Fuel-Flexible Gasification-Combustion Technology for Production of H_2 and Sequestration-Ready CO_2

Quarterly Technical Progress Report No. 10

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DISCLAIMER

ABSTRACT

It is expected that in the 21st century the Nation will continue to rely on fossil fuels for electricity, transportation, and chemicals. It will be necessary to improve both the process efficiency and environmental impact performance of fossil fuel utilization. GE Energy and Environmental Research Corporation (GE EER) has developed an innovative fuel-flexible Unmixed Fuel Processor (UFP) technology to produce H_2, power, and sequestration-ready CO_2 from coal and other solid fuels. The UFP module offers the potential for reduced cost, increased process efficiency relative to conventional gasification and combustion systems, and near-zero pollutant emissions including NO_x. GE EER (prime contractor) was awarded a Vision 21 program from U.S. DOE NETL to develop the UFP technology. Work on this Phase I program started on October 1, 2000. The project team includes GE EER, Southern Illinois University at Carbondale (SIU-C), California Energy Commission (CEC), and T. R. Miles, Technical Consultants, Inc.

In the UFP technology, coal/opportunity fuels and air are simultaneously converted into separate streams of (1) pure hydrogen that can be utilized in fuel cells, (2) sequestration-ready CO_2, and (3) high temperature/pressure oxygen-depleted air to produce electricity in a gas turbine. The process produces near-zero emissions and, based on process modeling work, has an estimated process efficiency of 68%, based on electrical and H_2 energy outputs relative to the higher heating value of coal, and an estimated equivalent electrical efficiency of 60%. The Phase I R&D program will determine the operating conditions that maximize separation of CO_2 and pollutants from the vent gas, while simultaneously maximizing coal conversion efficiency and hydrogen production. The program integrates lab-, bench- and pilot-scale studies to demonstrate the UFP technology.

This is the tenth quarterly technical progress report for the Vision 21 UFP program supported by U.S. DOE NETL (Contract No. DE-FC26-00FT40974). This report summarizes program accomplishments for the period starting January 1, 2003 and ending March 31, 2003. The report includes an introduction summarizing the UFP technology, main program tasks, and program objectives; it also provides a summary of program activities and accomplishments covering progress in tasks including lab-scale experimental testing, pilot-scale assembly, and program management.

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EXECUTIVE SUMMARY

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Work conducted in the tenth quarter has focused on accelerating assembly of the pilot plant, with additional experimental analysis being conducted on the lab scale system.

The lab-scale effort has included high temperature fluidized bed experiments to assess the impact of coal loading on coal gasification performance in the presence of CAM and OTM. This information will aid in setting the desired bed residence times in the pilot-scale system.

The pilot-scale assembly effort has continued, with the testing, casting and assembly of the three main reactor vessels. Additional progress was made in finalizing the distributor plate design, fine-tuning the design and operation of the solids transfer system, designing systems to reduce air emissions, testing the slurry feeding system and selecting appropriate high-temperature, high-pressure instrumentation.

INTRODUCTION

Electricity produced from hydrogen in fuel cells can be highly efficient relative to competing technologies and has the potential to be virtually pollution free. Thus, fuel cells may become an ideal solution to many of this nation's energy needs if one has a satisfactory process for producing hydrogen from available energy resources such as coal, and low-cost alternative feedstocks including biomass, municipal solid waste, sewage sludge, and others.

This Vision 21 UFP program addresses a novel, energy-efficient, and near-zero pollution concept for converting a conventional fuel (coal) and opportunity fuels (e.g., biomass) into separate streams of hydrogen, oxygen-depleted air, and sequestration-ready CO_2. The technology module encompassing this concept will be referred to as the *Unmixed Fuel Processor (UFP)* throughout this report. [Note that earlier quarterly reports referred to the technology concept as Advanced Gasification-Combustion (AGC)]. When commercialized, the UFP technology may become one of the cornerstone technologies to fulfill Vision 21 energy plant objectives of efficiently and economically producing energy and hydrogen from coal with utilization of opportunity feedstocks.

The UFP technology is energy efficient because a large portion of the energy in the input coal leaves the UFP module as hydrogen and the rest as high-pressure, high-temperature gas that can power a gas turbine. The combination of producing hydrogen and electricity via a gas turbine is highly efficient, meets all objectives of Vision 21 energy plants, and makes the process product flexible. That is, the UFP module will be able to adjust the ratio at which it produces hydrogen and electricity in order to match changing demand.

The Phase I Vision 21 UFP program is being conducted primarily by General Electric Energy and Environmental Research Corporation (GE EER) under a Vision 21 contract from U.S. DOE NETL (Contact No. DE-FC26-00FT40974). Other project team members include Southern Illinois University at Carbondale (SIU-C), California Energy Commission (CEC), and T. R. Miles, Technical Consultants, Inc. The UFP project integrates lab-, bench- and pilot-scale studies to demonstrate the UFP technology. Engineering studies and analytical modeling are being performed in conjunction with the experimental program to develop the design tools necessary for scaling up the UFP technology to the demonstration phase. The remainder of this section presents objectives, concept, and main tasks progress of the UFP program.

Program Objectives

The primary objectives of the UFP program are to:

- Demonstrate and establish the chemistry of the UFP technology, measure kinetic parameters of individual process steps, and identify fundamental processes affecting process economics.
- Design and develop bench- and pilot-scale systems to test the UFP technology under dynamic conditions and estimate the overall system efficiency for the design.
- Develop kinetic and dynamic computational models of the individual process steps.
- Determine operating conditions that maximize separation of CO_2 and pollutants from vent gas, while simultaneously maximizing coal/opportunity fuels conversion and H_2 production.
- Integrate the UFP module into Vision 21 plant design and optimize work cycle efficiency.
- Determine extent of technical/economical viability & commercial potential of UFP module.

