filters: (Untitled Filter)_14, Level of Effort.

Activity ID	Activity Name	Days	Start	Finish
E-16440	Develop/Submit IFR Manual Valve List	10	13-Nov-15	30-Nov-15
E-16470	Manual Valve List - IFR / IFB	0		30-Nov-15
E-16450	Owner Review / Comment IFR Manual Valve List	10	01-Dec-15	14-Dec-15
E-16480	Manual Valve List - Incorporate Comments from Owner's Review	5	15-Dec-15	28-Dec-15
E-16460	Manual Valve List - IFP	0		28-Dec-15
Pipe Specialty Items List		45	05-Aug-16	06-Oct-16
E-3540	Develop/Submit Pipe Specialty Items List	30	05-Aug-16	15-Sep-16
E-10580	Pipe Specialty Items List - IFR / IFB	0		15-Sep-16
E-3550	Owner Review / Comment IFR Pipe Specialty Items List	10	16-Sep-16	29-Sep-16
E-10590	Pipe Specialty Items List - Incorporate Comments from Owner's Review	5	30-Sep-16	06-Oct-16
E-10600	Pipe Specialty Items List - IFP	0		06-Oct-16
Specifications		210	30-Jul-15	02-Jun-16
Heat Exchangers		90	11-Sep-15	27-Jan-16
Vessels		60	06-Nov-15	10-Feb-16
Deoxo Reactor		50	11-Sep-15	19-Nov-15
Ammonia Bullet Tanks		140	30-Jul-15	24-Feb-16
Ammonia Blowdown Tank		50	06-Nov-15	27-Jan-16
ASU Secondary Air Compressors		60	13-Aug-15	05-Nov-15
Mole Sieves		60	10-Mar-16	02-Jun-16
Mole Sieve Dryer		60	13-Aug-15	05-Nov-15
Mole Sieve Filter Cartridge		50	25-Feb-16	04-May-16
Pumps		80	09-Oct-15	10-Feb-16
Water Treatment Package		60	28-Jan-16	20-Apr-16
Raw Water Treatment		50	28-Jan-16	06-Apr-16
Cooling Tower Package		75	13-Aug-15	30-Nov-15
Cooling Water Supply & Separator Pumps		50	08-Dec-15	24-Feb-16
Cooling Water Separator Filter		50	11-Feb-16	20-Apr-16
Coalescing Filter		50	23-Oct-15	13-Jan-16
Catalyst / Packing		100	29-Dec-15	18-May-16
Oil Filter on Syngas Converter		60	28-Jan-16	20-Apr-16
DEGAN Compressor Intercooler		50	20-Nov-15	10-Feb-16
Ammonia PIG Launcher & Receiver		50	29-Dec-15	09-Mar-16
Ammonia Metering Station		50	14-Jan-16	23-Mar-16
Electric Start-Up Heater		60	28-Jan-16	20-Apr-16
Ammonia Storage Fogging System		60	28-Jan-16	20-Apr-16
Mechanical / Piping Engineering		295	16-Jul-15	15-Sep-16
General		0	15-Sep-16	15-Sep-16
E-1710	Mechanical / Piping Engineering Complete	0		15-Sep-16
Design Criteria		42	16-Jul-15	14-Sep-15
E-4040	Develop & /Submit Design Criteria - Mechanical / Piping	20	16-Jul-15	12-Aug-15
E-14300	Design Criteria - IFA	0		12-Aug-15
E-4050	Owner Review/Approve IFA Design Criteria - Mechanical / Piping	10	13-Aug-15	26-Aug-15
E-14310	Design Criteria - Incorporate Comments from Owner's Review	5	27-Aug-15	02-Sep-15
E-4060	Revise Design Criteria to IFD - Mechanical / Piping	7	03-Sep-15	14-Sep-15
Specifications		20	13-Nov-15	14-Dec-15
Pipe Specification		20	13-Nov-15	14-Dec-15
E-13700	Develop / Submit IFA Piping Specifications	20	13-Nov-15	14-Dec-15
E-13730	Piping Specifications - IFC	0		14-Dec-15
PDMS Modeling		124	16-Jul-15	19-Jan-16
E-1380	PDMS Modeling	124	16-Jul-15	19-Jan-16
E-14150	PDMS Model Review - 10%	5	06-Aug-15	12-Aug-15



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Ammonia FEED Study Project Schedule

Date	Revision	Checked	Approved
22-Jan-15	Ammonia FEED Estimate Submission	MM	GM

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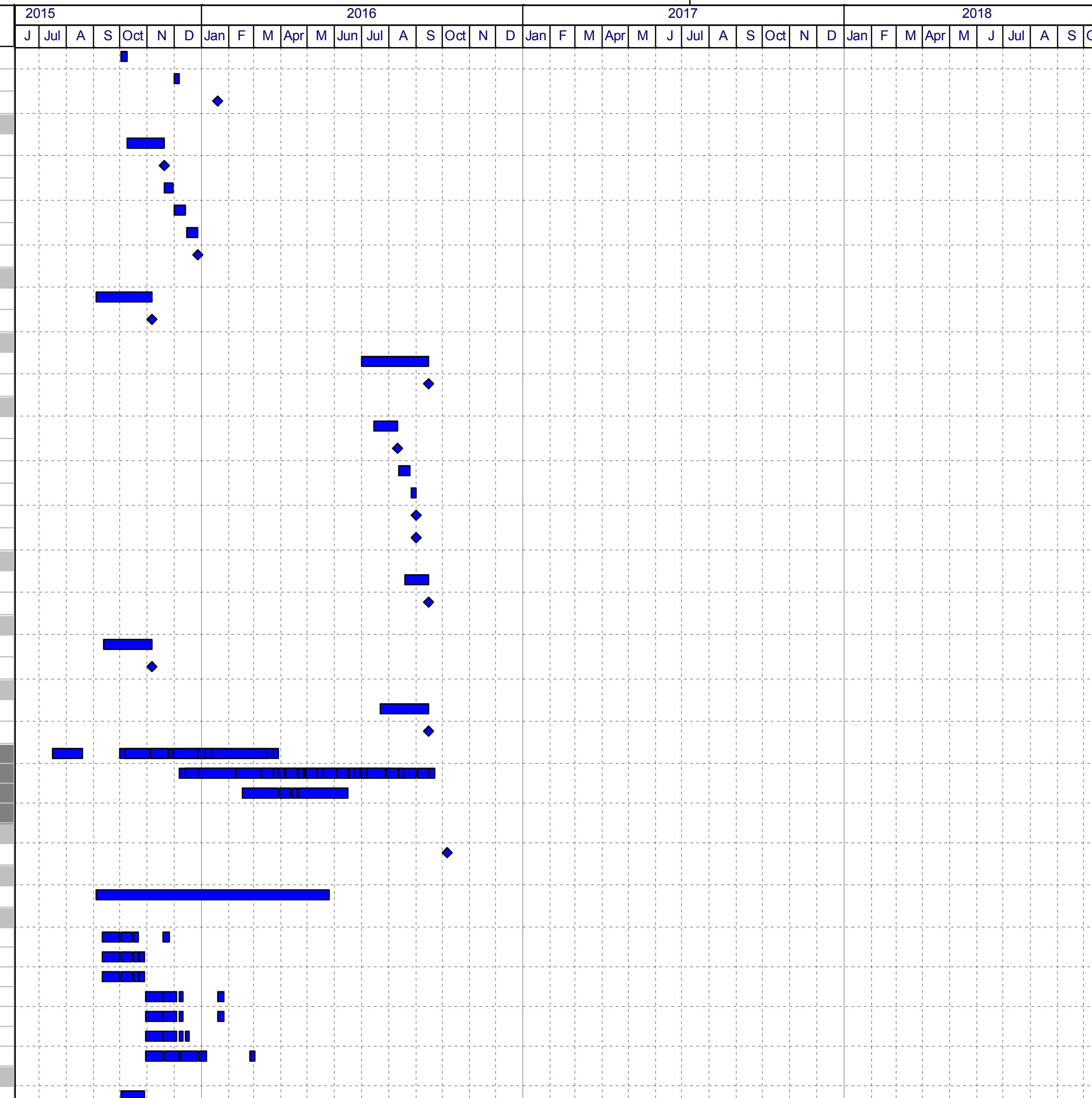
Activity ID	Activity Name	Days	Start	Finish
E-14160	PDMS Model Review - 40%	5	02-Oct-15	08-Oct-15
E-14170	PDMS Model Review - 90%	5	01-Dec-15	07-Dec-15
E-14180	PDMS Model Complete	0		19-Jan-16
General Arrangement Drawing		50	09-Oct-15	28-Dec-15
E-4270	Develop/Submit General Arrangement Drawings	30	09-Oct-15	19-Nov-15
E-11470	General Arrangement Drawings - IFA	0		19-Nov-15
E-11480	Owner Review/Approve General Arrangement Drawings	5	20-Nov-15	30-Nov-15
E-14110	General Arrangement Drawings - Incorporate Comments from Owner's Revie	10	01-Dec-15	14-Dec-15
E-14130	Check General Arrangement Drawings	5	15-Dec-15	28-Dec-15
E-14120	General Arrangement Drawings Complete - IFD	0		28-Dec-15
Underground Piping Design		45	03-Sep-15	05-Nov-15
E-13740	Develop/Submit Underground Piping Design	45	03-Sep-15	05-Nov-15
E-13760	Underground Piping Design - IFC	0		05-Nov-15
Above Ground Piping Design		55	01-Jul-16	15-Sep-16
E-13790	Develop/Submit Above Ground Piping Design	55	01-Jul-16	15-Sep-16
E-13810	Above Ground Piping Design - IFC	0		15-Sep-16
Equipment General Arrangements		35	15-Jul-16	01-Sep-16
E-13840	Develop/Submit IFA Equipment General Arrangements	20	15-Jul-16	11-Aug-16
E-20880	Equipment General Arrangements - IFA	0		11-Aug-16
E-20890	Owner Review/Approve IFA Equipment General Arrangements	10	12-Aug-16	25-Aug-16
E-20900	Equipment General Arrangements - Incorporate Comments from Owner's Re	5	26-Aug-16	01-Sep-16
E-13860	Equipment General Arrangements - IFD With Holds	0		01-Sep-16
E-14320	Equipment General Arrangements - IFD Without Holds	0		01-Sep-16
Pipe Support Design		20	19-Aug-16	15-Sep-16
E-13890	Develop/Submit Pipe Support Design	20	19-Aug-16	15-Sep-16
E-13910	Pipe Support Design - IFC	0		15-Sep-16
Underground Piping General Arrangements		40	11-Sep-15	05-Nov-15
E-14250	Develop/Submit Underground Piping General Arrangements	40	11-Sep-15	05-Nov-15
E-14270	Underground Piping General Arrangements - IFC	0		05-Nov-15
Above Ground Piping General Arrangements		40	22-Jul-16	15-Sep-16
E-14330	Develop/Submit Above Ground Piping General Arrangements	40	22-Jul-16	15-Sep-16
E-14340	Above Ground Piping General Arrangements - IFC	0		15-Sep-16
Civil Engineering		787	16-Jul-15	20-Jul-18
Structural Engineering		201	07-Dec-15	22-Sep-16
Architectural Engineering		85	17-Feb-16	15-Jun-16
Electrical Engineering		296	05-Aug-15	06-Oct-16
General		0	06-Oct-16	06-Oct-16
E-1750	Electrical Engineering Complete	0		06-Oct-16
3D Modeling		180	03-Sep-15	25-May-16
E-4920	Electrical 3D Modeling (AVEVA)	180	03-Sep-15	25-May-16
Specifications		116	10-Sep-15	02-Mar-16
7500 KVA Transformer		55	10-Sep-15	25-Nov-15
1500 KVA Transformer		35	10-Sep-15	28-Oct-15
Miscellaneous Power Transformers		35	10-Sep-15	28-Oct-15
LV Switchgear		55	29-Oct-15	26-Jan-16
MV Motor Control Center (MCC)		55	29-Oct-15	26-Jan-16
480V Motor Control Centers (MCC)		35	29-Oct-15	18-Dec-15
Prefabricated Electrical / Control Building		81	29-Oct-15	02-Mar-16
Preliminary MV Single Line Diagrams		35	01-Oct-15	18-Nov-15
E-18410	Develop/Submit IFA Preliminary MV Single-Line Diagrams	20	01-Oct-15	28-Oct-15



