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

Quarterly Technical Progress Report No. 13

Reporting Period:

October 1, 2003 – December 31, 2003

George Rizeq, Janice West, Arnaldo Frydman, Raul Subia, and Vladimir Zamansky
(GE Global Research)
Hana Loreth, Krzysztof Piotrowski, Tomasz Wiltowski, and Edwin Hippo
(Southern Illinois University at Carbondale)

January 2004

DOE Award No. DE-FC26-00FT40974

GE Global Research
18 Mason
Irvine, CA 92618

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 Global Research 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 Global Research (prime contractor) was awarded a contract 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 Global Research, Southern Illinois University at Carbondale (SIU-C), California Energy Commission (CEC), and T. R. Miles, Technical Consultants, Inc.

In the UFP technology, coal and air are simultaneously converted into separate streams of (1) high-purity hydrogen that can be utilized in fuel cells or turbines, (2) sequestration-ready CO_2, and (3) high temperature/pressure vitiated air to produce electricity in a gas turbine. The process produces near-zero emissions and, based on ASPEN Plus process modeling, has an estimated process efficiency of 6% higher than IGCC with conventional CO_2 separation. The current R&D program will determine the feasibility of the integrated UFP technology through pilot-scale testing, and will investigate 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 experimental testing, modeling and economic studies to demonstrate the UFP technology.

This is the thirteenth quarterly technical progress report for the UFP program, which is supported by U.S. DOE NETL under Contract No. DE-FC26-00FT40974. This report summarizes program accomplishments for the period starting October 1, 2003 and ending December 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, pilot-scale demonstration and program management and technology transfer.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This is the thirteenth quarterly technical progress report for the UFP program, which is supported by U.S. DOE NETL under Contract No. DE-FC26-00FT40974. This report summarizes program accomplishments for the period starting October 1, 2003 and ending December 31, 2003. The report provides a description of the technology concept and a summary of program activities and accomplishments in lab-scale experimental testing, pilot-scale system assembly, pilot plant demonstration and program management and technology transfer.

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 is highly efficient relative to conventional electricity producing technologies and produces near-zero emissions. This R&D program will investigate operating conditions that maximize separation of CO_2 and pollutants from the vent gas, while simultaneously maximizing coal conversion to electricity efficiency and hydrogen production. The program integrates lab-, bench- and pilot-scale studies to demonstrate the UFP technology.

Work conducted in the thirteenth quarter of this program has focused on the assembly of the pilot plant, conducting additional experimental analysis on the lab-scale system, and on management and technology transfer.

The lab-scale effort in this quarter has included experimental investigations into OTM reduction behavior and OTM behavior at high temperatures. This information will provide key results to guide experimental efforts and provide qualitative validation of process models.

All major components of the pilot plant have been assembled; wiring of instrumentation is nearly complete. Planning efforts undertaken while awaiting permit approval facilitated streamlined assembly of the pilot plant, enabling major components of the system to be assembled in only a few short weeks. Many of the key subsystems were previously tested individually, thus, the shakedown testing of the integrated system is planned for early in the next quarter, with operational evaluation to follow soon after.

System assembly efforts have included the assembly of the reactors and their solids transfer ducts, installation of the boiler, superheater and second-stage superheaters, integration of the high-pressure air delivery system, installation of the emissions control system (afterburner and scrubber), and completion of the flow control panel for product gas analysis. In addition, process instrumentation (flowmeters, pressure transducers, thermocouples, valves, etc.) was installed and ready to be being wired to the data acquisition and control system, and the piping was installed to connect individual system components.

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 the ideal solution to many of this nation's energy needs if a satisfactory process for producing hydrogen from available energy resources such as coal, and low-cost alternative feedstocks such as biomass exists.

This UFP program addresses a novel, energy-efficient, and near-zero pollution concept for converting coal into separate streams of hydrogen, vitiated air, and sequestration-ready CO_2. The technology module comprising this concept is referred to as the *Unmixed Fuel Processor (UFP)* throughout this report. When commercialized, the UFP technology may become one of the cornerstone technologies to meet the DOE's future 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 coal feed 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 DOE future 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.

General Electric Global Research is the primary contractor for the UFP program under a contract from U.S. DOE NETL (Contract 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 the objectives, concept, and main tasks 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.
- Investigate 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 is partially gasified with steam in the first reactor, producing H_2, CO and CO_2. As CO_2 is absorbed by the CAM, 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.