UFP technology

The conceptual design of the UFP technology is depicted in Figure 1. The UFP technology makes use of three circulating fluidized bed reactors containing CO_2 absorbing material (CAM) and oxygen transfer material (OTM), as shown in Figure 1. Coal and some opportunity fuels (5-10% by heat input) are partially gasified with steam in the first reactor, producing H_2, CO and CO_2. As CO_2 is absorbed by the CO_2 sorbent, CO is also depleted from the gas phase via the water-gas shift reaction. Thus, the first reactor produces a H_2-rich product stream suitable for use in liquefaction, fuel cells, or turbines.

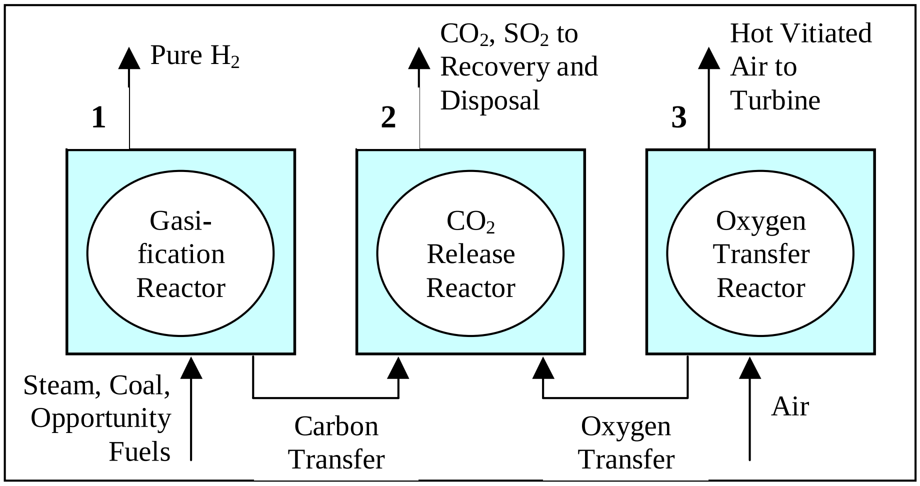

Figure 1. Conceptual design of the UFP technology.

Gasification of the char, transferred from the first reactor, is completed with steam fluidization in the second reactor. The oxygen transfer material is reduced as it provides the oxygen needed to oxidize CO to CO_2 and H_2 to H_2O. The CO_2 sorbent is regenerated as the hot moving material from the third reactor enters the second reactor. This increases the bed temperature forcing the release of CO_2 from the sorbent, generating a CO_2-rich product stream suitable for sequestration.

Air fed to the third reactor re-oxidizes the oxygen transfer material via a highly exothermic reaction that consumes the oxygen in the air fed. Thus, reactor three produces oxygen-depleted air for a gas turbine as well as generating heat that is transferred to the first and second reactors via solids transfer.

Solids transfer occurs between all three reactors, allowing for the regeneration and recirculation of both the CO_2 sorbent and the oxygen transfer material. Periodically, ash and bed materials will be removed from the system and replaced with fresh bed materials to reduce the amount of ash in the reactor and increase the effectiveness of the bed materials.

Project Plan

The tasks planned for the UFP project are summarized in Table 1. These tasks are being conducted over approximately three-year period that started October 1, 2000. The success of the UFP program depends on the efficient execution of the various research tasks outlined in Table 1 and on meeting the program objectives summarized above.

PROGRAM PLANNING AND MANAGEMENT

Program planning activities have focused on meeting the objectives of the program as stated previously. GE EER has made use of several GE methodologies to obtain desired results and systematically conduct program design, construction and testing activities. Methodologies utilized in this program include New Technology Introduction (NTI) and Design For Six Sigma (DFSS). The NTI program is a detailed and systematic methodology used by GE to identify market drivers, and continually ensure that the program will meet both current and future market needs. The NTI program is also strongly coupled with the DFSS and other quality programs, providing structure to the design process and ensuring that the design accomplished through regular program reviews, detailed design reviews, market assessments, planning and decision tools, and specific quality projects aimed at identifying system features and attributes that are critical to quality (CTQ) for customers.

Table 1. Main tasks of the UFP program.

Task	Task Description
Lab-Scale Experiments – Fundamentals *Task 1*	Design & assembly Demonstration of chemical processes Sulfur chemistry
Bench-Scale Test Facility & Testing *Tasks 2 & 3*	Bench test facility design Subsystems procurement& assembly Bench test facility shakedown Reactor design testing Parametric evaluation Fuel-flexibility evaluation Pilot operation support
Engineering & Modeling Studies *Task 4*	Opportunity fuels resource assessment Preliminary economic assessment Kinetic & process modeling Integration into Vision 21 plant Pilot plant control development
Pilot Plant Design, Assembly & Demonstration *Tasks 5, 6, & 7*	Process design Subsystems specification/procurement Reactor design & review Reactors manufacture Components testing Pilot plant assembly Operational shakedown modifications Operational evaluation Fuel-flexibility evaluation Performance testing
Vision 21 Plant Systems Analysis *Task 8*	Preliminary Vision 21 module design Vision 21 plant integration Economic & market assessment
Project Management *Task 9*	Management, reporting, & technology transfer

The project team meets weekly to assess progress, distribute workload, and identify and remove potential roadblocks. An expanded NTI project team that includes senior management and other expert personnel also meets biweekly to gauge progress and ensure that adequate company resources are allocated and technical issues resolved to allow steady progress toward program objectives.

Program management activities also involve continuous oversight of program expenditures. This includes monthly review of actual expenditures and monthly projections of labor, equipment, contractor costs, and materials costs.

Technology transfer and networking with experts in the advanced power generation field is an important and ongoing part of project management. Team members continue to seek out opportunities to present the UFP technology and progress at several conferences.

