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

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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 thermodynamic efficiency and environmental impact performance of fossil fuel utilization. General Electric Energy and Environmental Research Corporation (GE EER) has developed an innovative fuel-flexible Advanced Gasification-Combustion (AGC) concept to produce H_2 and sequestration-ready CO_2 from solid fuels. The AGC module offers potential for reduced cost and increased energy efficiency relative to conventional gasification and combustion systems. GE EER was awarded a Vision-21 program from U.S. DOE NETL to develop the AGC technology. Work on this three-year program started on October 1, 2000. The project team includes GE EER, California Energy Commission, Southern Illinois University at Carbondale, and T. R. Miles, Technical Consultants, Inc.

In the AGC 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 preliminary modeling work in the first quarter of this program, has an estimated process efficiency of approximately 67% based on electrical and H_2 energy outputs relative to the higher heating value of coal. The three-year 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 AGC concept.

This is the seventh quarterly technical progress report for the Vision-21 AGC program supported by U.S. DOE NETL (Contract: DE-FC26-00FT40974). This report summarizes program accomplishments for the period starting April 1, 2002 and ending June 30, 2002. The report includes an introduction summarizing the AGC concept, main program tasks, and program objectives; it also provides a summary of program activities covering program management and progress in tasks including lab-/bench-scale experimental testing and pilot-scale design.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AGC	Advanced gasification-combustion
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
GE EER	General Electric Energy and Environmental Research Corporation
IGCC	Integrated gasification combined cycle
NETL	National Energy Technology Laboratory
NPI	New product introduction
OTM	Oxygen transfer material
P&ID	Process and instrumentation diagram
SIU-C	Southern Illinois University – Carbondale
U.S. DOE	United States Department of Energy

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 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. This concept is referred to throughout this report as *Advanced Gasification-Combustion (AGC)*. When commercialized, the AGC process may become one of the cornerstone technologies to fulfill Vision-21 energy plant objectives of efficiently and economically producing energy and hydrogen with utilization of opportunity feedstocks.

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

The three-year Vision-21 AGC 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 AGC project integrates lab-, bench- and pilot-scale studies to demonstrate the AGC concept. Engineering studies and analytical modeling will be performed in conjunction with the experimental program to develop the design tools necessary for scaling up the AGC technology to the demonstration phase. The remainder of this section presents objectives, concept, and main tasks of the AGC program.

Program Objectives

The primary objectives of the AGC program are to:

- Demonstrate and establish the chemistry of the AGC concept, 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 AGC concept 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 AGC module into Vision-21 plant design and optimize work cycle efficiency.
- Determine extent of technical/economical viability & commercial potential of AGC module.

AGC Concept

The conceptual design of the AGC technology is depicted in Figure 1. The AGC 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.

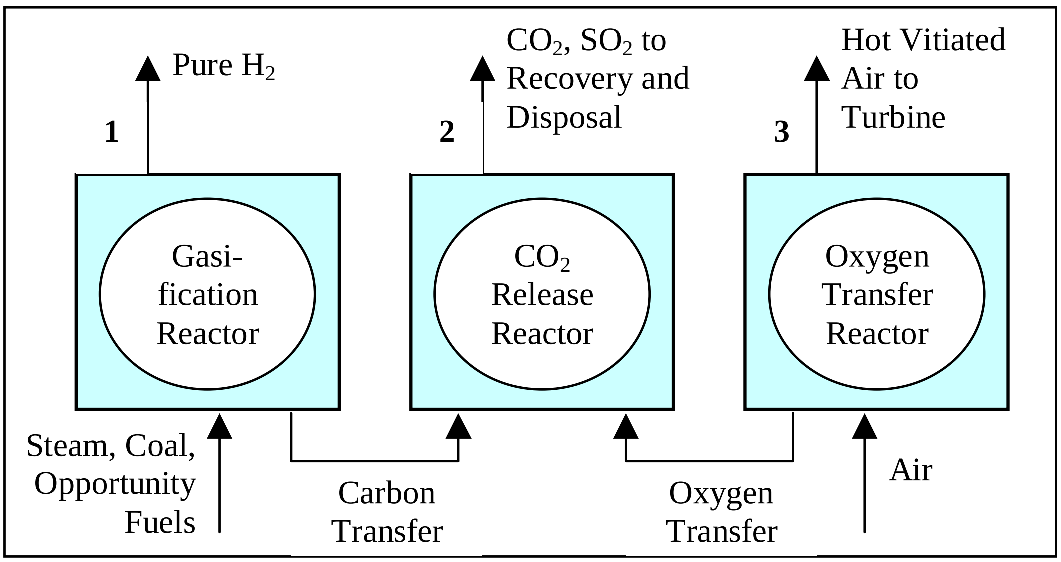

Figure 1. Conceptual design of the AGC technology.

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

Table 1. Main tasks of the AGC 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

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. These methodologies include New Product Introduction (NPI) and Design For Six Sigma (DFSS). The NPI 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 NPI 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 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.

The project team meets weekly to assess progress, distribute workload, and identify and remove potential roadblocks. An expanded NPI project team that includes senior management personnel also meets biweekly to gauge progress and ensure that company resources are allocated and technical issues resolved to allow steady progress toward program objectives. Another purpose of the biweekly NPI meeting is to ensure that the technology is developed in a manner that continues to allow it to meet emerging market needs by following the GE NPI methodology. This includes detailed design reviews as progress is made on system designs.