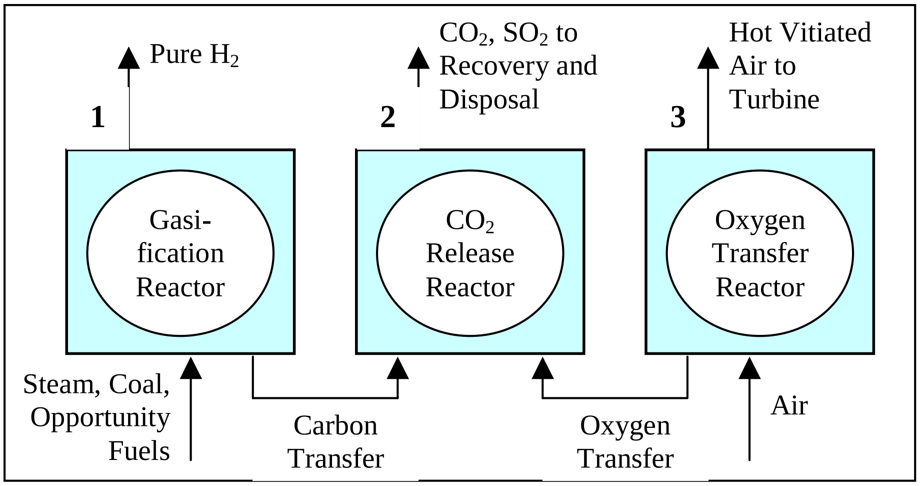


Figure 1. Conceptual design of the UFP technology.

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 3 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 system and increase the effectiveness of the bed materials.

Project Plan

Work on tasks planned for the UFP project (Table 1) was initiated in October 2000. The project was originally scheduled for completion in three years, but a nine-month no-cost extension granted by the DOE in August 2003 extended the completion date until June 2004. This extension was necessary due to delays in obtaining South Coast AQMD permit to construct the pilot plant. 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.

MANAGEMENT AND TECHNOLOGY TRANSFER

Program planning activities have focused on meeting the objectives of the program as stated previously. GE Global Research 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 meets program objectives. This is accomplished through the use of 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 include the continuous oversight of program expenditures. This includes a 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 technical conferences. During the last quarter, the following technical papers were presented:

- George Rizeq, Raul Subia, Arnaldo Frydman, Janice West, Vladimir Zamansky, and Kamalendo Das, "Unmixed Fuel Processor for Production of H_2, Power, and Sequestration-Ready CO_2," *Twelfth International Conference on Coal Science (ICCS)*, Cairns, Queensland, Australia, November 2-6, 2003.
- George Rizeq, Arnaldo Frydman, Janice West, Raul Subia, Vladimir Zamansky, and Kamalendo Das, "Advanced Gasification-Combustion Technology for Production of Hydrogen, Power and Sequestration-Ready CO_2", *Gasification Technologies 2003*, San Francisco, CA, October 12-15, 2003.

Two Abstracts for technical conferences to be held in 2004 were also submitted during this reporting quarter, as summarized below:

- George Rizeq, Arnaldo Frydman, Raul Subia, Janice West, Vladimir Zamansky, and Kamalendo Das, "Unmixed Fuel Processor: Pilot-Scale System Design and Initial Experimental Results," *The 29th International Technical Conference on Coal Utilization & Fuel Systems (Clearwater Conference)*, Clearwater, Florida, April 18-22, 2004. <u>The theme for 2004 will be "Hydrogen from Coal is Here</u>!"
- Arnaldo Frydman, George Rizeq, Janice West, Raul Subia, Parag Kulkarni, and Vladimir Zamansky, "Modeling of Unmixed Fuel Processor for Production of Hydrogen from Coal," *15th Annual U.S. Hydrogen Conference*, Los Angeles, CA, April 26-30, 2004.

During the last quarter, the GE Global Research UFP team held a review meeting with DOE representatives (Gary Stiegel, Stewart Clayton and Gil McGurl) on October 16, 2003 at the GE Global Research offices in Irvine, CA. During the daylong meeting, the UFP engineering team provided an overview of the UFP technology including progress to date and planned technology development activities. During the meeting, DOE and GE Global Research teams were engaged in fruitful discussions that helped in optimizing R&D work on the UFP tasks. The executive summary of that meeting is attached as Appendix A.

In October, the UFP process was selected as one of the most promising technologies currently under development at GE Global Research, and was presented as such to John Rice, the CEO and President of GE Power Systems, on October 30, 2003 in Niskayuna, NY. Several follow-up meetings/conference calls with GE Power Systems representatives were held to further discuss the market potential of this technology, and GE Energy/Power Systems continues to monitor the progress of the program closely.

During the last quarter, the pilot plant was assembled and is nearly ready for process shakedown testing. Plans have been developed for initial testing of mechanical aspects of the system design. Additional results from the experimental facilities were obtained, analyzed and used to assess operating characteristics of the UFP. Laboratory-scale activities are being conducted by SIU in Carbondale, IL, while the pilot-scale system is located at GE Global Research site in 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'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 this quarter included high-temperature lab-scale fluidized bed testing of OTM fluidized with steam and mixtures of CO and H_2. The reduction of OTM is a key UFP process that has been tested extensively by SIU. The objective of the fluidized bed tests is to observe OTM reduction behavior in a fluidized bed system with similar operating conditions to the UFP pilot plant.

In addition, some preliminary heat treatment testing has been conducted to characterize the behavior of CAM and OTM after exposure to high temperatures. Initial testing was conducted by heating different weight ratios of CAM and OTM in air for 45 minutes at 1200^oC then cooling the sample in air. The samples were characterized for their propensity to agglomerate after heat treatment, and x-ray analyses are currently being conducted to identify the formation of new phases.