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Ammonia FEED Study Project Schedule

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Data Date: 28-Dec-14
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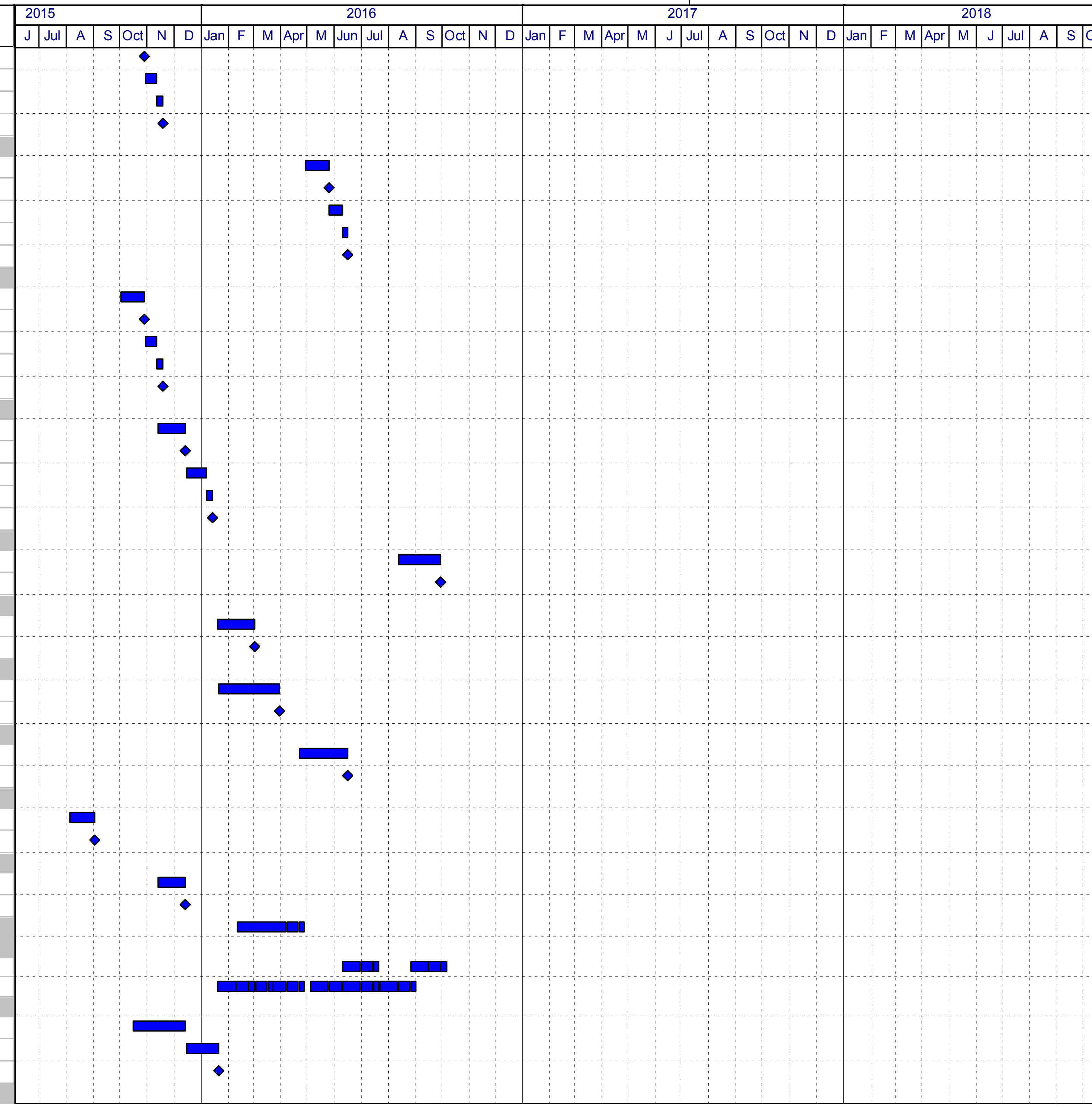
TASK filters: (Untitled Filter)_14, Level of Effort.