GE EER's Vision 21 team hosted a program review meeting for several U.S. DOE representatives at GE EER's offices in Irvine, CA on Wednesday, January 8, 2003. A simultaneous videoconference with the DOE NETL office in Pittsburgh allowed the participation of DOE personnel who could not travel to Irvine. The goals of the meeting were to review GE EER's progress on the Vision 21 Unmixed Fuel Processor (UFP) program and discuss related technology development plans. The all-day meeting included eight GE EER presentations, one DOE presentation, discussions, a visit to GE EER Cold Flow Modeling Laboratory, and a visit to GE EER's Test Site to tour the Vision 21 UFP facilities and other R&D program facilities at the site. During the meeting, DOE and GE EER teams were engaged in fruitful discussions that will help optimize R&D work on the Vision 21 UFP technology and advance this technology to demonstration stage. GE EER progress on the UFP project and further development steps were discussed in detail. An executive summary, including a list of participants, topics discussed and the agenda of the meeting, is provided as Appendix A.

During this quarter, additional results from the experimental facilities were obtained, analyzed and used to assess operating characteristics of the system. The laboratory-scale activities are being conducted by SIU in Carbondale, IL, while the bench-scale and pilot-scale systems are located at GE EER's test facility in Irvine, CA. Significant progress was made toward the assembly of the pilot-scale system located at Irvine, CA.

EXPERIMENTAL

LABORATORY-SCALE TESTING

The primary objective of Task 1 is to perform a laboratory-scale demonstration of the individual chemical and physical processes involved in GE EER's fuel-flexible UFP technology. Specific objectives of Task 1 include:

- Support bench- and pilot-scale studies;
- Assist in process optimization and engineering analysis;
- Identify key kinetic and thermodynamic limitations of the process; and
- Verify the process parameters at laboratory scale.

Work conducted in the tenth quarter of this program has focused on experiments conducted in a high-temperature fluidized bed reactor at atmospheric pressure. Mixtures of OTM and CAM were used as the fluidization medium, with different coal loadings.

Fluidization solids were inserted into the reactor, which was heated to the desired temperature under flowing nitrogen at atmospheric pressure. The furnace temperature was set to 870^0C for all experiments; temperature profile measurements inside the reactor revealed that the temperature approximately 1 inch above the bed was 810^0C. Steam was introduced into the reactor and the nitrogen flow rate was adjusted to provide a total gas flow rate equal to 15 times the minimum fluidization velocity. Steam content in the reactor atmosphere was 85% for all experiments. Coal samples were injected into the reactor using the coal delivery system, which is driven by nitrogen. Immediately after coal injection, gas samples and mass flow rate data were taken at one-minute intervals for 30 minutes. Gas samples were analyzed using a gas chromatograph. Results from these tests are summarized in the next section, Results and Discussion.

BENCH-SCALE TESTING

The objectives of the bench-scale testing task are to demonstrate the technical feasibility of the UFP technology and aid in developing modeling tools and pilot plant equipment design. The bench-scale system is also intended to provide data on individual UFP reactor modes to aid in pilot plant design and testing. Bench-scale testing was not conducted in the tenth quarter to allow accelerated progress on the pilot-scale system. Testing will be resumed to further investigate key behaviors in future quarters.

RESULTS AND DISCUSSION

LABORATORY-SCALE TESTING RESULTS

During the first 5 minutes of each test [described in the previous Experimental (Laboratory-Scale Testing) section] significantly larger outlet flow rates were detected, presumably due to the early release of volatile matter. Meanwhile, hydrogen production was observed to fall to negligible amounts approximately 15 minutes after the start of all experiments. After 15 minutes, the CO_2 content in the outlet gases tends to increase slightly as the CAM begins to desorb CO_2 (caused by a shift in equilibrium since CO_2 concentrations have been depleted from the gas phase due to consumption of the injected coal batch). Thus, the first 5 and 15 minutes of each test were chosen as evaluation periods of significance, and the results are reported accordingly. Selected lab-scale test results are provided in Table 2.

Table 2. Product gas composition and volume results obtained for tests conducted with a variety of bed:coal ratios and bed compositions.

Test conditions	Total volume (N_2 free basis) [l] per 1g of coal	H_2 vol fraction	H_2 volume [l] per 1g of coal	CO vol fraction	CO_2 vol fraction	CH_4 vol fraction
After 5 minutes						
85.7g CAM /1g of coal (0.7 g coal charge)	0.800	0.59	0.472	0.20	0.09	0.13
48g CAM / 1g of coal (1.25g coal charge)	0.344	0.74	0.255	0.14	0.09	0.02
24g CAM / 1 g of coal (2.5g coal charge)	0.224	0.63	0.141	0.18	0.14	0.05
48g OTM / 1g of coal (1.25g coal charge)	0.232	0.48	0.111	0.07	0.34	0.10
After 15 minutes						
85.7g CAM /1g of coal (0.7 g coal charge)	1.070	0.63	0.674	0.17	0.11	0.09
48g CAM / 1g of coal (1.25g coal charge)	0.648	0.70	0.454	0.12	0.15	0.02
24g CAM / 1 g of coal (2.5g coal charge)	0.360	0.59	0.212	0.17	0.21	0.03
48g OTM / 1g of coal (1.25g coal charge)	0.312	0.51	0.159	0.05	0.36	0.08

For these batch tests with the same bed size, increasing the amount of coal places an increased performance demand on the bed materials. For CAM beds, it is possible to exceed the capacity of the CAM to absorb CO_2, as shown by the increasing concentrations of CO_2 at decreased CAM:coal ratios. OTM beds react with CO and H_2 to form reduced-state OTM, thus the CO and H_2 concentrations are markedly reduced for the tests conducted with an OTM bed. These relationships are being assessed and analyzed to provide insight into the kinetics that will be used to influence the relationship between bed size and bed residence time.

ENGINEERING AND MODELING STUDIES

Process Modeling

The objectives of the process-modeling task are to develop models for the UFP technology, validate them using experimental data, and apply the models to assist in the design and operation of the pilot-scale system. In addition, process models will be used to make meaningful comparisons of the performance of the UFP technology relative to competing technologies.