RESULTS AND DISCUSSION

LABORATORY-SCALE TESTING RESULTS

A series of tests were completed to identify the concentrations of H_2, CO, and CO_2 as a function of time at different operating temperatures and fluidizing gas concentrations. Each test was conducted with 90% steam and either 2, 4, or 5% H_2, with the balance CO. Because of the number of reactions that occur in these tests, particularly the water-gas shift reaction, the measured gas concentrations exiting the reactor provide qualitative information about the system behavior. The gas concentrations, therefore, could not be used directly to obtain kinetic constants, as was the case in the previously reported TGA experiments, where changes in the OTM mass are measured in-situ (see 2003 Annual Report).

Because both CO and H_2 can react with oxidized OTM to form reduced OTM, yet both CO and H_2 participate in the water-gas shift reaction, it is difficult to directly relate the exit gas concentration of CO or H_2 to the degree of OTM reduction. An assessment of the qualitative findings of these experiments is currently in progress.

As indicated in the previous section, preliminary heat treatment tests of the solid bed materials were also conducted in this quarter to assess solids agglomeration tendency at operating conditions. Figure 2 shows two photos of the same OTM/CAM mixture, depicting its appearance before (a) and after (b) heat treatment as described previously. In this figure, some agglomeration is evident, and x-ray analyses are currently being conducted to identify the formation of new phases. A variety of OTM:CAM ratios are being tested to identify problematic mixture compositions. More results will be presented in the next quarterly report.

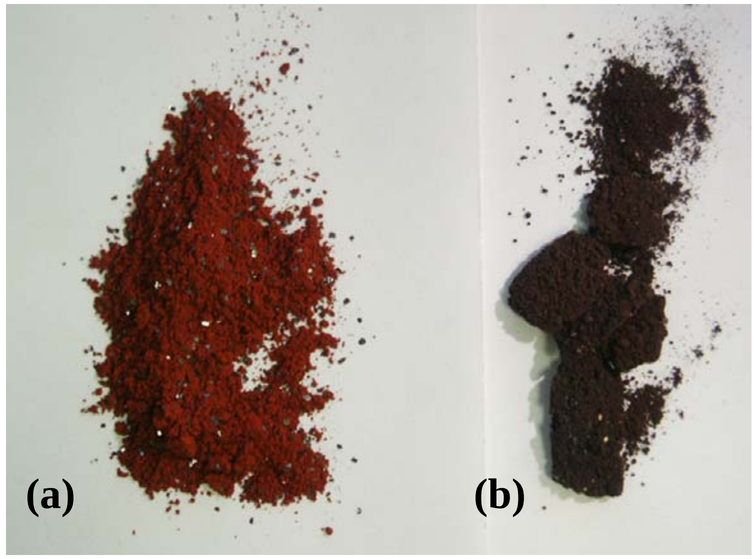


Figure 2. Samples of CAM/OTM mixture (a) before and (b) after heat treatment at 1200°C, demonstrating some agglomeration after heat treatment.

PILOT PLANT ASSEMBLY

The long-awaited South Coast AQMD Permit to "construct and operate" the UFP pilot plant was finally issued in November 2003. The planning work conducted while awaiting permit approval greatly expedited the assembly of the pilot plant, allowing most system components to be assembled in few short weeks. Only the wiring of instrumentation remains to be completed early in the next quarter.

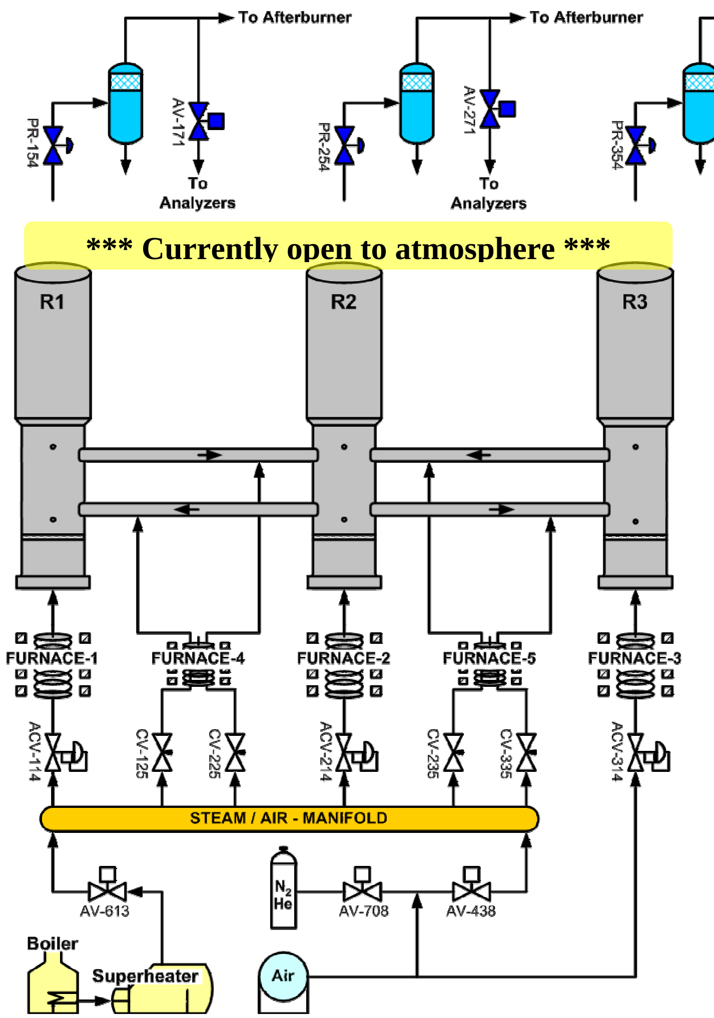
System assembly efforts have included the assembly of the following key components and subsystems:

- Three reactor vessels and their interconnecting solids transfer ducts,
- Steam boiler, superheater, and second stage superheaters,
- Air compressor and high-pressure booster,
- Emissions control system (afterburner and scrubber),
- Product gas analysis system (CEMS and GC), and
- Process instrumentation for control and monitoring (flowmeters, pressure transducers, thermocouples, valves, etc.).

A summary of key activities and accomplishments is provided in Figure 3, a simplified process flow diagram showing the currently installed components and controls. The timeframe of major accomplishments in component manufacture and assembly are also detailed in Figure 3. All system components have been assembled. As noted in Figure 3, the top flanges of the reactors are not currently in place—they will be installed after initial shakedown testing is conducted. Keeping the reactors open to the atmosphere allows an opportunity for test personnel to visualize the behavior of the bed materials during initial bed fluidization shakedown testing. Currently, with wiring 90% complete, the system is near ready for process shakedown, and a detailed plan for the initial sequence of shakedown tests has been documented.

Reactor Assembly

A support frame was constructed for the reactors to facilitate appropriate placement and alignment of the vessels. The framework also included personnel access to the top of the reactors, as shown in Figure 4. The reactors were assembled on the framework immediately after the permit to construct was issued. A special crane was required to place the reactors in the frame. Figure 5 is a photo of the reactors as assembled on the support frame. An important aspect of reactor assembly, requiring precise positioning and alignment, was the installation of the four sets of solids transfer legs that interconnect the three reactors as shown in Figure 6. Careful design and construction, as well as a brief alignment test in October 2003 facilitated the assembly of the reactors without incident. Several ports for instrumentation and solid sampling were created during reactor assembly to allow the installation of thermocouples, differential pressure transmitters, and other monitoring instruments critical to the control and operation of the system.



Pilot Plant Assembly Milestones

UFP Reactors:
- Manufactured (June 2003)
- Support frame (July 2003)
- System assembled (Nov 2003)
- Testing pad (Nov 2003)

Steam Feed System:
- 2nd stage superheater coils manufactured (Sep 2003)
- 2nd stage superheaters assembled (Oct 2003)
- Boiler & superheater delivered (Nov 2003)
- Steam/Air manifold installed (Dec 2003)
- Shakedown (In Progress)

Air Feed System:
- HP air system assembled (July 2003)
- Shakedown (Dec 2003)

Product sampling / Emissions control:
- Afterburner and scrubber units assembled (Sep 2003)
- Sampling assembled (Jan 2004)
- Shakedown (Planned)

Figure 3. Simplified process flow diagram showing assembled equipment and controls, with listing of assembly milestones.

Figure 4. Reactor support framework before pilot plant assembly.

Figure 5. Reactors assembled on support framework.

Figure 6. Assembly of solids transfer legs connecting the three main reactors.

Steam Feed System

The system to feed steam to the UFP reactors includes three major components: the boiler, superheater and second-stage superheaters. Because of temperature-related instrumentation limitations, the steam flow is metered after the superheater exit and sent to five separate superheaters in six individual streams—two to the main reactors with steam feed (the third reactor is fed air), and four to the solids transfer legs. The boiler and superheater were installed as part of the pilot plant in November 2003, and a manifold was constructed to allow separation of the individual flow streams between the superheater and the second-stage superheater. All of the piping was installed and appropriately insulated, with all piping distances minimized to avoid excessive heat loss. Figure 7 shows the steam feed system components and their proximity to the main reactors. The second-stage superheaters are located directly below the main reactors, and the boiler and superheater are just behind the 2nd stage superheaters, with the steam manifold and control valves located between them.