Activity ID	Activity Name	Days	Start	Finish
E-18440	Preliminary MV Single-Line Diagrams - IFA	0		28-Oct-15
E-18420	Owner Review/Approve IFA Preliminary MV Single-Line Diagrams	10	29-Oct-15	11-Nov-15
E-18450	Preliminary MV Single-Line Diagrams - Incorporate Comments from Owner's I	5	12-Nov-15	18-Nov-15
E-18430	Preliminary MV Single-Line Diagrams - IFC	0		18-Nov-15
Final MV Single Line Diagrams		35	28-Apr-16	16-Jun-16
E-19260	Develop/Submit IFA Final MV Single-Line Diagrams	20	28-Apr-16	25-May-16
E-19290	Final MV Single-Line Diagrams - IFA	0		25-May-16
E-19270	Owner Review/Approve IFA Final MV Single-Line Diagrams	10	26-May-16	09-Jun-16
E-19300	Final MV Single-Line Diagrams - Incorporate Comments from Owner's Review	5	10-Jun-16	16-Jun-16
E-19280	Final MV Single-Line Diagrams - IFC	0		16-Jun-16
Preliminary LV Single Line Diagrams		35	01-Oct-15	18-Nov-15
E-18810	Develop/Submit IFA Preliminary LV Single-Line Diagrams	20	01-Oct-15	28-Oct-15
E-18840	Preliminary LV Single-Line Diagrams - IFA	0		28-Oct-15
E-18820	Owner Review/Approve IFA Preliminary LV Single-Line Diagrams	10	29-Oct-15	11-Nov-15
E-18850	Preliminary LV Single-Line Diagrams - Incorporate Comments from Owner's F	5	12-Nov-15	18-Nov-15
E-18830	Preliminary LV Single-Line Diagrams - IFC	0		18-Nov-15
Final LV Single Line Diagrams		35	13-Nov-15	13-Jan-16
E-19310	Develop/Submit IFA Final LV Single-Line Diagrams	20	13-Nov-15	14-Dec-15
E-19340	Final LV Single-Line Diagrams - IFA	0		14-Dec-15
E-19320	Owner Review/Approve IFA Final LV Single-Line Diagrams	10	15-Dec-15	06-Jan-16
E-19350	Final LV Single-Line Diagrams - Incorporate Comments from Owner's Review	5	07-Jan-16	13-Jan-16
E-19330	Final LV Single-Line Diagrams - IFC	0		13-Jan-16
Ductbank Design		35	12-Aug-16	29-Sep-16
E-20530	Develop/Submit IFA Ductbank Design	35	12-Aug-16	29-Sep-16
E-20550	Ductbank Design - IFC	0		29-Sep-16
Outdoor Power & Controls Designs		30	20-Jan-16	01-Mar-16
E-20430	Develop/Submit IFA Outdoor Power & Control Designs	30	20-Jan-16	01-Mar-16
E-20450	Outdoor Power & Control Designs - IFC	0		01-Mar-16
Balance of Power & Controls Designs		50	21-Jan-16	30-Mar-16
E-18460	Develop/Submit IFA Balance of Power & Control Designs	50	21-Jan-16	30-Mar-16
E-18480	Balance of Power & Control Designs - IFC	0		30-Mar-16
Motor Elementry Drawings		40	21-Apr-16	16-Jun-16
E-18560	Develop/Submit IFA Motor Elementry Drawings	40	21-Apr-16	16-Jun-16
E-18580	Motor Elementry Drawings - IFC	0		16-Jun-16
Preliminary Electrical Load List		20	05-Aug-15	01-Sep-15
E-18610	Develop/Submit IFA Preliminary Electrical Load List	20	05-Aug-15	01-Sep-15
E-18630	Preliminary Electrical Load List - IFI	0		01-Sep-15
Final Electrical Load List		20	13-Nov-15	14-Dec-15
E-19130	Develop/Submit IFA Final Electrical Load List	20	13-Nov-15	14-Dec-15
E-19150	Final Electrical Load List - IFC	0		14-Dec-15
Lighting Plans		55	11-Feb-16	27-Apr-16
Grounding		186	20-Jan-16	06-Oct-16
Inside Battery Limits		85	10-Jun-16	06-Oct-16
Outside Battery Limits		161	20-Jan-16	01-Sep-16
Power Cable Schedules		60	16-Oct-15	20-Jan-16
E-20590	Develop/Submit IFP Power Cable Schedule for Bulk Purchase	40	16-Oct-15	14-Dec-15
E-20570	Develop/Submit IFC Power Cable Schedule	20	15-Dec-15	20-Jan-16
E-20580	Power Cable Schedule - IFC	0		20-Jan-16
Controls Cable Schedules		91	29-Oct-15	16-Mar-16



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RTI International, TEC Polk Station

Ammonia FEED Study Project Schedule

Date	Revision	Checked	Approved
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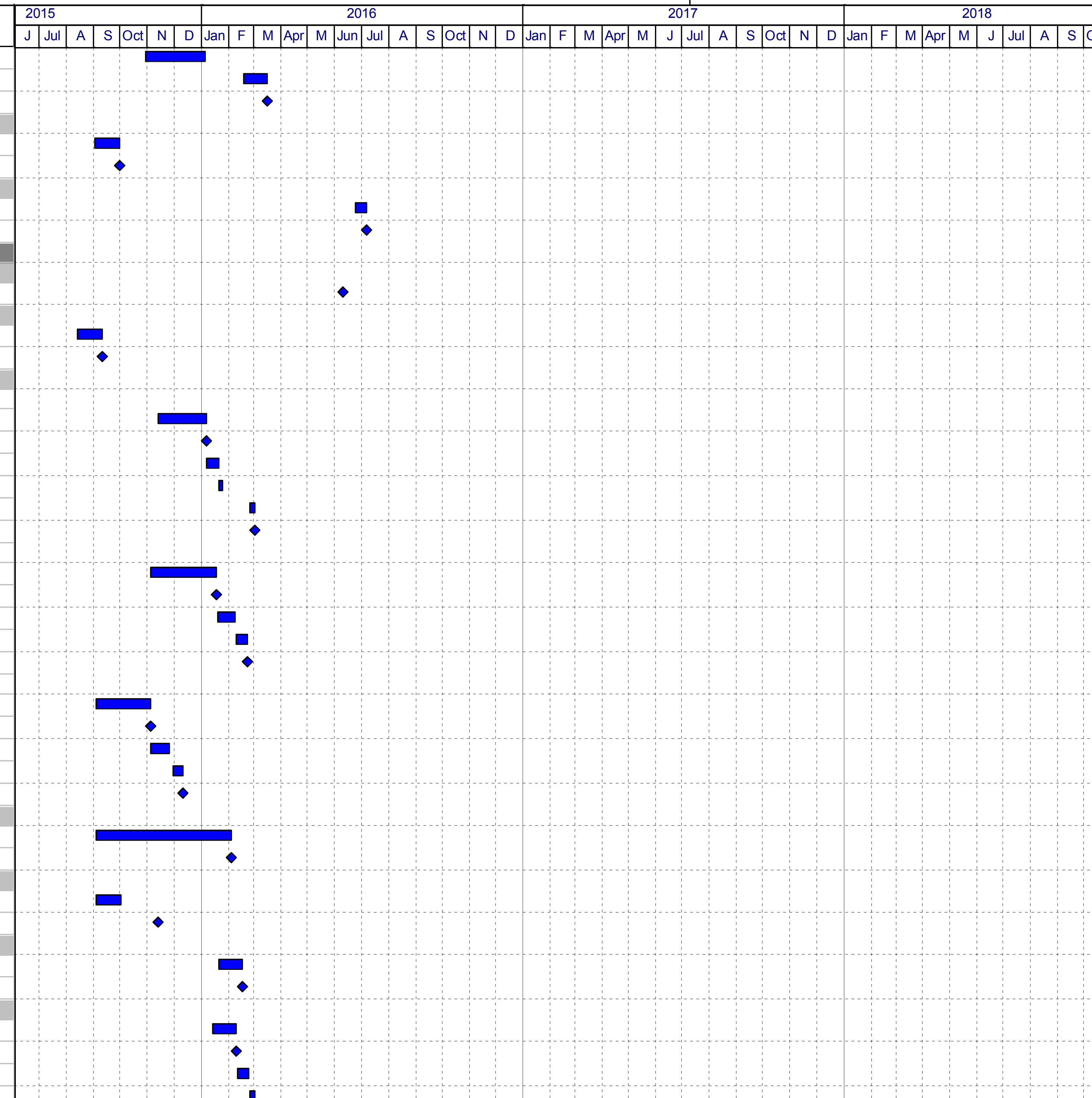
Activity ID	Activity Name	Days	Start	Finish
E-18860	Develop/Submit IFP Control Cable Schedule for Bulk Purchase	40	29-Oct-15	05-Jan-16
E-18710	Develop/Submit IFC Control Cable Schedule	20	18-Feb-16	16-Mar-16
E-18730	Control Cable Schedule - IFC	0		16-Mar-16
Preliminary Power System Study		20	02-Sep-15	30-Sep-15
E-19020	Develop/Submit Preliminary Power System Study (ETAP)	20	02-Sep-15	30-Sep-15
E-18990	Preliminary Power System Study (ETAP) - IFI	0		30-Sep-15
Final Power System Study		10	24-Jun-16	07-Jul-16
E-19120	Develop/Submit IFA Final Power System Study (ETAP)	10	24-Jun-16	07-Jul-16
E-19090	Final Power System Study (ETAP) - IFI	0		07-Jul-16
Instrumentation & Controls Engineering		205	13-Aug-15	09-Jun-16
General		0	09-Jun-16	09-Jun-16
E-1760	Instrumentation & Controls Engineering Complete	0		09-Jun-16
Design Criteria		20	13-Aug-15	10-Sep-15
E-17480	Develop/Submit IFA Design Criteria - I&C	20	13-Aug-15	10-Sep-15
E-17500	Design Criteria - I&C - IFD	0		10-Sep-15
Instrumentation Specifications		120	03-Sep-15	02-Mar-16
Distributed Control System (DCS)		70	13-Nov-15	02-Mar-16
E-13400	Develop / Submit IFR / IFB DCS Specification	30	13-Nov-15	06-Jan-16
E-13410	DCS Specification - IFR / IFB	0		06-Jan-16
E-13390	Owner Review IFR DCS Specification	10	07-Jan-16	20-Jan-16
E-13420	DCS Specification - Incorporate Comments from Owner's Review	3	21-Jan-16	25-Jan-16
E-13440	Conform Specification for DCS	5	25-Feb-16	02-Mar-16
E-13430	DCS Specification - IFP	0		02-Mar-16
Instrumentation		69	05-Nov-15	22-Feb-16
E-3410	Develop/Submit IFB Spec Sheets for Instruments	44	05-Nov-15	18-Jan-16
E-18280	Spec Sheets for Instruments - IFB	0		18-Jan-16
E-3420	Quotation Period / Review / Comment / & Make Recommendations - Spec Sh	15	19-Jan-16	08-Feb-16
E-6070	Confirm Process Data - Spec Sheets for Instruments	10	09-Feb-16	22-Feb-16
E-3430	Spec Sheets for Instruments - IFP	0		22-Feb-16
Control Valves		69	03-Sep-15	11-Dec-15
E-6080	Develop/Submit IFB Spec Sheets for Control Valves	44	03-Sep-15	04-Nov-15
E-18290	Spec Sheets for Control Valves - IFB	0		04-Nov-15
E-6090	Quotation Period / Review / Comment / & Make Recommendations - Spec Sh	15	05-Nov-15	25-Nov-15
E-6110	Confirm Process Data - Spec Sheets for Control Valves	10	30-Nov-15	11-Dec-15
E-6100	Spec Sheets for Control Valves - IFP	0		11-Dec-15
Instrument Index		100	03-Sep-15	03-Feb-16
E-17830	Develop/Submit IFA Database / Instrument Index	100	03-Sep-15	03-Feb-16
E-17850	Database / Instrument Index - IFP	0		03-Feb-16
Control Valve List		50	03-Sep-15	12-Nov-15
E-16490	Develop/Submit IFR Control Valve List	20	03-Sep-15	01-Oct-15
E-16510	Control Valve List - IFP	0		12-Nov-15
Instrumentation Cable Schedule		20	21-Jan-16	17-Feb-16
E-17880	Develop/Submit IFA Instrumentation Cable Schedule	20	21-Jan-16	17-Feb-16
E-17900	Instrumentation Cable Schedule - IFP	0		17-Feb-16
I/O List		35	14-Jan-16	02-Mar-16
E-17930	Develop/Submit IFA I/O List	20	14-Jan-16	10-Feb-16
E-17960	I/O List - IFA	0		10-Feb-16
E-17940	Owner Review/Approve IFA I/O List	10	11-Feb-16	24-Feb-16
E-17970	I/O List - Incorporate Comments from Owner's Review	5	25-Feb-16	02-Mar-16