Ongoing and future process modeling and analyses include the following:

- Comparing the efficiency of the advanced IGCC and UFP technologies at various H_2 to electricity co-production ratios to identify the optimum operating conditions.
- Developing a dynamic model to analyze the start-up of the UFP technology to aid in development of a UFP technology control strategy.

PILOT PLANT ASSEMBLY

The assembly of the pilot plant has continued in the tenth quarter. The reactors have been manufactured, tested and cast with two-layers of refractory lining. Additional revisions to the solids transfer mechanism have been made based on cold-flow model experimental results. The designs and specifications of key subsystems and components have been finalized, and procurement is continuing. A summary of key activities and accomplishments are described below.

Pilot-Scale Reactors

Significant progress has been made in the manufacture and assembly of the three pilot-scale reactors. The reactor shells were manufactured and tested, the tow-refractory linings of the reactors were cast, the reactor distributor plate design was finalized, and the support structure for the reactors was manufactured. Details on these accomplishments are provided below.

Reactor Testing

During this quarter, the three reactor shells were manufactured, including the welding of flanges and solids transfer ducts. To ensure the integrity of these welds and each vessel as a whole, the reactors were subjected to hydrostatic testing. During each hydrostatic test, the reactor shell was first filled with water, then N_2 from a pressurized cylinder was fed into the top of the reactor until the desired pressure was reached. The inlet was then closed and the pressure in the vessel monitored for a period of 48 hours.

Mechanical stress analysis was used to find the pressure/temperature combination that would most closely represent the design safety factor for the vessel under actual operating conditions. Figure 2 shows effect of metal shell temperature on the maximum allowable stress for the three reactors.

The safety factor is defined as the ratio of the maximum allowable stress (from ASME tables) to the actual stress produced. The maximum allowable stress for 100,000h+ of operation was used with the stress at actual reactor operating conditions to calculate a safety factor of 2.09. An "iso-factor" (= 2.09) curve of metal temperature versus system pressure is shown in Figure 3. Any set of conditions on this curve represents a safety factor of 2.09.

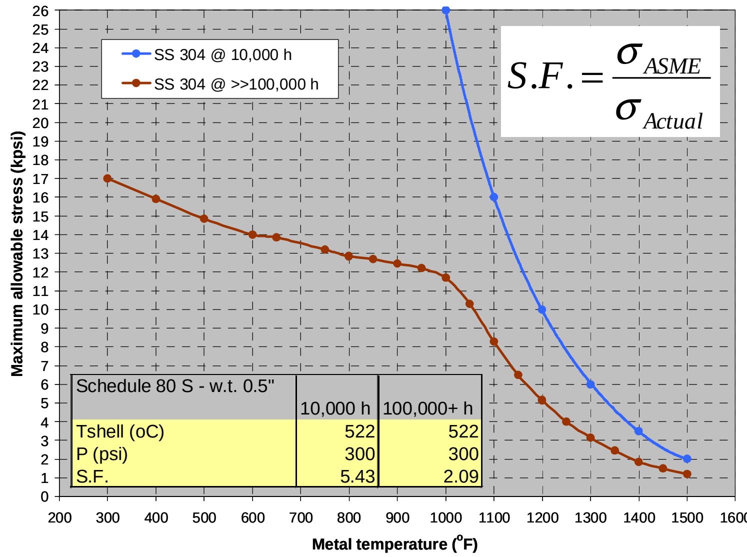

Figure 2. Maximum allowable stress on the reactor metal shell as a function of temperature.

Hydrostatic testing was conducted at 900 psi and ambient temperature, providing a more severe test with a safety factor of about 1.1. After 48 hours of exposure, minimal pressure loss was identified and inspection showed no loss of integrity in the reactor or welds. All the welded ports on all three vessels passed the test. Figure 4 is a picture of the hydrostatic test of Reactor 2.

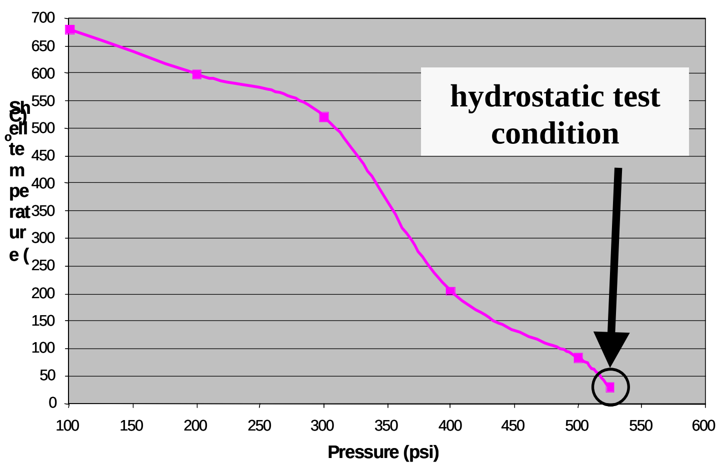

Figure 3. Shell temperature vs. internal pressure for a constant safety factor of 2.09.

Figure 4. Hydrostatic test of Reactor 2.

Reactor Casting

After hydrostatic testing was completed, the three reactor shells were cast with two layers of refractory lining. First, a 2 1/8" layer of Kaolite 2300-LI was cast, followed by 1 3/8" of Kao TAB95. At the same time, the solids transfer ducts were cast with two layers of refractory lining. For each layer cast, forms were designed to provide the appropriate refractory thickness, and a jig was used to hold the forms in place with the reactors standing vertically. A combination of mixing and vibration were used to ensure that the refractory material was packed tightly as it was poured. The refractory was allowed to set for over 24 hours before removal of the jig and forms. The process was then repeated for the second refractory layer.