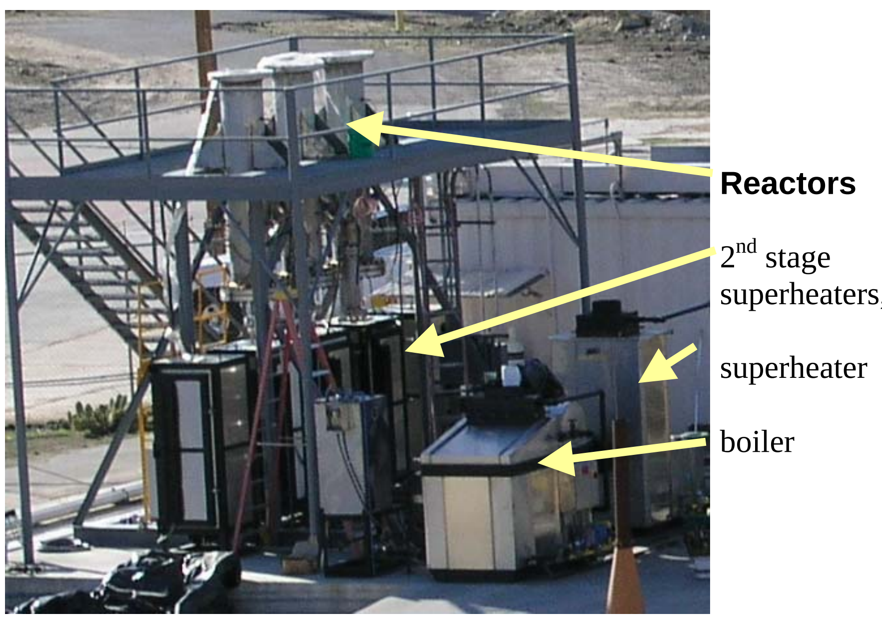


Figure 7. Boiler, superheater, and second-stage superheaters shown as assembled to feed steam to system.

Figure 8. High-pressure air system assembly.

Air Feed System

The air system makes use of a low-pressure air compressor and a high-pressure booster, along with two 240-gallon receiver vessels to provide uninterrupted flow of high-pressure air to the UFP system. The high-pressure receiver vessel is maintained at 500psi, and allows steady flow of high-pressure air to the system while the booster cycles on and off. Figure 8 is a photo of the air feeding system, which was integrated into the pilot plant in the last quarter. This involved installation of piping from the air system to the steam manifold and Reactor 3 inlet. During start-up, air is used to preheat all of the reactors prior to the introduction of steam. The second-stage superheaters are used to provide a hot air stream to heat the bed materials. During normal system operation, air fed to R3 is preheated using the second-stage superheater located below R3.

Product Sampling and Emission Control Systems

As shown in Figure 3, a slipstream of the product gas leaving the three reactors is sent to the product gas analysis system, which includes CEMS and a GC. The CEMS system requires the use of a complex flow control panel that can alternately send calibration gases and product gases to the analyzers for analysis and calibration. A photo of the control panel is shown in Figure 9, with all of the toggle switches and flowmeters allowing the operator to control the type of gas sent to each analyzer individually. Additional analyzers will be installed in the rack as performance analysis testing approaches.

Figure 9. CEMS rack with controls for product and calibration gas flow to analyzers.

The bulk of the product gases will be sent to the emission control system, which is required by the local AQMD to prevent emissions air pollutants. The piping to the afterburner and scrubber has also been installed, connecting them to the rest of the pilot plant.

Control, Monitoring and Analysis Systems

The pilot-scale system has been designed to allow the control of operating parameters within design limits and the monitoring and recording of key process variables and performance indicators. The substantial effort required to wire each instrument and control is 90% complete. Once wiring is complete, the safety system will be tested to ensure safe operation of the pilot plant.

The LabVIEW virtual controllers and the interactive user interface will then be tested and modified as needed. System shakedown testing will be conducted making use of the LabVIEW program to control the system as well as record all monitored data. These results will be used to characterize the operation of the system and identify any operational issues that need to be addressed.

PILOT PLANT DEMONSTRATION

Process Shakedown Testing

Since most of the system components were tested individually, the shakedown testing for the process is the next step after completion of system assembly. Table 2 is a list of tests planned for the pilot plant, with the test type, key operating conditions, and key measurements noted for each test.

Table 2. Process shakedown tests.

#	*Test Type*	Feed (air or steam (St))			Operating conditions		Reactor Top Flanges	Bed circulation	Key Measurements
		R1	R2	R3	T (^{o}C)	P (psig)			
1	dP of leg distributor plate (no bed)	Air	Air	Air	Ambient	14.7	Open	On	dP_leg
2	dP of bed distributor plate (no bed)	Air	Air	Air	Ambient	14.7	Open	Off	dP_reactor
3	dP of bed	Air	Air	Air	Ambient	14.7	Open	Off	dP_reactor, bed height
4	Verify bed movement	Air	Air	Air	Ambient	14.7	Open	On	dP_reactor, dP_leg
5	Bed circulation rate	Air	Air	Air	Ambient	14.7	Open	Varies	dP_leg, bed height
6	Cross-contamination	Air	Air	Air/He	Ambient	14.7	Closed	On	He slip from R1 & R2
7	Leak test	Air	Air	Air	Ambient	400	Closed	Off	System pressure
8	Pressure uniformity across reactors	Air	Air	Air	300	80	Closed	On	Reactor pressure
9	Verify bed movement	Air	Air	Air	300	80	Closed	On	dP_reactor, dP_leg
10	Solids transfer rate	Air	Air	Air	300	80	Closed	On	dP_leg, bed height
11	Cross-contamination	Air	Air	Air/He	300	80	Closed	On	He slip from R1 & R2
12	Reactor heat-up	St	St	Air	800	80	Closed	On	Temperature