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Data Date: 28-Dec-14
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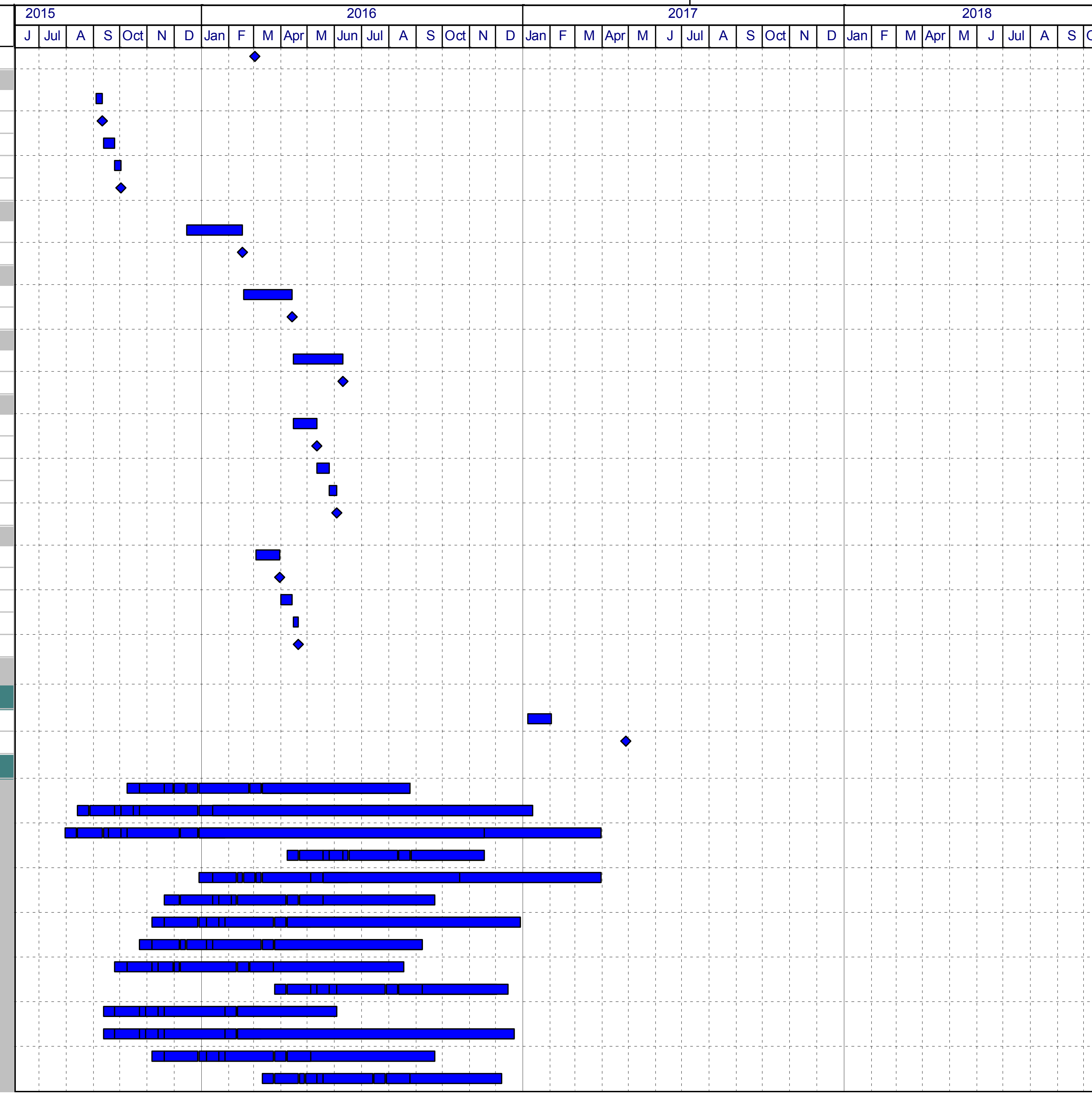
TASK filters: (Untitled Filter)_14, Level of Effort.

Activity ID	Activity Name	Days	Start	Finish
E-17950	I/O List - IFC	0		02-Mar-16
Installation Standard Details & Construction Specification 13440		20	03-Sep-15	01-Oct-15
E-17980	Develop/Submit IFA Installation Standard Details & Construction Specification	5	03-Sep-15	10-Sep-15
E-18010	Installation Standard Details & Construction Specification 13440 - IFA	0		10-Sep-15
E-17990	Owner Review/Approve IFA Installation Standard Details & Construction Speci	10	11-Sep-15	24-Sep-15
E-18020	Installation Standard Details & Construction Specification 13440 - Incorporate	5	25-Sep-15	01-Oct-15
E-18000	Installation Standard Details & Construction Specification 13440 - IFC	0		01-Oct-15
Instrument Location Drawings		40	15-Dec-15	17-Feb-16
E-18030	Develop/Submit IFA Instrument Location Drawings	40	15-Dec-15	17-Feb-16
E-18050	Instrument Location Drawings - IFC	0		17-Feb-16
Logic Diagrams		40	18-Feb-16	13-Apr-16
E-18080	Develop/Submit IFA Logic Diagrams	40	18-Feb-16	13-Apr-16
E-18100	Logic Diagrams - IFD	0		13-Apr-16
Loop Sheets		40	14-Apr-16	09-Jun-16
E-18130	Develop/Submit IFA Loop Sheets	40	14-Apr-16	09-Jun-16
E-18150	Loop Sheets - IFC	0		09-Jun-16
Controls Narrative		35	14-Apr-16	02-Jun-16
E-18180	Develop/Submit IFA Controls Narrative	20	14-Apr-16	11-May-16
E-18210	Controls Narrative - IFA	0		11-May-16
E-18190	Owner Review/Approve IFA Controls Narrative	10	12-May-16	25-May-16
E-18220	Controls Narrative - Incorporate Comments from Owner's Review	5	26-May-16	02-Jun-16
E-18200	Controls Narrative - IFD	0		02-Jun-16
DCS Architecture		35	03-Mar-16	20-Apr-16
E-18230	Develop/Submit IFA DCS Architecture	20	03-Mar-16	30-Mar-16
E-18260	DCS Architecture - IFA / IFP	0		30-Mar-16
E-18240	Owner Review/Approve IFA DCS Architecture	10	31-Mar-16	13-Apr-16
E-18270	DCS Architecture - Incorporate Comments from Owner's Review	5	14-Apr-16	20-Apr-16
E-18250	DCS Architecture - IFD	0		20-Apr-16
Procurement		446	30-Jul-15	28-Apr-17
General		81	06-Jan-17	28-Apr-17
P-17180	Develop Priced Spare Parts List	20	06-Jan-17	02-Feb-17
P-1780	Procurement Complete	0		28-Apr-17
Equipment Procurement		425	30-Jul-15	30-Mar-17
PIC-203 Shell and Tube Heat Exchangers		220	09-Oct-15	25-Aug-16
PIC-205 ASME Coded Vessels		360	13-Aug-15	12-Jan-17
PIC-211 Compressors		425	30-Jul-15	30-Mar-17
PIC-212 Mole Sieves		160	07-Apr-16	17-Nov-16
PIC-215 Ammonia Bullet Tanks		325	29-Dec-15	30-Mar-17
Ammonia Blowdown Tank		210	20-Nov-15	22-Sep-16
PIC-226 Centrifugal Pumps		290	06-Nov-15	29-Dec-16
PIC-228 Ammonia Feed Steam Generators		220	23-Oct-15	08-Sep-16
PIC-229 Deoxo Reactor		225	25-Sep-15	18-Aug-16
PIC-231 Catalyst / Packing		190	24-Mar-16	15-Dec-16
ASU Secondary Air Compressors		180	11-Sep-15	02-Jun-16
PIC-232 Mole Sieve Dryer		325	11-Sep-15	22-Dec-16
PIC-233 Coalescing Filter		220	06-Nov-15	22-Sep-16
PIC-235 Mole Sieve Filter Cartridge		195	10-Mar-16	08-Dec-16