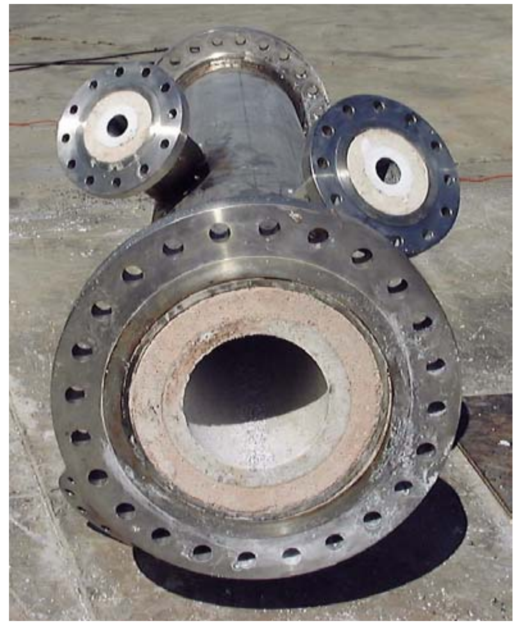

Figure 5. Reactor 1 shell with two cast refractory layers.

Figure 5 shows Reactor 1 with its two cast refractory layers. The refractory will be cured when the complete system is assembled and the preheating system is installed. Details of the refractory design and associated reactor temperature profiles are provided in Appendix B.

Reactor Distributor Plate

The distributor plates that will be used in the pilot-scale system have been designed and tested. The same design will be used for the distributor plate in each reactor. Working closely with GE EER's machine shop, the innovative approach includes the use of ½" hex bolts with a ¼" hole drilled from the bottom up to the bolt head, where three 1/16" nozzle holes were drilled completely through the bolt head to produce six nozzles. The orientation of the bolts allows for staggered nozzle flows to enhance fluidization. The distributor plate was designed to operate at temperatures up to 1000ºC and provide 10psi of differential pressure. A support sleeve is used to locate the distributor plate in the correct region and prevent the fluidization gas from bypassing the distributor plate. The distributor plate design is shown in Figure 6, including a close-up view of the bolts used as nozzles.

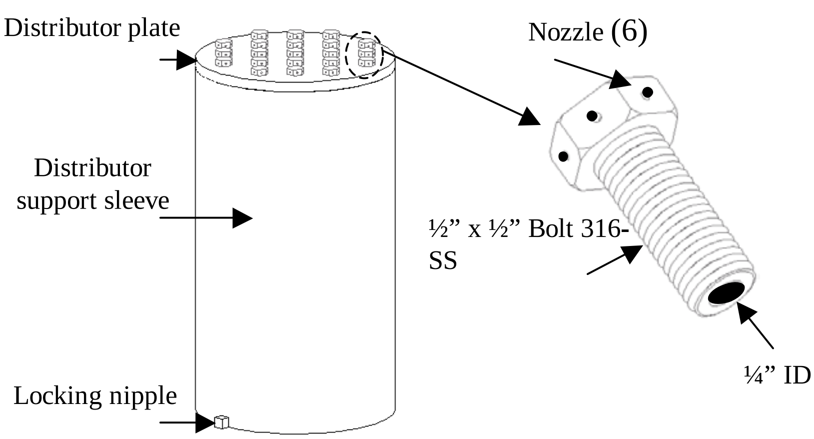

Figure 6. Pilot-scale distributor plate design with detail of nozzle bolts.

Reactor Assembly

The three reactors are connected by a series of flanged solids transfer ducts. Each of Reactors 1 and 3 have two solids transfer ducts, while Reactor 2 has four solids transfer ducts. The appropriate alignment of the reactors is essential to their leak-free assembly. A stand was manufactured to provide the appropriate reactor spacing and alignment. The stand is also designed to support the weight of the filled, flanged reactors. The design of the stand required that pairs of gussets be welded to each reactor. These gussets allow the reactors to be supported from the middle of the reactors, allowing for thermal expansion while providing access to the reactors from below. Figure 7 is a photo of the three reactors mounted on the stand next to the machine shop with assembly of the solids transfer ducts.

Figure 7. Photo of three pilot-scale reactors mounted on stand.

Solids Transfer Mechanism

The transfer of solid bed materials between reactors is a critical part of the UFP technology, as it serves to transfer heat and regenerated reactants between reactors. As described in the second annual report (Oct 2002), a full-size pilot-scale cold flow model was constructed to simulate the action of the solids transfer ducts and aid in the development of the solids transfer mechanism for the pilot-scale system. This cold flow model has provided valuable data regarding the effectiveness of different configurations. In the tenth quarter, experiments were conducted to fine-tune the optimized solids transfer configuration.

Previous tests included the discharge of bed solids onto a scale at atmospheric pressure for flow rate measurements. This procedure was modified to allow the discharge of bed solids into a water-filled vessel to better simulate operating conditions, mimicking the head pressure at point of entry into the neighboring reactor and providing other advantages to aid in the robust design of the solids transfer system.

Since previous experiments had already identified the key variables affecting solids transfer flow rates, the experimental matrix was optimized to provide meaningful data with fewer experiments. The experimental data were analyzed using the Design-Expert 6.0 tool, which can be used to generate contour plots of the design space. One key experimental observation centers around the identification of an optimized flow rate of carrier gas. As carrier gas flow increases, solids flow increases with carrier flow up to the optimum carrier flow. Above this optimum carrier gas flow rate, solids flow decreases with increasing carrier gas flow, presumably due to a "vortex effect" at the induction point.

The contour plots obtained from experimental data analysis were used to identify the optimum carrier gas flow at different operating conditions, as shown in Figure 8. This information, in turn, was used to identify the analogous pilot-scale operating conditions that will be able to provide the required solids transfer flow. Understanding the trends in behavior will aid in the assessment of solids transfer performance when the three reactors are integrated and the solids transfer rate cannot be measured directly.