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 is an important part of project management. During the 7th quarter of this program, an Abstract for a Work in Progress (WIP) poster was prepared and submitted to the *29th International Symposium on Combustion* to be held in Sapporo, Japan, July 22-26, 2002. It was accepted and the WIP poster is to be presented in Sapporo Japan on 7/22/02. This WIP poster will highlight the AGC program and its objectives and show recent results from the ongoing activities to an international audience.

EXPERIMENTAL ACTIVITIES AND RESULTS

During the seventh quarter, results from the experimental facilities have been 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 system is located at GE EER's test facility in Irvine, CA.

Laboratory-Scale (Task 1)

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 AGC 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 seventh quarter has focused on the impact of OTM on coal gasification reaction rates in a fixed bed reactor system.

Experimental method

The effect of OTM addition on coal gasification was studied by analyzing the product gas compositions produced from gasification of a variety of mixtures of Utah coal and OTM. A quartz glass tube reactor with an inner diameter of 1 cm was used as the primary reaction chamber. Glass wool packing material was used to fix the bed position and to facilitate steam superheating. The basic configuration of the system is shown in Figure 2. The

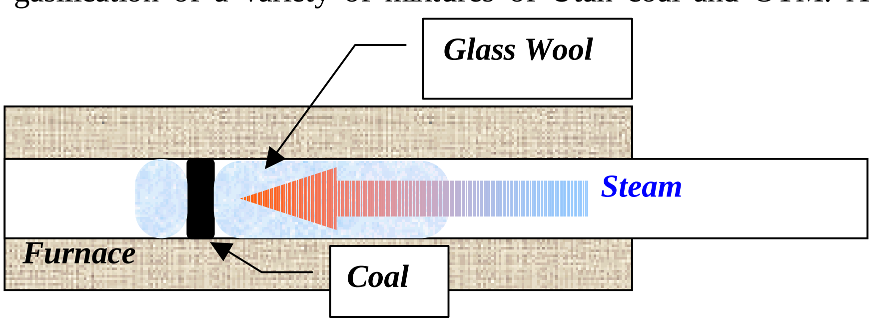

Figure 2. Experimental system configuration: relative positions of coal and glass wool packing material.

reactor was moved into position inside the furnace and steam fed to the system once the desired furnace temperature was achieved. Nitrogen was used as carrier gas for all the experiments. A cold trap was located before the sampling outlet to condense out any tar components. Reaction progress was followed by gas chromatography (Gow-Mac series 600) analysis of product gas samples. Testing was conducted at 800, 850 and 900°C. The OTM was either mixed with the coal or layered behind the coal, as shown in Figure 3.

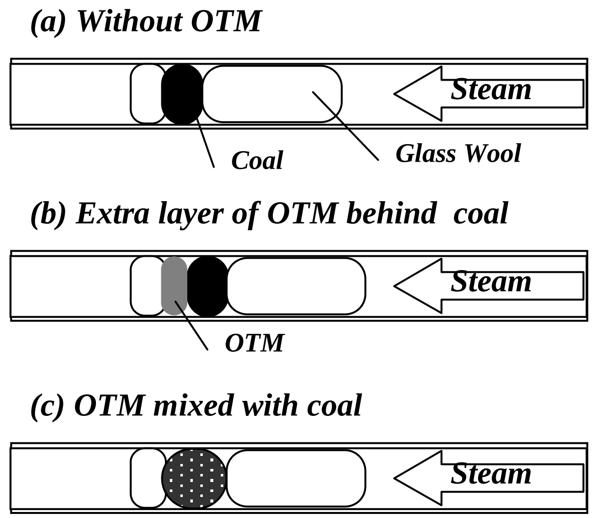

Figure 3. Arrangement of OTM relative to coal (layered or mixed).

The reaction rate constants and activation energy of coal gasification (without OTM) were calculated for basic reaction conditions (carrier gas flow rate of 30ml/min, water flow rate of 0.5ml/min, reaction temperature 800°C or 900°C). Reaction rate constants were obtained from coal residue measurements. Tests were performed for reaction times of 3, 5 and 10 minutes.

Effect of OTM addition

The reaction rate constants and activation energy of steam gasification of coal with OTM addition were calculated for basic reaction conditions (carrier gas flow rate of 30 ml/min, water flow rate of 0.5 ml/min, reaction temperature of 800°C, and 900°C). Results were compared to those obtained from experiments performed with coal only (under same conditions). The OTM added to the reactor was either mixed with coal sample or layered behind the coal sample. The initial OTM mass was 0.065g (4.0 x 10^{-4} mol) per coal sample (0.2g) for all tests. Coal reactivity was observed to be strongly dependent on both reaction temperature and steam concentration.

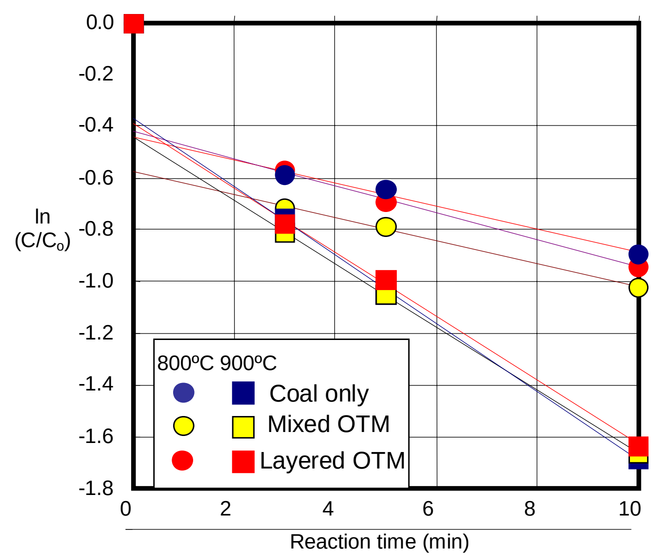

Figure 4. First order plot at 800°C and 900°C.