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Activity ID	Activity Name	Days	Start	Finish
PIC-236 Vessels & Drums		240	08-Dec-15	17-Nov-16
PIC-239 Heat Exchangers		280	20-Nov-15	29-Dec-16
PIC-240 Pumps		260	08-Dec-15	15-Dec-16
PIC-241 Syngas & Ammonia Compressors		340	27-Aug-15	29-Dec-16
PIC-242 DEGAN Compressor Intercooler		210	08-Dec-15	06-Oct-16
Oil Filter on Syngas Converter		230	25-Feb-16	12-Jan-17
PIC-243 Hydrogen Recovery Unit		380	13-Aug-15	09-Feb-17
PIC-018 Syngas Compressor Intercoolers		210	30-Jul-15	02-Jun-16
PIC-052 Cooling Water Supply & Separator Pumps		210	29-Dec-15	20-Oct-16
PIC-062 Water Treatment Package		210	25-Feb-16	15-Dec-16
PIC-064 Ammonia PIG Launcher & Receiver		210	14-Jan-16	03-Nov-16
PIC-065 Ammonia Metering Station		210	28-Jan-16	17-Nov-16
PIC-066 Raw Water Treatment		210	11-Feb-16	01-Dec-16
PIC-067 Cooling Water Separator Filter		210	25-Feb-16	15-Dec-16
PIC-068 Electric Start-Up Heater		210	25-Feb-16	15-Dec-16
Ammonia Storage Fogging System		115	25-Feb-16	04-Aug-16
Structural Steel		150	24-Jun-16	19-Jan-17
Relief Valves		105	09-Oct-15	16-Mar-16
Specialty Items		115	16-Sep-16	23-Feb-17
Transformers		150	01-Oct-15	10-May-16
LV Switchgear		195	19-Nov-15	31-Aug-16
Motor Control Centers (MCC)		180	19-Nov-15	10-Aug-16
Prefabricated Electrical / Control Building		165	08-Dec-15	04-Aug-16
Distributed Control System (DCS)		200	07-Jan-16	13-Oct-16
Instrumentation		130	19-Jan-16	19-Jul-16
Control Valves		180	13-Nov-15	04-Aug-16
Subcontracts & Services		446	30-Jul-15	28-Apr-17
Site Survey		42	06-Aug-15	05-Oct-15
Geotechnical Investigation		43	30-Jul-15	29-Sep-15
Sitework Contractor		207	30-Mar-16	13-Jan-17
Foundation & Grounding Contractor		116	02-Sep-16	10-Feb-17
Structural Contractor		53	24-Jun-16	06-Sep-16
Architectural Contractor		53	20-Apr-16	04-Jul-16
Mechanical / Piping Contractor		53	16-Sep-16	29-Nov-16
Electrical / I&C Contractor		53	30-Sep-16	13-Dec-16
PIC-061 Cooling Tower Supply & Erect Contractor		406	25-Sep-15	28-Apr-17
Construction		285	02-Jan-17	02-Feb-18
Sitework		85	02-Jan-17	28-Apr-17
C-0000	Mobilize Trailers to Site	10	02-Jan-17	13-Jan-17
C-1010	Clearing / Grubbing	20	16-Jan-17	10-Feb-17
C-1030	Establish Laydown and Parking Lot (Civil Work)	15	30-Jan-17	17-Feb-17
C-1120	Install Ductbanks	20	13-Feb-17	10-Mar-17
C-1080	Install UG Utility Piping	25	13-Feb-17	17-Mar-17
C-4600	Grade Ammonia Plant Area	20	13-Feb-17	10-Mar-17
C-4590	Mass dirt work in Ammonia Plant Area	20	20-Mar-17	14-Apr-17
C-1040	Prep Truck Unloading / Ammonia Bullet Tank Area	10	17-Apr-17	28-Apr-17
Construction Inside the Battery Limits		220	13-Feb-17	15-Dec-17

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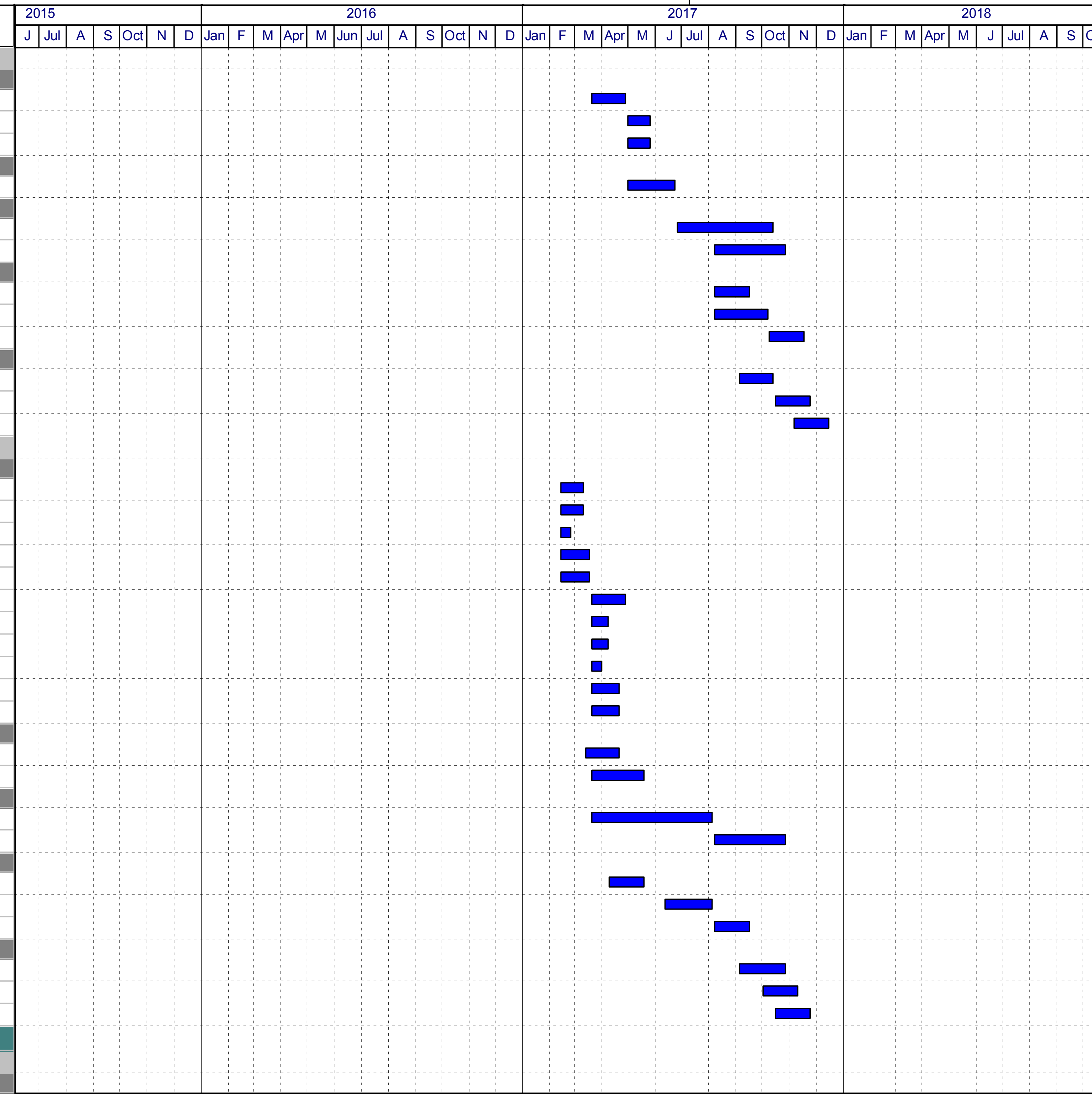
Activity ID	Activity Name	Days	Start	Finish
Compressor Area		195	20-Mar-17	15-Dec-17
Foundations		50	20-Mar-17	26-May-17
C-1150	FRP - Compressor Building & Equipment Platforms Foundations	30	20-Mar-17	28-Apr-17
C-1820	FRP - Compressor Area Miscellaneous Foundations	20	01-May-17	26-May-17
C-1840	FRP - Compressor Area Slab on Grade	20	01-May-17	26-May-17
Structural		40	01-May-17	23-Jun-17
C-2760	Install Compressor Building & External Equipment Platforms	40	01-May-17	23-Jun-17
Mechanical / Piping		90	26-Jun-17	27-Oct-17
C-5880	Set Mechancial Equipment in Compressor Building	80	26-Jun-17	13-Oct-17
C-5890	Install Piping in Compressor Building	60	07-Aug-17	27-Oct-17
Electrical		75	07-Aug-17	17-Nov-17
C-5920	Set Electrical Equipment in Compressor Area	30	07-Aug-17	15-Sep-17
C-5930	Install Cable Tray / Raceway in Compressor Area	45	07-Aug-17	06-Oct-17
C-5940	Pull & Term Cables in Compressor Area	30	09-Oct-17	17-Nov-17
Instrumentation & Controls		75	04-Sep-17	15-Dec-17
C-5950	Install Instrumentation in Compressor Area	30	04-Sep-17	13-Oct-17
C-5960	Install Instrumentation Tray in Compressor Area	30	16-Oct-17	24-Nov-17
C-5970	Install Instrumentation Tubing in Compressor Area	30	06-Nov-17	15-Dec-17
Ammonia Synthesis Area		205	13-Feb-17	24-Nov-17
Foundations		55	13-Feb-17	28-Apr-17
C-1110	FRP - D-833 Ammonia L.P. Let Down Drum Foundation	20	13-Feb-17	10-Mar-17
C-1650	FRP - P-833 A/B Product Pumps Foundation	20	13-Feb-17	10-Mar-17
C-1660	FRP - FLT-811 Oil Filter on Syngas Converter Foundation	10	13-Feb-17	24-Feb-17
C-1740	FRP - PKG-801 Hydrogen Recovery Unit Foundation	25	13-Feb-17	17-Mar-17
C-1900	FRP - R-811 Steel Tower Foundation	25	13-Feb-17	17-Mar-17
C-1670	FRP - Ammonia Synthesis Area Miscellaneous Foundations	30	20-Mar-17	28-Apr-17
C-1690	FRP - C-821 Centrifugal Compressor Foundation	15	20-Mar-17	07-Apr-17
C-1720	FRP - C-801 Reciprocating Compressor Foundation	15	20-Mar-17	07-Apr-17
C-1730	FRP - D-821 Oil Tank Separator Foundation	10	20-Mar-17	31-Mar-17
C-1790	FRP - TWR-831 Ammonia Absorber Foundation	25	20-Mar-17	21-Apr-17
C-1980	FRP - D-811 HP NH3 Separator Foundation	25	20-Mar-17	21-Apr-17
Structural		50	13-Mar-17	19-May-17
C-4130	Install D-833 Support Structure	30	13-Mar-17	21-Apr-17
C-4110	Install R-811 / UHE-811 Support Structure	45	20-Mar-17	19-May-17
Mechanical / Piping		160	20-Mar-17	27-Oct-17
C-6070	Set Mechancial Equipment in Ammonia Synthesis Area	100	20-Mar-17	04-Aug-17
C-6080	Install Piping in Ammonia Synthesis Area	60	07-Aug-17	27-Oct-17
Electrical		115	10-Apr-17	15-Sep-17
C-6090	Set Electrical Equipment in Ammonia Synthesis Area	30	10-Apr-17	19-May-17
C-6100	Install Cable Tray / Raceway in Ammonia Synthesis Area	40	12-Jun-17	04-Aug-17
C-6110	Pull & Term Cables in Ammonia Synthesis Area	30	07-Aug-17	15-Sep-17
Instrumentation & Controls		60	04-Sep-17	24-Nov-17
C-6120	Install Instrumentation in Ammonia Synthesis Area	40	04-Sep-17	27-Oct-17
C-6130	Install Instrumentation Tray in Ammonia Synthesis Area	30	02-Oct-17	10-Nov-17
C-6140	Install Instrumentation Tubing in Ammonia Synthesis Area	30	16-Oct-17	24-Nov-17
Construction Outside the Battery Limits		230	20-Mar-17	02-Feb-18
LTS Area		150	20-Mar-17	13-Oct-17
Foundations		20	20-Mar-17	14-Apr-17