Although one set of operating conditions will be used for initial assembly of the solids transfer ducts, flexibility is the key to the solids transfer system design. Allowances are being made to ensure that potential changes to the key operating conditions will cause minimal downtime.

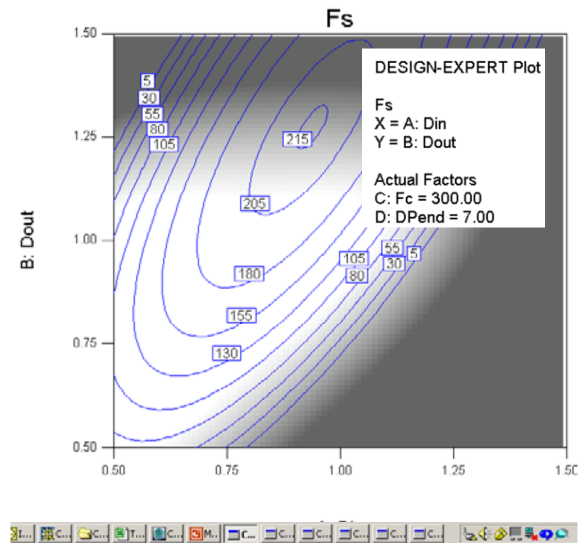

Figure 8. Contour plots of cold flow model data: relationship between flow rate and inlet and outlet diameters.

Additional details on the cold flow model experimental activities are provided as Appendix C.

Pilot-Scale Key Subsystems and Components

Air Pollution Control Systems

The pilot-scale system will include an afterburner and a scrubber to reduce emissions of air pollutants. The afterburner is designed to provide complete combustion of all H_2 and unburned hydrocarbon fuels. The scrubber will remove sulfur compounds from the stack gases. Product gases from Reactors 1 and 2 will pass through the afterburner, and then be sent to the scrubber.

The afterburner will include a custom-built combustion chamber built around an off-the-shelf low-NO_x natural gas burner. Product gas will be injected around the natural gas flame. The natural gas will act as a pilot flame as well as supplemental fuel, as the product gas may have a low heating value (<150 Btu/scf). Overfire air will be used to ensure complete combustion and reduce exhaust temperatures. The combustion chamber will be approximately 18"ID by 90" tall.

A packed tower scrubber has been designed to provide >95% sulfur removal efficiency. The exhaust gases from the afterburner will first pass through a quench to cool the gas to its saturation temperature. The wet gas will then flow up through the packed tower scrubber, as shown in Figure 9. Jaeger Tripax™ packing has been selected for the packed tower. A dilute solution of NaOH will be used as scrubber liquor. This solution will flow down from the top of the packed tower to a reservoir at the bottom of the packed tower, where it will be recycled. The pH of the scrubber liquor reservoir will be monitored, and fresh NaOH solution will be added as needed. The packed tower will have dimensions of approximately 14” ID and 60” tall.

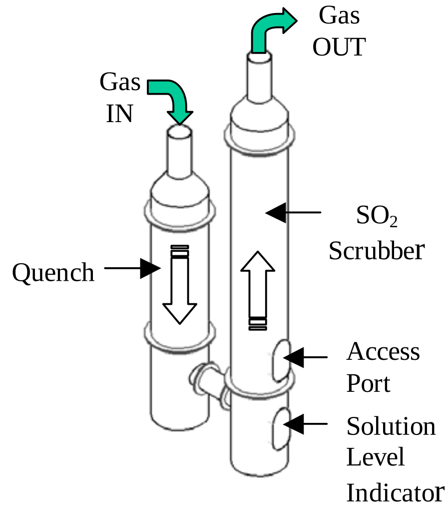

Figure 9. Packed tower scrubber design showing gas flow path.

Coal Slurry Feed System

During the tenth quarter, experimental investigations have provided insight into the appropriate design of the coal slurry feeding system. The slurry pump has previously been specified, purchased and tested with water. Detailed review meetings were held with GE EER experts to leverage their experience with slurry systems used in previous projects. The diameter of the slurry feed at the entrance to the reactor was identified as a key parameter influencing slurry trajectory and preventing the slurry from pooling at the refractory wall. Preliminary calculations of the trajectory of slurry fed into the fluidized bed show that reasonable flow and line size conditions will allow good mixing and an adequate slurry trajectory.

Initial experiments with the slurry system have been conducted on a 50/50 coal/water mixture. The mechanics of feeding the slurry mixture are currently being resolved, and the shakedown testing of the slurry pump will include pumping slurry into a pressurized vessel to simulate actual pilot-scale operating conditions.

Instrumentation

The high operating temperatures and pressures of the pilot-scale system provide difficult operating conditions for most instrumentation. Detailed surveys of severe service instrumentation have led to the selection of appropriate flowmeters and control valves. Above 500ºC, stainless steel instrumentation (316 or 304SS) begins to deform, leading to unacceptable flow measurement performance. Flowmeters that can perform reliably at high temperatures include vortex shedding flowmeters and orifice plates. Vortex flowmeters provide high resolution and accuracy, though at high cost, while orifice plates have limited resolution, but operate simply and are relatively inexpensive. Analysis of the system operation has led to the selection of a combination of these flowmeter types, depending on the location and the need for flow measurement accuracy. The latest version of the pilot-scale P&ID is shown in Figures 10 and 11.

The type of material used for the sealing gasket typically limits the operating temperature of control valves. At temperatures above 350ºC, only Grafoil, 316SS and Inconel wire perform well as sealing gaskets. Of these materials, however, grafoil gaskets provide superior chemical resistivity, which is important in the pilot-scale system.