Initial testing of the pilot plant will involve the identification of baseline values for fluidization parameters. The differential pressure is a key indicator of both fluidization quality and solids transfer. Thus, it is important to quantify baseline values of pressure drop across the distributor plates in the system. The three reactors each have a distributor plate, and each solids transfer leg also has a distributor plate that must be characterized without a bed in place to provide a baseline value for comparison (Tests 1 and 2). In addition, baseline values of pressure drop across a well-characterized bed provide the basis for monitoring changes in pressure drop during process operation (Test 3).

Validation of the solids transfer mechanism can be conducted by comparing baseline pressure drops to the pressure drops indicated during solids transfer (Test 4). By altering the solids transfer flow selectively, it is possible to cause accumulation of bed solids in one reactor. Testing the responsiveness of solids transfer (Test 5) will provide valuable information for operation. These tests will be repeated at high pressure (Tests 9 and 10) after the top flanges are put in place.

The unmixed combustion concept is based on the separation of air and fuel. Thus, it is important that air be confined to the third reactor. However, the solids transfer leg provides a path between R3 and R2. To ensure that possible system damage and unsafe operating conditions are prevented, testing will be conducted to assess the extent of contamination of R2 with air (if any), first at low pressure (Test 6), then at high pressure (Test 11).

Operation at high pressures requires the minimization of leaks from the system. A leak test (Test 7) will be conducted to identify any leaks in the system prior to testing at high temperatures. Characterization tests have been grouped to allow all testing with the reactor flanges open to be completed before conducting tests with the top flanges closed. The responsiveness of the valves controlling reactor pressure will be evaluated in Test 8, with the ability to maintain the same pressure in all three reactors a key to successful system operation. Test 8 will also provide insight into the effectiveness of solids transfer and the absence of plugging in the solids transfer legs. After testing at high pressure, additional testing will be conducted at high temperatures, first with air, and then with steam. Once the ability to transfer solids, feed steam and air and maintain the desired working pressure is verified, performance testing will take place.

Performance Testing

The key distinction between shakedown testing and performance testing is the use of coal in the first reactor. Much of the shakedown testing focuses on mechanical aspects of system design, but the heart of the process is the gasification of coal and its ability to drive the OTM oxidation-reduction cycle that generates heat for the process. Testing will be conducted first at low pressure to validate system operation and safety before conducting high-pressure tests with coal slurry feed. Initial tests will focus on establishing baseline performance at conditions identified by process modeling. Parametric testing will then be conducted to identify desirable regions of operating conditions.

CONCLUSIONS

Work conducted in the thirteenth quarter has focused on assembling the pilot plant. In addition, lab-scale experiments continue to characterize OTM behavior with respect to reduction reactions and behavior at elevated temperatures.

The lab-scale effort has included experimental investigations into oxygen transfer material (OTM) reduction behavior and OTM/CAM bed behavior at elevated temperatures.

The pilot-scale system has been assembled, with piping between components completed, and wiring of process instrumentation is near completion. The detailed plans developed while waiting for the construction permit significantly streamlined system assembly, allowing rapid progress once the permit was issued. Figure 10 shows the 3-D layout designed prior to system assembly, while Figure 11 is a photo of the assembled system.