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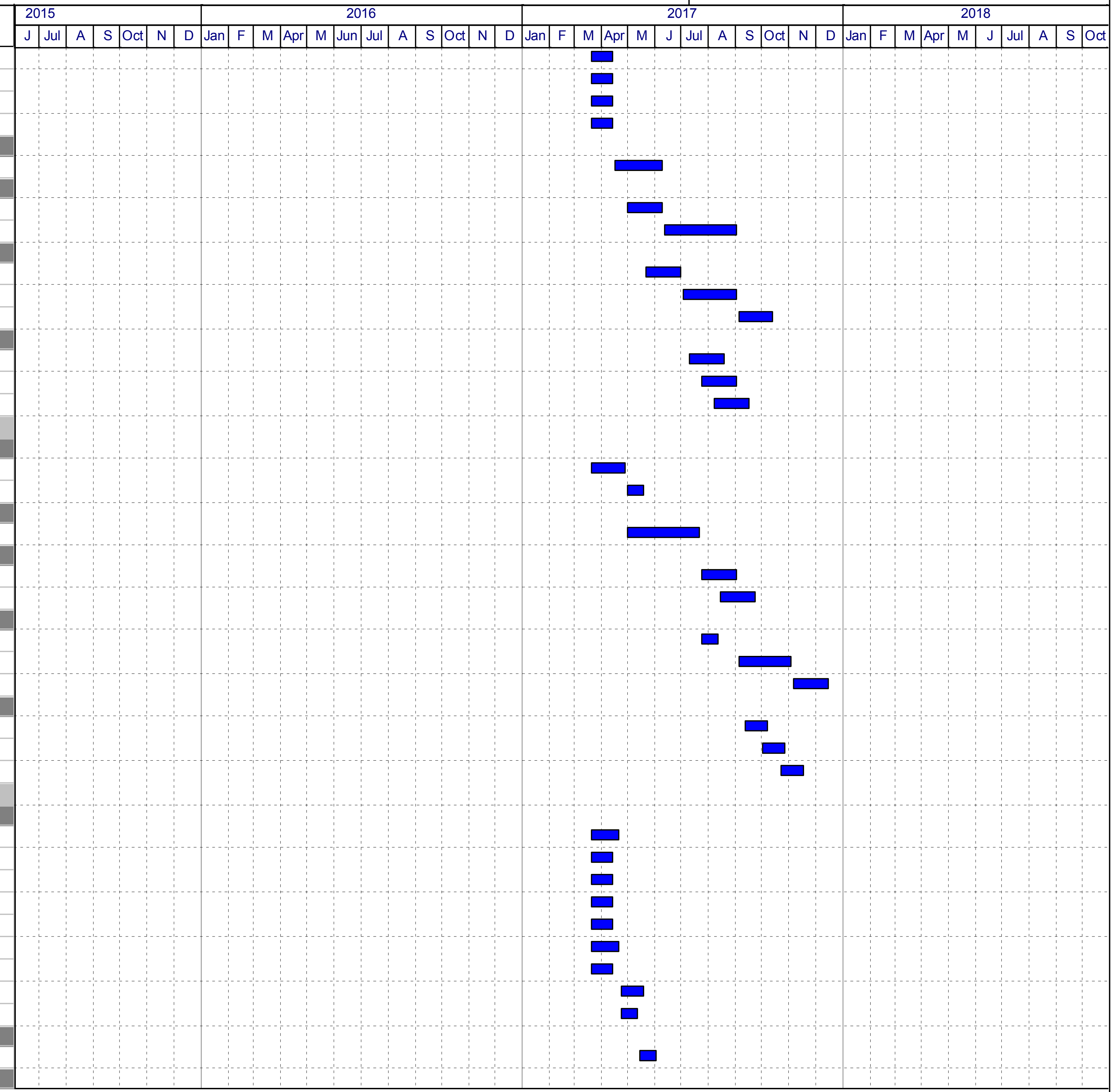
Activity ID	Activity Name	Days	Start	Finish
C-1710	FRP - REV-404 Hydrogen Sulfide Guard Bed Vessel Foundation	20	20-Mar-17	14-Apr-17
C-1760	FRP - REV-405 Carbonyl Sulfide Guard Bed Vessel Foundation	20	20-Mar-17	14-Apr-17
C-1770	FRP - REV-406 LTS Reactor Vessel Foundation	20	20-Mar-17	14-Apr-17
C-1830	FRP - LTS Area Miscellaneous Foundations	20	20-Mar-17	14-Apr-17
Structural		40	17-Apr-17	09-Jun-17
C-4150	Install LTS Structure	40	17-Apr-17	09-Jun-17
Mechanical / Piping		90	01-May-17	01-Sep-17
C-6230	Set Mechancial Equipment in LTS Area	30	01-May-17	09-Jun-17
C-6240	Install Piping in LTS Area	60	12-Jun-17	01-Sep-17
Electrical		105	22-May-17	13-Oct-17
C-6250	Set Electrical Equipment in LTS Area	30	22-May-17	30-Jun-17
C-6260	Install Cable Tray / Raceway in LTS Area	45	03-Jul-17	01-Sep-17
C-6270	Pull & Term Cables in LTS Area	30	04-Sep-17	13-Oct-17
Instrumentation & Controls		50	10-Jul-17	15-Sep-17
C-6280	Install Instrumentation in LTS Area	30	10-Jul-17	18-Aug-17
C-6290	Install Instrumentation Tray in LTS Area	30	24-Jul-17	01-Sep-17
C-6300	Install Instrumentation Tubing in LTS Area	30	07-Aug-17	15-Sep-17
Cooling Tower Area		195	20-Mar-17	15-Dec-17
Foundations		45	20-Mar-17	19-May-17
C-1850	FRP - Cooling Tower Basin, Pumpwell, Tank, & Pump Foundations	30	20-Mar-17	28-Apr-17
C-1860	FRP - Cooling Tower Area Miscellaneous Foundations	15	01-May-17	19-May-17
Structural		60	01-May-17	21-Jul-17
C-4880	Erect Cooling Tower	60	01-May-17	21-Jul-17
Mechanical / Piping		45	24-Jul-17	22-Sep-17
C-6390	Set Mechancial Equipment in Cooling Tower Area	30	24-Jul-17	01-Sep-17
C-6400	Install Piping in Cooling Tower Area	30	14-Aug-17	22-Sep-17
Electrical		105	24-Jul-17	15-Dec-17
C-6410	Set Electrical Equipment in Cooling Tower Area	15	24-Jul-17	11-Aug-17
C-6420	Install Cable Tray / Raceway in Cooling Tower Area	45	04-Sep-17	03-Nov-17
C-6430	Pull & Term Cables in Cooling Tower Area	30	06-Nov-17	15-Dec-17
Instrumentation & Controls		50	11-Sep-17	17-Nov-17
C-6440	Install Instrumentation in Cooling Tower Area	20	11-Sep-17	06-Oct-17
C-6450	Install Instrumentation Tray in Cooling Tower Area	20	02-Oct-17	27-Oct-17
C-6460	Install Instrumentation Tubing in Cooling Tower Area	20	23-Oct-17	17-Nov-17
Methanation Area		170	20-Mar-17	10-Nov-17
Foundations		45	20-Mar-17	19-May-17
C-1870	FRP - REV-701 Deoxo Reactor Vessel Foundation	25	20-Mar-17	21-Apr-17
C-1880	FRP - D-705 KO Drum Foundation	20	20-Mar-17	14-Apr-17
C-1920	FRP - DRY-707A & B Mole Sieve Bed Foundation	20	20-Mar-17	14-Apr-17
C-1940	FRP - E-708 & 710 Mole Sieve Heater Foundation	20	20-Mar-17	14-Apr-17
C-1960	FRP - D-710 Regeneration KO Pot Foundation	20	20-Mar-17	14-Apr-17
C-1970	FRP - REV-601 Methanation Reactor Foundation	25	20-Mar-17	21-Apr-17
C-1990	FRP - Air Receiver Foundation	20	20-Mar-17	14-Apr-17
C-2020	FRP - Methanation Area Miscellaneous Foundations	20	24-Apr-17	19-May-17
C-3280	FRP - Methanation Area Slab on Grade	15	24-Apr-17	12-May-17
Structural		15	15-May-17	02-Jun-17
C-4140	Install Structural Steel in Methanation Area	15	15-May-17	02-Jun-17
Mechanical / Piping		80	24-Apr-17	11-Aug-17