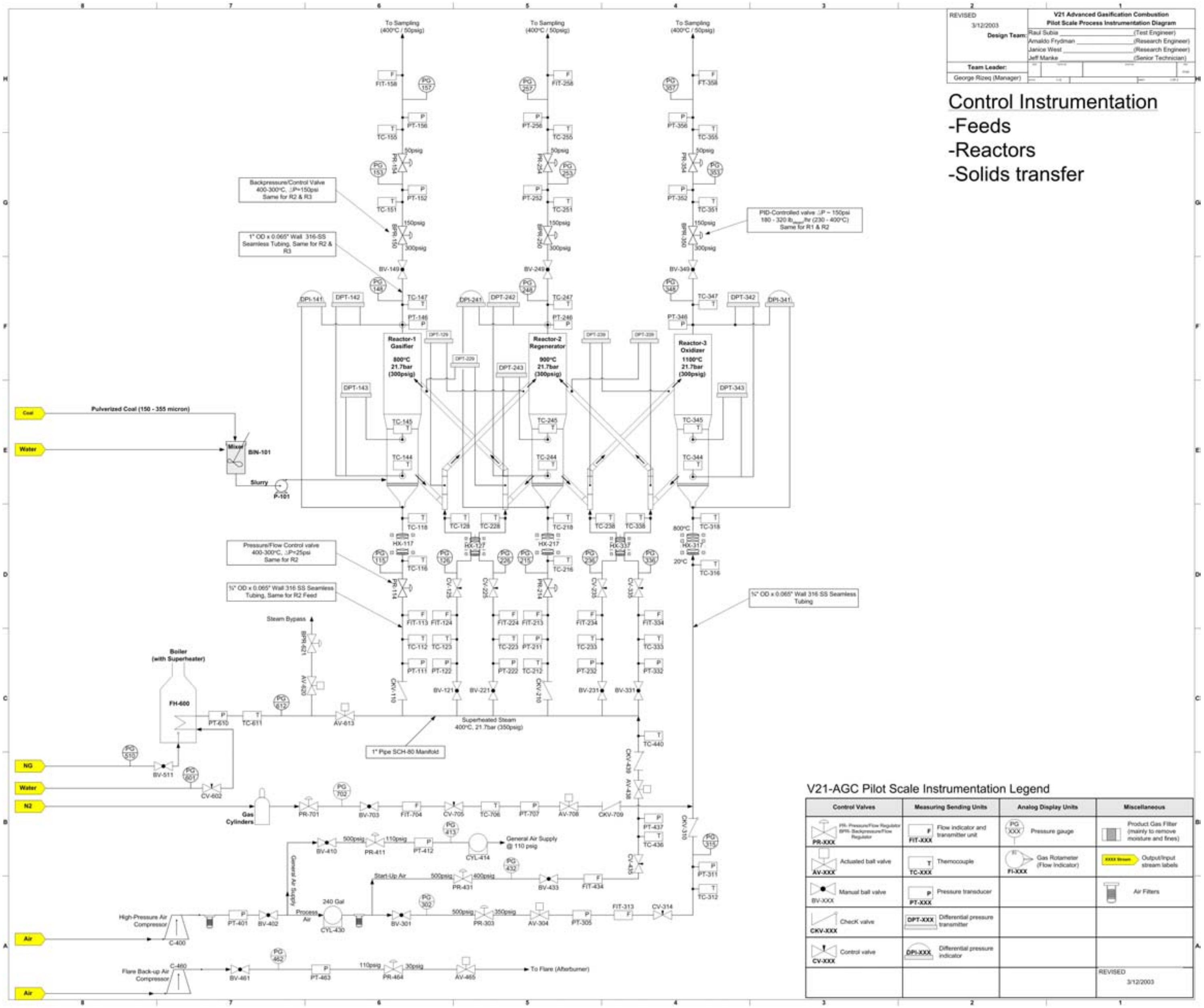

Figure 10. P&ID of pilot-scale system (Page 1 of 2).