The gasification reaction with OTM addition was assumed to be a first-order reaction, as in the case of coal only. The relationship between ln(C/C_0) and reaction time is shown in Figure 4, where C_0 is the initial coal sample mass [g] and C is obtained by subtracting the added OTM mass from the residue mass [g]. The calculated rate constants are provided in Figure 4 and Table 2.

Table 2. Reaction rate constants (min^{-1})

	Furnace Temp. (°C)	
	800	900
Coal only	.0444	.132
Layered OTM	.0523	.124
Mixed OTM	.0446	.122

For experiments conducted at 800°C, the rate constant increased slightly for the layered OTM case. The difference in behavior with OTM addition type suggests that different mechanisms are impacting behavior. Specifically, it seems that mixed OTM facilitates the decomposition of coal volatile matter, while layered OTM promotes the decomposition of fixed carbon in coal. However, for experiments at 900ºC, OTM addition did not impact the coal decomposition behavior. Thus, the impact of OTM on coal decomposition is most significant at temperatures below 900ºC.

Arrhenius parameters were calculated based on the results provided above and are listed in Table 3. The presence of OTM lowered both the activation energy (***E_a***) and the frequency factor (***A***). The change in activation energy was especially significant for layered OTM.

Table 3. Arrhenius parameters.

	E_a ($kJ\ mol^{-1}$)	A (min^{-1})
Coal only	114.2	16349
Layered OTM	90.0	1259
Mixed OTM	105.1	5820

Bench-Scale Testing (Task 3)

The objectives of the bench-scale testing task are to collect data on process operation and kinetics under dynamic conditions and aid in developing modeling tools and pilot plant equipment design. The bench-scale system is also intended to provide data on individual AGC processes to aid in pilot plant design and testing. Bench-scale testing conducted in the seventh quarter has focused on parametric testing and performance assessment of the oxygen transfer material (OTM) at reactor 2 and 3 operating conditions.

OTM performance is related to the ability of the OTM to undergo the reduction reactions in Reactor 2 that in turn allow the OTM to be oxidized in Reactor 3. Experiments conducted to date under Reactor 3 conditions have shown that oxidation of reduced-state OTM occurs rapidly and readily and is highly exothermic. OTM performance is most often limited by the reduction step. OTM tests are conducted in two parts. First, a 920ºC OTM bed is fluidized by steam, then a batch of coal is fed to the reactor. The coal gasification products provide the fuel for OTM reduction. In the AGC process, the fuel for OTM reduction is char that is transferred from Reactor 1. However, as the objective of these initial tests was to verify that the OTM bed could undergo oxidation/reduction with gasified fuel, the use of coal in place of char has a minimal impact on the interpretation of results. Later tests will focus on char burnout levels required to provide sufficient fuel for OTM reduction once limits of OTM reduction are established.

The second part of the OTM test is OTM oxidation, which is accomplished by first lowering the temperature of the reactor to 750ºC under nitrogen flow (to protect system components once the reactor temperature is elevated due to OTM oxidation), then feeding air to the reactor and measuring the temperature increase in the bed and the oxygen concentration of the product gas. Figure 5 shows the temperature profile during an OTM test. This figure indicates that the temperature increase during the oxidation step is rapid and significant. The magnitude of the temperature increase during the oxidation step is an indirect measure of the amount of OTM that was reduced (and thus made available for oxidation) in the reduction step.

The extent of OTM reduction is related to the amount of reducing fuel present. During the OTM tests, varying amounts of coal were used to provide the fuel for OTM reduction. The objective of these tests was to identify the maximum temperature increase achievable during the oxidation step.

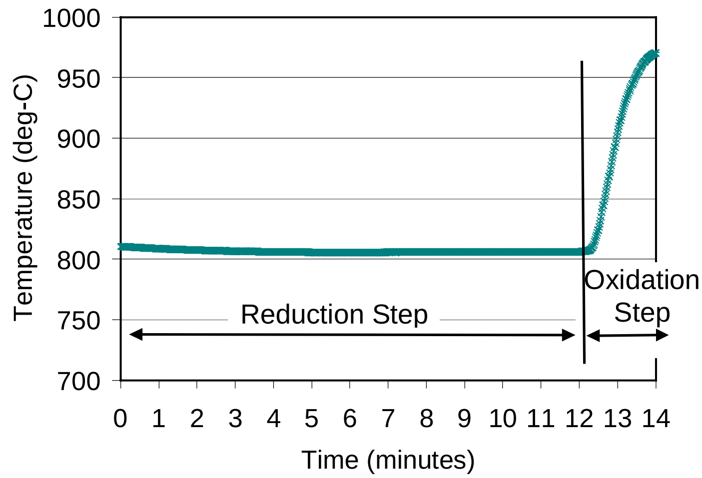

Figure 5. Temperature profile during reduction and oxidation steps of OTM test.

During the reduction step of OTM tests, CO_2 concentrations in the product gas are an indication of the extent of both coal gasification and OTM reduction, as CO_2 is a product of both of these reactions. Figure 6 shows the measured CO_2 concentrations for tests conducted at three different coal:OTM ratios. It is interesting to note that the highest CO_2 concentrations were achieved during the 0.033 coal:OTM test, although this was not the highest fuel input tested.