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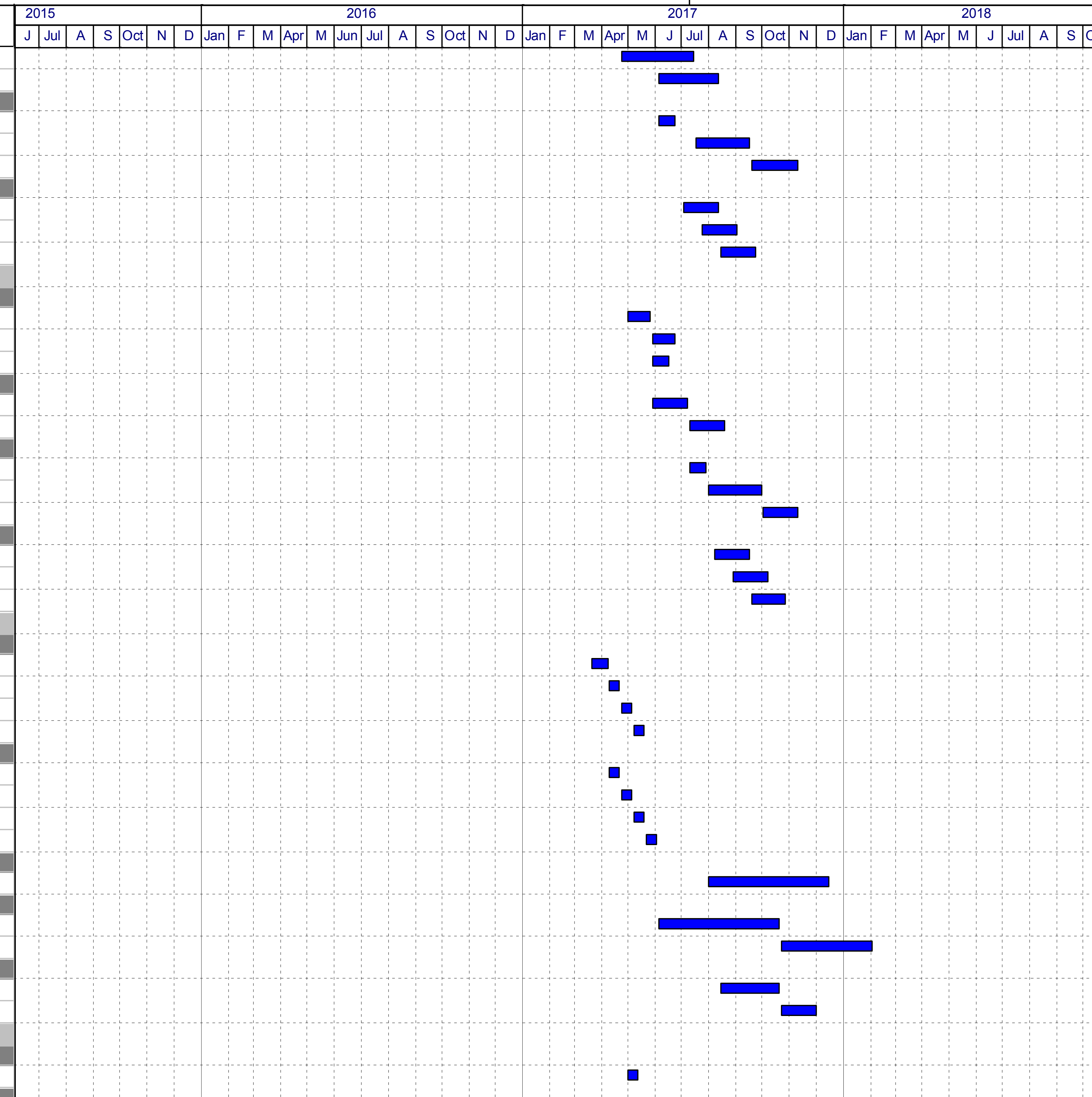
Activity ID	Activity Name	Days	Start	Finish
C-6550	Set Mechancial Equipment in Methanation Area	60	24-Apr-17	14-Jul-17
C-6560	Install Piping in Methanation Area	50	05-Jun-17	11-Aug-17
Electrical		115	05-Jun-17	10-Nov-17
C-6570	Set Electrical Equipment in Methanation Area	15	05-Jun-17	23-Jun-17
C-6580	Install Cable Tray / Raceway in Methanation Area	45	17-Jul-17	15-Sep-17
C-6590	Pull & Term Cables in Methanation Area	40	18-Sep-17	10-Nov-17
Instrumentation & Controls		60	03-Jul-17	22-Sep-17
C-6600	Install Instrumentation in Methanation Area	30	03-Jul-17	11-Aug-17
C-6610	Install Instrumentation Tray in Methanation Area	30	24-Jul-17	01-Sep-17
C-6620	Install Instrumentation Tubing in Methanation Area	30	14-Aug-17	22-Sep-17
Ammonia Storage Area		140	01-May-17	10-Nov-17
Foundations		40	01-May-17	23-Jun-17
C-1280	FRP - Tank Support Footing & Pier Foundations	20	01-May-17	26-May-17
C-1310	FRP - Containment Area Perimeter Curb & Slab	20	29-May-17	23-Jun-17
C-1630	FRP - Pump Area Curb & Slab	15	29-May-17	16-Jun-17
Mechanical / Piping		60	29-May-17	18-Aug-17
C-6710	Set Mechancial Equipment in Ammonia Storage Area	30	29-May-17	07-Jul-17
C-6720	Install Piping in Ammonia Storage Area	30	10-Jul-17	18-Aug-17
Electrical		90	10-Jul-17	10-Nov-17
C-6730	Set Electrical Equipment in Ammonia Storage Area	15	10-Jul-17	28-Jul-17
C-6740	Install Cable Tray / Raceway in Ammonia Storage Area	45	31-Jul-17	29-Sep-17
C-6750	Pull & Term Cables in Ammonia Storage Area	30	02-Oct-17	10-Nov-17
Instrumentation & Controls		60	07-Aug-17	27-Oct-17
C-6760	Install Instrumentation in Ammonia Storage Area	30	07-Aug-17	15-Sep-17
C-6770	Install Instrumentation Tray in Ammonia Storage Area	30	28-Aug-17	06-Oct-17
C-6780	Install Instrumentation Tubing in Ammonia Storage Area	30	18-Sep-17	27-Oct-17
Pipe Bridge		230	20-Mar-17	02-Feb-18
Foundations		45	20-Mar-17	19-May-17
C-1640	FRP - E-W Section 1 of Pipe Bridge Foundation	15	20-Mar-17	07-Apr-17
C-3300	FRP - N-S Section 2 of Pipe Bridge Foundation	10	10-Apr-17	21-Apr-17
C-1780	FRP - N-S Section 3 of Pipe Bridge Foundation	10	24-Apr-17	05-May-17
C-1800	FRP - N-S Section 4 of Pipe Bridge Foundation	10	08-May-17	19-May-17
Structural		40	10-Apr-17	02-Jun-17
C-4120	Install E-W Section 1 of Pipe Bridge Steel	10	10-Apr-17	21-Apr-17
C-4710	Install N-S Section 2 of Pipe Bridge Steel	10	24-Apr-17	05-May-17
C-4720	Install N-S Section 3 of Pipe Bridge Steel	10	08-May-17	19-May-17
C-4730	Install N-S Section 4 of Pipe Bridge Steel	10	22-May-17	02-Jun-17
Mechanical / Piping		100	31-Jul-17	15-Dec-17
C-6880	Install Piping in Pipe Bridge	100	31-Jul-17	15-Dec-17
Electrical		175	05-Jun-17	02-Feb-18
C-6900	Install Cable Tray / Raceway in Pipe Bridge	100	05-Jun-17	20-Oct-17
C-6910	Pull & Term Cables in Pipe Bridge	75	23-Oct-17	02-Feb-18
Instrumentation & Controls		80	14-Aug-17	01-Dec-17
C-6930	Install Instrumentation Tray in Pipe Bridge	50	14-Aug-17	20-Oct-17
C-6940	Install Instrumentation Tubing in Pipe Bridge	30	23-Oct-17	01-Dec-17
Truck Loadout Area		150	01-May-17	24-Nov-17
Foundations		10	01-May-17	12-May-17
C-1810	FRP - Truck Loading Area Slab & Ramps	10	01-May-17	12-May-17
Mechanical / Piping		45	15-May-17	14-Jul-17