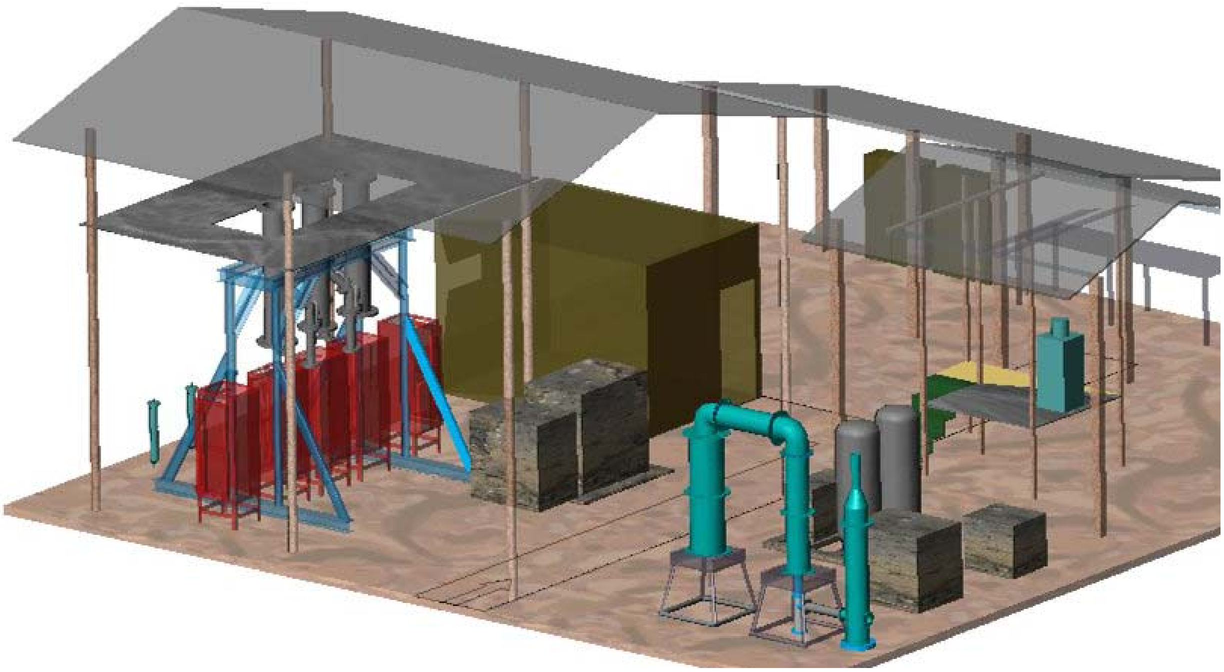


Figure 10. Planned layout for pilot plant assembly.

Figure 11. Photo of assembled pilot plant system.

Despite delays in initiating system assembly, significant progress was made in the thirteenth quarter. The system is nearly ready for performance testing. The pilot plant system has been designed to further establish the feasibility and performance of the UFP system. Lab and bench-scale experiments, as well as process modeling efforts have supported the pilot plant design efforts and will be used to support optimization of pilot plant operation through targeted testing of key UFP processes individually. The progress made to date has continued to establish the viability and promise of this novel technology, and planned experimental efforts aim to further establish the UFP process as a key technology that meets future power generation needs economically, efficiently and environmentally.

FUTURE WORK

Future work on UFP technology development will include pilot-scale process shakedown testing and the operational evaluation of the UFP process at pilot scale. Additional lab- and bench-scale testing will be conducted as needed to provide further insight into the rates and mechanisms of char burnout, CO_2 release and OTM reduction processes. 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 and qualitative tests involving coal, char, steam, air and combinations of oxygen-transfer material and CO_2 absorber material will be conducted and the results analyzed. These experimental efforts will be closely coupled with the ongoing modeling efforts to ensure that the experiments will provide information useful in model validation. Planned experimental investigations include the characterization of OTM/CAM mixture behavior at elevated temperatures.

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

Task 3 Bench-Scale Testing
Additional bench-scale tests will be conducted as needed to identify optimized operating conditions and characterize 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, such as setting solids recirculation rates. Ongoing economic assessments will continue to gauge the economic feasibility of the process, at different scales and considering competing technologies with additional costs associated with emerging CO_2 regulations.

Task 5 Pilot Plant Design and Engineering

This task has been completed.

Task 6 Pilot Plant Assembly

Pilot plant assembly was completed in this quarter, despite delays in receiving a permit from the local AQMD. The wiring of system instrumentation will be completed early in the next quarter. Testing of the safety and emergency shutdown systems and their integration with all equipment will also be completed early in the next quarter.

Task 7 Pilot Plant Demonstration

After validation of the pilot plant systems extensive process 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 H_2 yields and CO_2 separation/release that can be achieved with thorough analysis of the experimental data.

REFERENCES

(no references)

LIST OF ACRONYMS AND ABBREVIATIONS

AQMD	Air Quality Management District
CAM	CO_2 Absorber Material
CEC	California Energy Commission
CEMS	Continuous Emissions Monitoring System
CTQ	Critical to Quality
DFSS	Design for Six Sigma
GC	Gas Chromatograph
IGCC	Integrated Gasification Combined Cycle
NETL	National Energy Technology Laboratory
NTI	New Technology Introduction
OTM	Oxygen Transfer Material
R1	Reactor 1
R2	Reactor 2
R3	Reactor 3
SIU-C	Southern Illinois University – Carbondale
TGA	ThermoGravimetric Analyzer
UFP	Unmixed Fuel Processor
U.S. DOE	United States Department of Energy

APPENDIX A

Unmixed Fuel Processor (UFP) for Production of Hydrogen, Power and Sequestration-Ready CO_2

Program Review Meeting (DE-FC26-00FT40974) at GE Global Research
October 16, 2003, Irvine, California

EXECUTIVE SUMMARY

A program review meeting between U.S. DOE representatives and GE Global Research was held at GE's offices in Irvine, CA on Thursday, October 16, 2003. The goals of the meeting were to review GE's progress on the Unmixed Fuel Processor (UFP) program and discuss related technology development plans. Three U.S. DOE personnel attended the meeting: Gary Stiegel, Gasification Technologies Product Manager; Stewart Clayton, IGCC Portfolio Manager; and Gilbert McGurl, Deputy Associate Director, Office of Policy and Support.