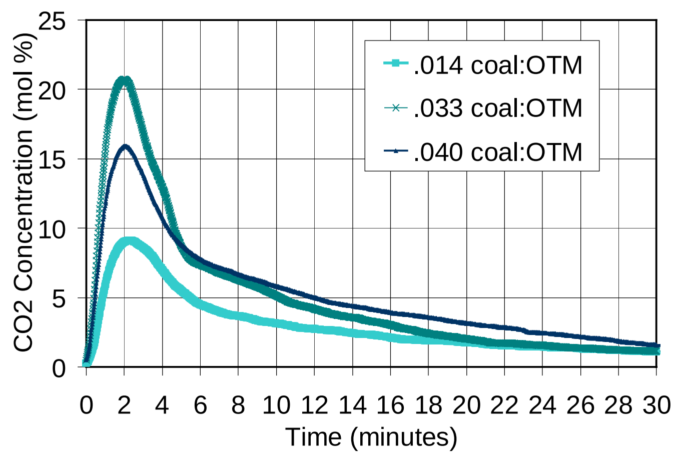

Figure 6. CO_2 concentrations during the reduction step of OTM tests for three different coal:OTM ratios.

However, temperature increases measured during the oxidation step of the OTM tests are consistent with the CO_2 concentration results, as the 0.033 coal:OTM ratio test also produced the largest temperature increase (Figure 7). Preliminary results in this figure suggest that excess fuel may adversely impact the OTM oxidation/reduction cycle, as can insufficient fuel. The test with the highest coal:OTM ratio (0.040) produced a significantly lower temperature increase than the two tests with lower fuel inputs. Further investigation is currently in progress to look into the reproducibility of this data and provide more information on the mechanism by which increased fuel decreases the ability of the OTM to be reduced and oxidized, as well as exploring the limiting value of the fuel input required to promote optimized OTM oxidation/reduction.

As part of this effort, another set of experiments was conducted to separately identify the extent of OTM oxidation by CO and H_2. In these tests, coal was replaced with gas mixtures of either CO or H_2 (balance N_2) to simulate Reactor 2 OTM reduction conditions. A sample of experimental results is provided below. Figure 8 shows the outlet H_2 concentration during two tests of OTM reduction performed at different H_2 feed concentrations. As may be expected, the H_2 concentration more quickly reaches its inlet concentration for the 20% H_2 case, while the 6% H_2 case approached the inlet concentration more gradually.

However, during the oxidation step that followed these OTM reduction steps, the 6% H_2 case experienced a significantly larger temperature increase, as shown in Figure 9. The temperature increase was so large, it was necessary to reduce the air feed flow rate to prevent equipment damage. After the system temperature decreased, the airflow rate was increased, causing another temperature spike that required a subsequent airflow reduction. The airflow rate was later increased again to its original level. The temperature increase for the 20% H_2 case was much more gradual and had a lower maximum. Initially, it was thought that the extent of OTM reduction might be more complete for the higher H_2 feed concentration and lead to a larger temperature increase, but this was not supported by experimental results. Obviously, the concentration of the reducing fuel (here H_2) plays an important role in the extent of OTM reduction, which needs to be explored further in future experiments.

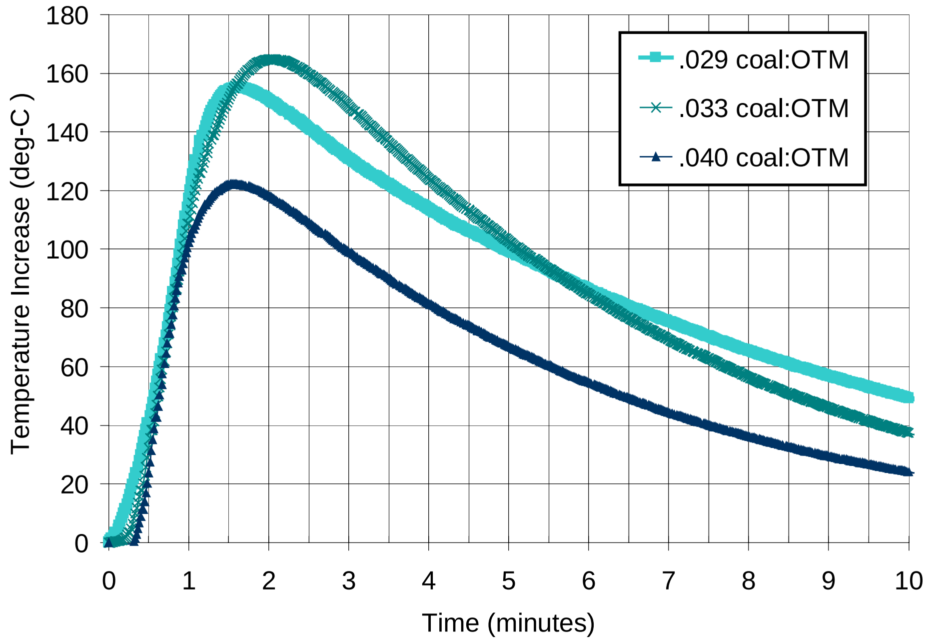

Figure 7. Temperature increase during oxidation step of OTM tests for three different coal:OTM ratios.