Current
Milestone
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RTI International, TEC Polk Station

Ammonia FEED Study Project Schedule

Date	Revision	Checked	Approved
22-Jan-15	Ammonia FEED Estimate Submission	MM	GM

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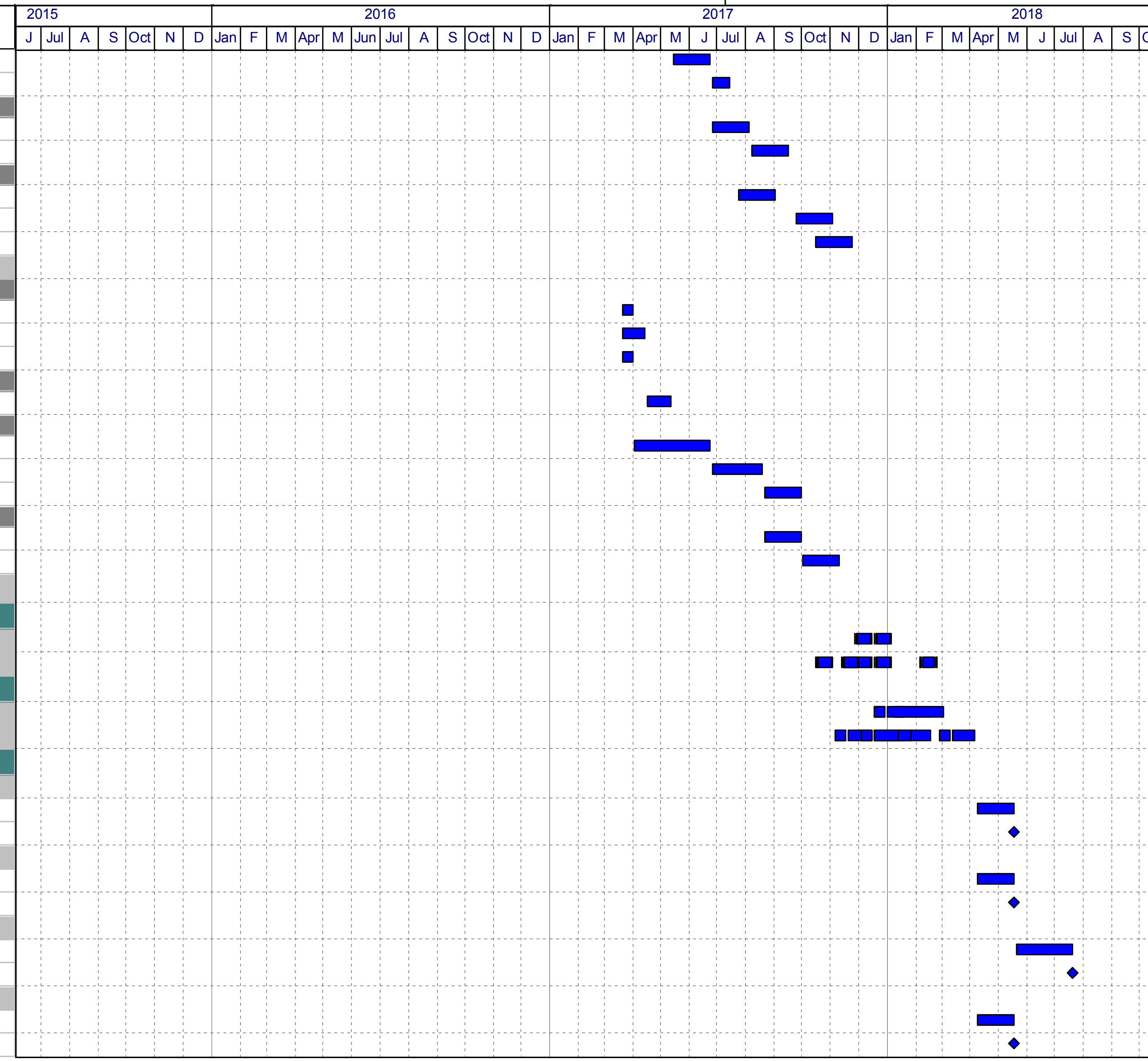
Activity ID	Activity Name	Days	Start	Finish
C-7030	Set Mechancial Equipment in Truck Loading Area	30	15-May-17	23-Jun-17
C-7040	Install Piping in Truck Loading Area	15	26-Jun-17	14-Jul-17
Electrical		60	26-Jun-17	15-Sep-17
C-7060	Install Cable Tray / Raceway in Truck Loading Area	30	26-Jun-17	04-Aug-17
C-7070	Pull & Term Cables in Truck Loading Area	30	07-Aug-17	15-Sep-17
Instrumentation & Controls		90	24-Jul-17	24-Nov-17
C-7080	Install Instrumentation in Truck Loading Area	30	24-Jul-17	01-Sep-17
C-7090	Install Instrumentation Tray in Truck Loading Area	30	25-Sep-17	03-Nov-17
C-7100	Install Instrumentation Tubing in Truck Loading Area	30	16-Oct-17	24-Nov-17
Electrical Building Area		170	20-Mar-17	10-Nov-17
Foundations		20	20-Mar-17	14-Apr-17
C-1090	FRP - Transformers & Switchgear Foundations	10	20-Mar-17	31-Mar-17
C-1140	FRP - Cable Tray Support (T-Poles) Foundations	20	20-Mar-17	14-Apr-17
C-1950	FRP - Electrical Building Foundation	10	20-Mar-17	31-Mar-17
Structural		20	17-Apr-17	12-May-17
C-2770	Install Cable Tray Supports (T-Poles)	20	17-Apr-17	12-May-17
Electrical		130	03-Apr-17	29-Sep-17
C-7270	Set Electrical Equipment in Electrical Building Area	60	03-Apr-17	23-Jun-17
C-7220	Install Cable Tray / Raceway in Electrical Building Area	40	26-Jun-17	18-Aug-17
C-7230	Pull & Term Cables in Electrical Building Area	30	21-Aug-17	29-Sep-17
Instrumentation & Controls		60	21-Aug-17	10-Nov-17
C-7250	Install Instrumentation Tray in Electrical Building Area	30	21-Aug-17	29-Sep-17
C-7260	Install Instrumentation Tubing in Electrical Building Area	30	02-Oct-17	10-Nov-17
Start-up & Commissioning		200	16-Oct-17	20-Jul-18
Turnovers to Commissioning		95	16-Oct-17	23-Feb-18
Turnovers to Commissioning - Inside Battery Limits		30	27-Nov-17	05-Jan-18
Turnovers to Commissioning - Outside Battery Limits		95	16-Oct-17	23-Feb-18
Commissioning		110	06-Nov-17	06-Apr-18
Commissioning - Inside Battery Limits		55	18-Dec-17	02-Mar-18
Commissioning - Outside Battery Limits		110	06-Nov-17	06-Apr-18
Startup		75	09-Apr-18	20-Jul-18
Warm Gas Clean Up Modification		30	09-Apr-18	18-May-18
SU-2610	Perform Startup - Warm Gas Clean Up Modification	30	09-Apr-18	18-May-18
SU-2620	Warm Gas Clean Up Modification Startup Complete	0		18-May-18
Nitrogen Modifications		30	09-Apr-18	18-May-18
SU-2630	Perform Startup - Nitrogen Modifications	30	09-Apr-18	18-May-18
SU-2640	Nitrogen Modifications Startup Complete	0		18-May-18
Ammonia Plant		45	21-May-18	20-Jul-18
SU-2650	Perform Startup - Ammonia Plant	45	21-May-18	20-Jul-18
SU-2660	Ammonia Plant Startup Complete	0		20-Jul-18
Utilities / Product Storage		30	09-Apr-18	18-May-18
SU-2670	Perform Startup- Utilities / Product Storage	30	09-Apr-18	18-May-18
SU-2680	Utilities / Product Storage Startup Complete	0		18-May-18



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