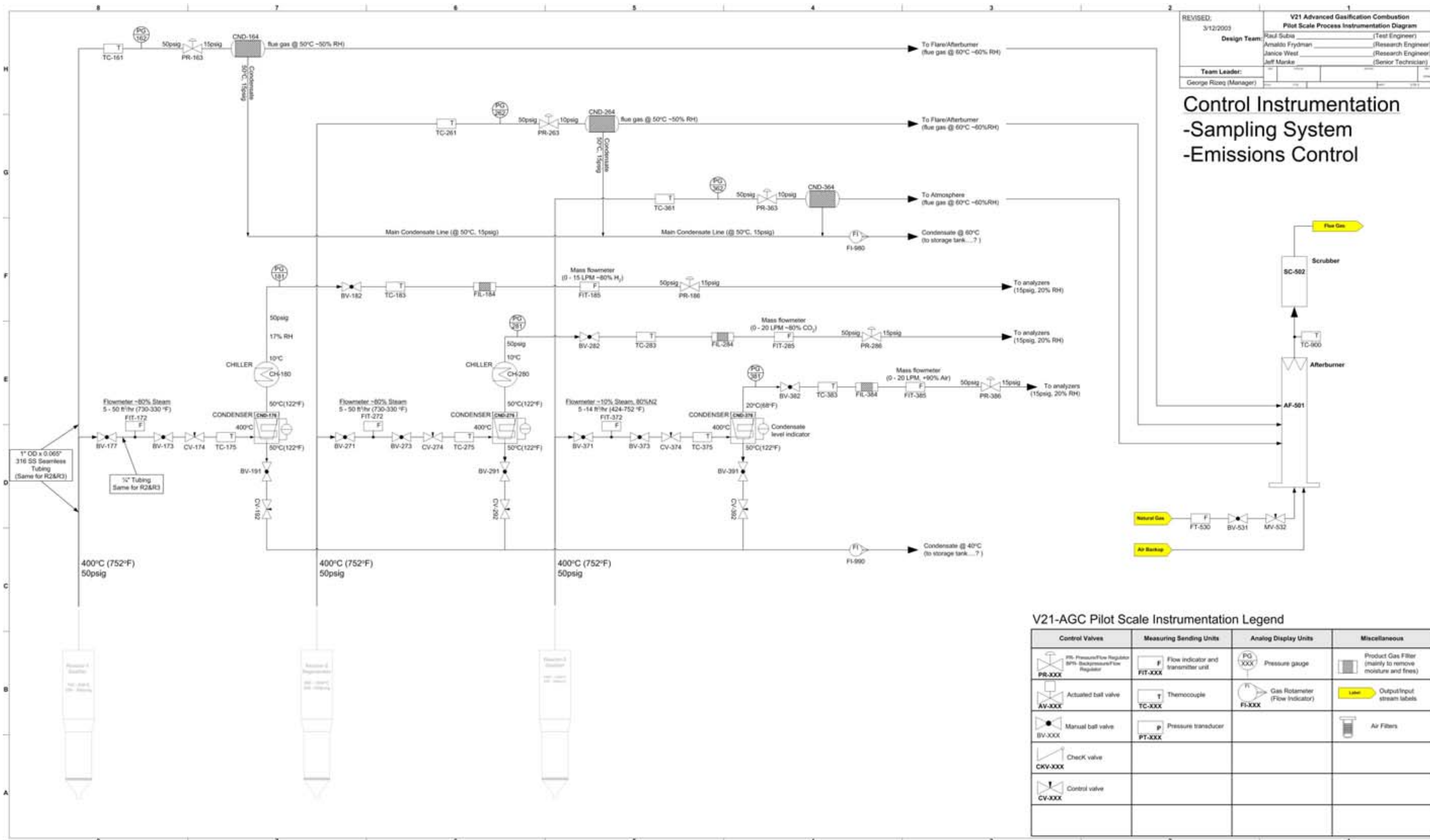

Figure 11. P&ID of pilot-scale system (Page 2 of 2).

CONCLUSIONS

Work conducted in the tenth quarter has focused on accelerating assembly of the pilot plant, with additional experimental analysis being conducted on the lab scale system.

The lab-scale effort has included high temperature fluidized bed experiments to assess the impact of coal loading on coal gasification performance in the presence of CAM and OTM. This information will aid in setting the desired bed residence times in the pilot-scale system.

The pilot-scale assembly effort has continued, with the testing, casting and assembly of the three main reactor vessels. Additional progress was made in finalizing the distributor plate design, fine-tuning the design and operation of the solids transfer system, designing systems to reduce air emissions, testing the slurry feeding system and selecting appropriate high-temperature, high-pressure instrumentation.

FUTURE WORK

Additional lab and bench-scale testing is planned to provide further insight into the rates and mechanisms of char burnout, CO_2 release and OTM reduction processes. Other continuing work on UFP technology development will include the assembly and initial shakedown testing of the pilot-scale system, which will feature three fully integrated circulating, fluidized bed reactors. In addition, progress will be made on modeling tasks in support of pilot-scale system operation. Integral to all these efforts is the continuing analysis of the economics and competitiveness of the UFP technology based on experimental and theoretical findings. These tasks will aid in ensuring that the UFP system will meet the needs of the power generation industry both efficiently and economically.

Task 1 Lab-Scale Experiments – Fundamentals
Task 1 activities will continue to include testing using the lab-scale high-temperature, high-pressure reactor and furnace. Kinetic tests involving coal, char, steam, air and combinations of oxygen-transfer material and CO_2 absorber material will be conducted. These experimental efforts will be closely coupled with the ongoing modeling efforts to ensure that the experiments will provide information useful in model validation.

Task 2 Bench-Scale Facility – Design/Assembly
This task has been completed.

Task 3 Bench-Scale Testing
Future testing activities will focus on identification of optimized operating conditions and characterization of bed material performance and ash behavior. Results of these tests will be used along with lab-scale results to modify and validate kinetic and process models, as well as provide inputs for economic evaluation efforts.

Task 4 Engineering and Modeling Studies
Process and kinetic models will be further developed and validated using results from testing activities. These models will also be used to provide information for pilot plant design efforts. Specific tasks include: (1) comparing the efficiency of the advanced IGCC and UFP technologies at various H_2 to electricity co-production ratios to identify the optimum operating conditions and (2) developing a dynamic model to analyze the start-up of the UFP technology to aid in development of an UFP technology control strategy. Results obtained from the preliminary economic assessment will be used for identification of critical operating parameters that have significant impacts on the cost of electricity and hydrogen, and for recognition of limiting conditions from an economic standpoint.

Task 5 Pilot Plant Design and Engineering
This task has been completed.

Task 6 Pilot Plant Assembly
Key subtasks include: tracking ordered items, inspecting and testing manufactured parts, developing standard operating procedures, and designing the data acquisition interface. A plan will be developed for conducting shakedown testing of subsystems as they are installed, with special attention devoted to the safety and emergency shutdown systems and their integration with all equipment.

Task 7 Pilot Plant Demonstration
After the pilot plant is assembled, extensive shakedown testing will be conducted, with modifications made as needed. The operational evaluation of the UFP technology will then proceed, followed by performance testing to identify the optimum H_2 yield that can be achieved with thorough analysis of the experimental data. A fuel flexibility study will be conducted to assess the impact of blending biomass fuels with coal.

REFERENCES

No references were sited in this report.

LIST OF ACRONYMS AND ABBREVIATIONS

CAM	CO_2 Absorber Material
CEC	California Energy Commission
CTQ	Critical to Quality
DFSS	Design for Six Sigma
GE EER	General Electric Energy and Environmental Research Corporation
GHSV	Gas Hourly Space Velocity
GSV	Gas Space Velocity
IGCC	Integrated Gasification Combined Cycle
NETL	National Energy Technology Laboratory
NTI	New Technology Introduction
OTM	Oxygen Transfer Material
P&ID	Process and Instrumentation Diagram
R1	Reactor 1
R2	Reactor 2
R3	Reactor 3
SIU-C	Southern Illinois University – Carbondale
UFP	Unmixed Fuel Processor
U.S. DOE	United States Department of Energy