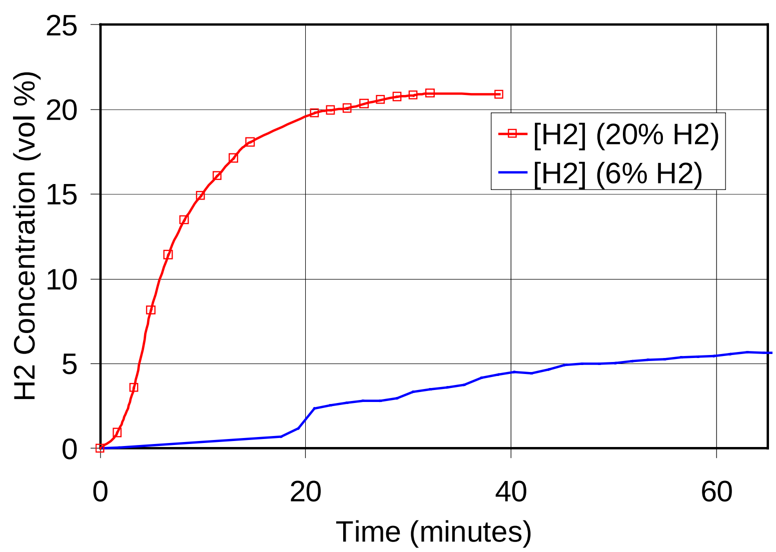

Figure 8. H_2 concentration during OTM reduction step for two different H_2 feed concentrations.

Tests were also conducted with 6% CO to compare the effectiveness of OTM reduction with CO and H_2. The CO and H_2 concentration profiles during the OTM reduction step are provided in Figure 10. The lower initial concentrations of H_2 are evidence of increased participation in OTM reduction reactions. During the H_2 test, the H_2 concentration reached inlet concentration levels more quickly than the CO test.

The improved performance of H_2 for OTM reduction is also evident in the results of the OTM oxidation step shown in Figure 11. The temperature increase for the 6% H_2 case was significantly higher than for the 6% CO case. Although these preliminary results indicate that CO may not be as effective as H_2 for OTM reduction and subsequent oxidation, the data show reasonable OTM reduction activity from CO and significant temperature increases during oxidation. Continuing investigations are in progress to further characterize OTM behavior relative to the CO and H_2 reducing agents under various concentrations/mixtures.

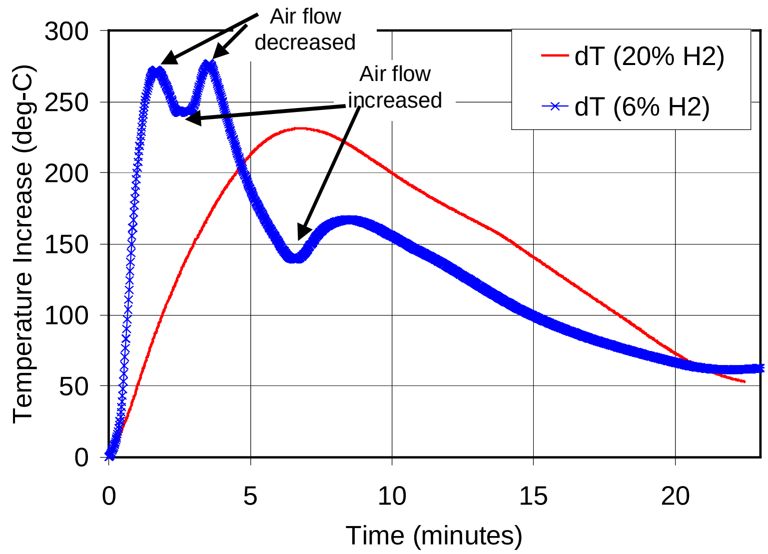

Figure 9. Temperature increase during OTM oxidation step for two different H_2 concentration tests.

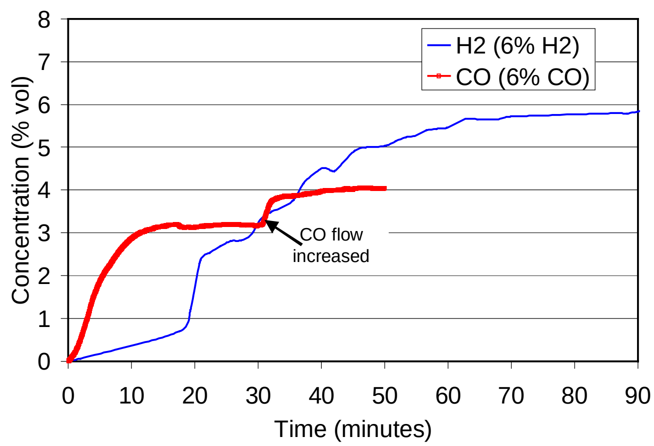

Figure 10. Concentrations of H_2 and CO during two tests of OTM reduction.

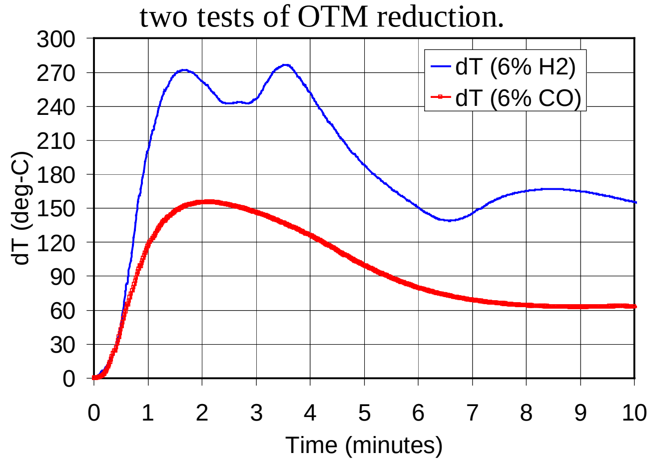

Figure 11. Comparison of temperature increase during OTM oxidation step for two tests with different OTM reduction feeds.