GE personnel attending included:

Sanjay Correa – Global Technology Leader, Energy & Propulsion Technologies (EPT)
Parag Kulkarni – Research Engineer
Ravi Kumar – Project Leader, Reformer Technology
George Rizeq – Project Leader, Advanced Power Generation
Raul Subia – Research Engineer
Mike VanDerwerken, Business Development Manager
Janice West – Research Engineer
Vladimir Zamansky – Manager, Fuel Conversion Lab (FCL)

The all day meeting, see agenda below, included several GE presentations, one DOE presentation, discussions, and a visit to GE's Test Site to see the UFP facilities and other R&D program facilities at the site.

Agenda – UFP-Coal - DOE Project Review Meeting, October 16, 2003

Start Time PST	**End Time PST**	**Dur (Min)**	Topic	**Presenter**
10:00 AM	10:10 AM	10	Introductions	
10:10 AM	10:30 AM	20	Overview of GE Global Research and Energy & Propulsion Technologies division	Correa
10:30 AM	11:40 AM	70	Test Site Visit	
11:40 AM	12:00 PM	20	Current GE Global Research Programs in Irvine	Zamansky
12:00 PM	1:00 PM	60	Working Lunch	
1:00 PM	2:30 PM	90	UFP-Coal Program Review	
		10	Program goals	Rizeq
		10	Overview of Project Results in 2001-2002	Rizeq
		10	Overview of Progress since Jan. 2003 Meeting	Rizeq
		20	Design of Pilot Scale System	Subia
		10	Pilot Plant Construction	West/ Subia
		10	Operational Evaluation	Subia
		10	Process modeling	Kulkarni
		10	Economic Analysis	West
2:30 PM	3:00 PM	30	GE Phase 2 Proposal	Rizeq / Zamansky
3:00 PM	3:30 PM	30	Discussion	All
3:30 PM	4:00 PM	30	DOE Perspectives/Activities in Adv. Gasification, V21 & FutureGen	Stiegel / Clayton
4:00 PM	4:30 PM	30	Closing Comments	All

During the meeting DOE and GE teams were engaged in fruitful discussions that will help optimize R&D work on the UFP technology and advance this technology to demonstration stage. Progress on the UFP project and further development steps were discussed in detail.

The GE team continues to make progress toward meeting program objectives. Although the delay of the permit to "construct and operate" the pilot-scale system has prevented pilot plant assembly, process analysis efforts have progressed, as well as the procurement and testing of key subsystems. Detailed plans for the eventual assembly and testing of the pilot plant have been developed.
Discussion topics included:

- Criteria for successful completion of current UFP program: (1) basic operability, (2) demonstration of H_2 production and inherent CO_2 separation, and (3) absence of show-stoppers
- Suggested objectives of continuing program: (1) identify final disposition of pollutants, (2) characterize attrition of bed, (3) find conditions for long-term operation, and (4) identify key data to help with validation and scale-up
- Comparisons of efficiency and cost with IGCC systems—current process models have been updated to provide comparison of UFP with IGCC co-producing H_2
- Recommended level of GE cofunding for future development program (35% as per Stiegel)

In addition, several potential areas of pilot plant operational challenges were identified and discussed:

- Continuous circulation of bed materials between three reactors
    - Insight gained from cold flow model has helped identify methods of effective solids transfer between reactors
    - Instrumentation will be installed to provide fine resolution and control of bed height
    - Heat transfer between beds, through circulation of solids, will be monitored closely to gauge effectiveness
- Introduction of slurry into fluidized bed
    - Use of nozzles and pressure differentials discussed
- Coal selection
    - Utah coal was initially selected for bench-scale tests due to its low sulfur content, but its high volatility and mineral content may make coal switching desirable
- Rapid temperature changes in R3 potentially leading to attrition of bed materials and/or refractory
    - Solids sampling and regular refractory inspection will identify trends in behavior

Key outstanding technical issues:

Topic	Issue	Response	Lead	Completion target
Modeling (kinetics)	UFP models should make use of kinetics as well as equilibrium limiting cases in modeling	Preliminary process modeling focused on equilibrium predictions along with energy and mass balance calculations, but lab and bench-scale data is being generated to obtain kinetic data and incorporate this data with existing UFP models	A. Frydman	03/04
Pollutants / trace elements	Ultimate fate and disposition of sulfur and other pollutants may impact operability and waste disposal	Test plan includes the use of a SO_x analyzer and GC, as well as analysis of all UFP waste streams	R. Subia	03/04
Economic analysis	Detailed analysis must follow approved DOE guidelines and include all unit operations required for gas cleanup and waste disposal	Economic modeling efforts are consistent with DOE guidelines and additional modeling and testing will provide information needed for more detailed economic analysis	J. West	03/04

In summary, the DOE team was generally pleased with progress to date on the UFP project and anxious to see future development milestones, particularly the successful operation of the pilot-scale system. The DOE team provided insight into current DOE policies and goals (H_2 production, CO_2 separation, high efficiency) met by the UFP technology and possible routes to continued funding of UFP development.