Pilot Plant Design and Engineering (Task 5)

Specific objectives of the pilot plant design effort include:

- Creation of a conceptual design for an AGC pilot-scale plant;
- Documentation of the process and instrumentation diagram (P&ID);
- Development of reactor designs for 1) fluidized gasification of coal/CO_2 absorption (Reactor 1), 2) CAM decomposition (Reactor 2) and 3) OTM oxidation (Reactor 3); and
- Identification and specification of subsystems.

During the seventh quarter, work has proceeded on the design of the pilot-scale unit. A preliminary process and instrumentation diagram (P&ID) was developed. In addition, decisions have been made on the reactor operating conditions, reactor configuration and the selection of a coal feeding system.

Process & Instrumentation Diagram

Figure 12 is a preliminary process and instrumentation diagram (P&ID) showing the location of different instruments that will be used in pilot-scale operation. The instrumentation is critical to the control and measurement of system operating parameters.

System Operating Conditions

The heart of the AGC process is the three fluidized bed reactors. Two types of criteria determine the operating conditions of the three reactors: fluid dynamics (or fluidization) and chemistry (or stoichiometry). These two criteria define the fluidization flow and the mass of bed material from AGC process requirements. It is important to identify operating conditions that meet both criteria. An Excel spreadsheet was developed to utilize fluidization correlations from literature[1] and match them as closely as possible to the chemistry requirements.

Several situations with different reactor diameters and particle sizes were assessed. From this sensitivity analysis, a range of practical operating conditions and reactor specifications was obtained. A summary of this analysis is provided in Table 4. Operating limits for main process variables are shown.

TABLE 4. Pilot-scale operating conditions for AGC reactors 1-3.

Reactor	ID (in)	L_{mf} (ft)	Bed mass (lb)	L (ft)		L_{total} (ft)	$d_{p.avg}$ (μm)	coal feed (lb/h)	Steam flow (lb/h)		Steam-to-Carbon		Re		u/u_{mf}		Chemistry		
				min	max				min	max	min	max	min	max	min	max	bed mass (lb)	Steam-to-Carbon	steam flow (lb/h)
1	10	1.52	115.6	1.76	2.05	7.72	300	50 (max. 100)	183.8	320.8	3.5	6	4.01	7	2	3.49	117	3.5	186

Reactor	ID (in)	L_{mf} (ft)	Bed mass (lb)	L (ft)		L_{total} (ft)	$d_{p.avg}$ (μm)	coal feed (lb/h)	Steam flow (lb/h)		Steam-to-Carbon		Re		u/u_{mf}		Chemistry		
				min	max				min	max	min	max	min	max	min	max	bed mass (lb)	Steam-to-Carbon	steam flow (lb/h)
2	10	1.52	115.6	1.76	2.05	7.72	300	N/A	154.9	270.4	5.22	9.11	4.01	7	2	3.49			

Reactor	ID (in)	L_{mf} (ft)	Bed mass (lb)	L (ft)		L_{total} (ft)	$d_{p.avg}$ (μm)	coal feed (lb/h)	Air flow (lb/h)		O_2/OTM		Re		u/u_{mf}		Chemistry		
				min	max				min	max	min	max	min	max	min	max	bed mass (lb)	O_2/OTM	air flow (lb/h)
3	10	1.49	113.8	1.74	2.16	5.28	300	N/A	177.6	378.2	0.098	0.209	2.93	6.25	2	4.26	113.8	0.125	237.4

[1] Octave Levenspiel and Daizo Kunii, *Fluidization Engineering*, 2nd edition, Butterworth-Heinemann, 1991.

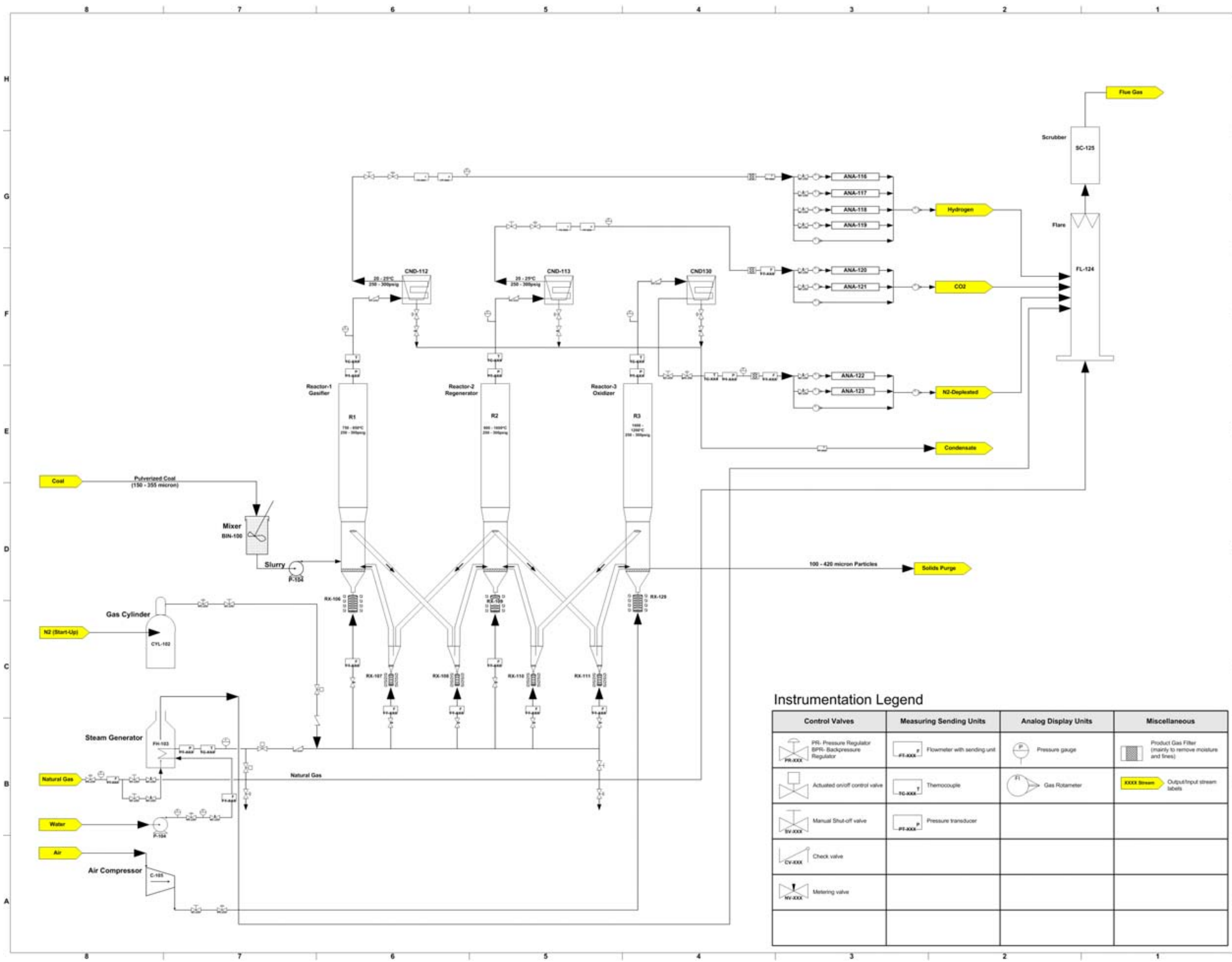

Figure 12. Preliminary pilot-scale process & instrumentation diagram.

Reactor Arrangement and Solid Transfer System

A study was performed to compare different configurations, based on critical-to-quality (CTQ) requirements and practical feasibility. For practical purposes, the three reactors will have the same height (8 ft) and diameter (10 in). The reactors are connected by transfer ducts. Carrier fluid (steam) will be injected into the ducts to push the solids to the next reactor. This mechanism will provide adjustable solid flow rates. Design calculations are being conducted to determine the appropriate carrier fluid flow rate. A cold flow model of this reactor system is also being designed to allow experimental evaluation of this transfer mechanism. The cold flow model design will include appropriate scaling procedures to ensure that its performance can provide insight into pilot-scale behavior.

Selection of Coal Feeding System

Two types of solids feeding technologies have been under consideration: dry pressurized lock-hoppers systems, and coal-water mixture (CWM) slurries. Table 5 is a comparison of features of these technologies. Capital cost and energy impact were identified as the two features of most concern. In the 6th quarterly report (April 2002), a cost estimate for the pressurized lock-hopper system was provided (nearly $100,000). The high cost includes significant design and engineering costs due to the need for extensive system customization. The coal slurry pump is much less costly (~$5,000). In this quarter, an evaluation of the energy impact on system was conducted.

Pilot-Scale System Equipment Floor Plan

The design effort for the pilot-scale system has included the design of the pilot-scale floor plan. A preliminary scaled diagram of the proposed layout of the major equipment is shown in Figures 13 and 14. Figure 13 provides a top view of the floor plan, while figure 14 shows a side view with elevations of the major components and their support structures. The design of the support structure for the reactors is currently in progress. The floor plan drawings will aid in system assembly and planning for piping and wiring needs.

Table 5. Comparison of features of coal-water slurry with pressurized coal lock-hopper systems.

Coal-Water Slurry	**Pressurized Coal Lock-Hoppers**
Low Cost	High cost (even at small scale)
Potential for complex maintenance requirements	Complex maintenance
Enhanced bed mixing	Causes gasifier product dilution
Increases energy demand of system	Increases energy demand of system
In-house prior experience	Team member has extensive prior experience
No need for complex design	Requires complex engineering design
Scalable to next phases of project	Not directly scalable to next phases of project

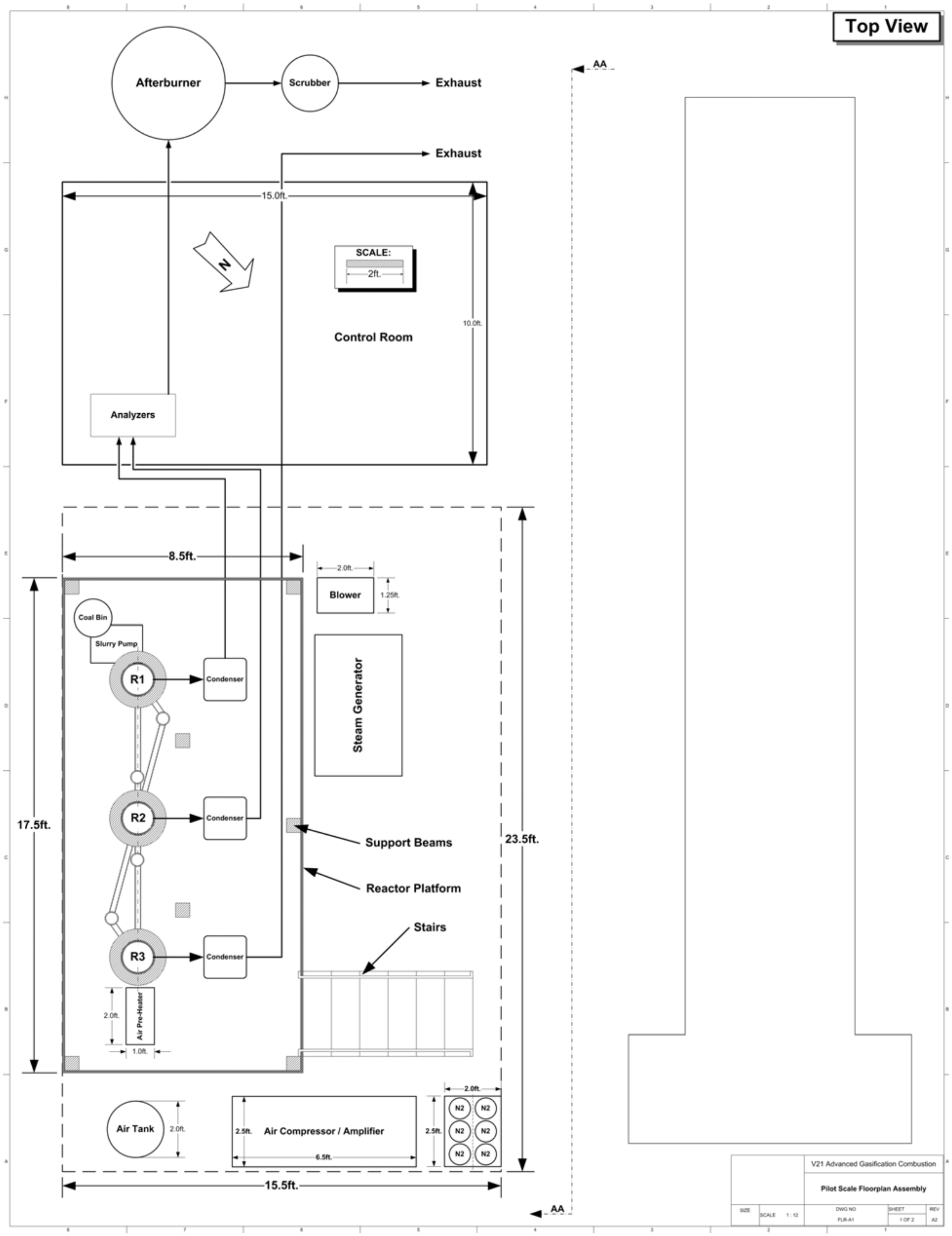

Figure 13. Pilot-scale floor plan (top view).

Figure 14. Pilot-scale floor plan (side view).

Assuming a 50 lb/h coal feed rate at 300 psi, the equilibrium temperature (T_{eq}) in the gasification reactor (Reactor 1) was calculated. This temperature can be used to compare the dry feed and slurry feed systems with a theoretical pure coal feed system. Table 6 shows the equilibrium temperatures achieved for different coal feeding systems. Both the coal feeding systems under consideration result in reduced equilibrium temperatures, and for the 70% coal slurry case, the energy impact of slurry and dry feeding are the same. The much higher cost of the dry feeding system is not justified by any enhanced performance, thus the coal-water slurry has been selected as the coal feeding technology for use in the pilot-scale AGC system.

Table 6. Energy impact considerations of coal feeder types.

Coal feed type (Reactor 1)	T_{eq} (ºC)	Wt % solids	H_2O (moles/hour)
Pure coal (700ºC steam feed)	788	100	--
Coal/water slurry	745	80	315
Coal/water slurry	715	70	540
Dry feed coal-N_2 mixture (N_2:C = 1)	715	(n/a)	--

SUMMARY AND CONCLUSIONS

Work conducted this quarter has continued to develop the framework for demonstration of AGC process capabilities. The laboratory-scale efforts for this quarter have included fixed-bed experiments to assess the impact of OTM on coal gasification.

Bench-scale experimental testing has included parametric testing on the effect of coal:OTM ratio on OTM performance. The relationship between coal gasification temperature and the heat released during OTM was assessed. An analysis of the experimental results suggests that a coal:OTM ration of 0.033 provides the best combination of CO_2 generation and heat release. Additional testing was conducted to assess the participation of H_2 and CO in OTM reduction reactions. OTM reduction occurs more rapidly with H_2, CO is also able to reduce OTM and produce significant temperature increases during OTM oxidation.

The pilot-scale design effort has continued with the development of a process & instrumentation diagram as well as the selection of operating conditions, a solids transfer mechanism and a coal feeding technology.

FUTURE WORK

Additional bench-scale testing is planned to further investigate the performance issues related to the CAM and OTM bed materials, as well as possible interaction effects. In addition, more detailed testing of the Reactor 2 processes will be conducted to provide further insight into the rates and mechanisms of the char burnout, CO_2 release and OTM reduction.

Other continuing work on AGC technology development will include the completion of design and initiation of construction 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 the pilot-scale system's design and operation. Integral to all these efforts is the continuing analysis of the economics and competitiveness of the AGC technology based on experimental and theoretical findings. These tasks will aid in ensuring that the technology is well established and that the AGC system will meet the needs of the power generation industry both efficiently and economically.

Task 1 Lab-Scale Experiments – Fundamentals
Task 1 activities will include experimental testing of 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. Cycling tests will also 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 3 Bench-Scale Testing
Activities will focus on parametric testing to identify optimized operating conditions and specific tests to characterize material performance. 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
Kinetic and process 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. 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
The design of system components will be finalized and reviewed internally and externally. Planning for start-up, shutdown and other operational issues will be considered. The budget for pilot-scale equipment will be updated to reflect the latest P&ID, and equipment will be purchased and fabricated according to schedule.