Advanced, Low/Zero Emission Boiler Design and Operation

Quarterly Technical Progress Report

Reporting Period from January 1st, 2003 through March 31st, 2003

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ABSTRACT

This document reviews the work performed during the quarter January – March 2003.

The main objectives of the project are:

- ⇒ To demonstrate the feasibility of the full-oxy combustion with flue gas recirculation on Babcock & Wilcox's 1.5MW pilot boiler,
- ⇒ To measure its performances in terms of emissions and boiler efficiency while selecting the right oxygen injection strategies,
- ⇒ To perform an economical feasibility study, comparing this solution with alternate technologies, and
- ⇒ To design a new generation, full oxy-fired boiler.

The main objective of this quarter was to initiate the project, primarily the experimental tasks. The contractor and its subcontractors have defined a working plan, and the first tasks have been started.

Task 1 (Site Preparation) is now in progress, defining the modifications to be implemented to the boiler and oxygen delivery system. The changes are required in order to overcome some current limitations of the existing system. As part of a previous project carried out in 2002, several changes have already been made on the pilot boiler, including the enrichment of the secondary and tertiary air with oxygen or the replacement of these streams with oxygen-enriched recycled flue gas. A notable modification for the current project involves the replacement of the primary air with oxygen-enriched flue gas. Consequently, the current oxygen supply and flue gas recycle system is being modified to meet this new requirement.

Task 2 (Combustion and Emissions Performance Optimization) has been initiated with a preliminary selection of four series of tests to be performed.

So far, the project schedule is on-track: site preparation (Task 1) should be completed by August 1st, 2003 and the tests (Task 2) are planned for September-October 2003.

The Techno-Economic Study (Task 3) will be initiated in the following quarter.

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PROJECT OBJECTIVES FOR THE QUARTER

The main objective of this quarter was to initiate the project, primarily the experimental tasks. The contractor and its subcontractors have defined a working plan, and the first tasks have been started.

Task 1 (Site Preparation) is now in progress, since:

- The modification to be implemented on the pilot boiler have been identified and initiated.
- The required O₂ delivery system adaptations have been specified (valve skid and related control system update) and initiated.

Task 2 (Combustion and Emissions Performance Optimization) has been initiated with a preliminary selection of four series of tests to be performed.

Task 3 (Techno-Economic Study) will be initiated in the following quarter.

INTRODUCTION

1 PROJECT DESCRIPTION

Over the past years, environmental concerns for various combustion-generated pollutants have grown dramatically. In addition to acid rain precursors (NO_x and SO_x), which were the first ones to be targeted and remain a short-term issue, carbon dioxide emissions have become a major concern due to the associated greenhouse effect. As a consequence, the governments have tightened the regulations on SO_2 , NO_x and mercury emission limits in a growing number of areas, and have started to regulate CO_2 release into the atmosphere and/or encourage the development of new technologies aimed at controlling this release.

The power generation industry and more specifically coal-fired units account for a large amount of above-mentioned pollutants – around 10% of the worldwide CO_2 emissions result from coal-fired power plants. Therefore, it is imperative that new combustion concepts be developed and customized for power-plant needs, so that existing and new coal-fired units may utilize available options to comply with existing and future emission regulations.

The traditional pollutant control method consists of a post-combustion flue gas treatment system comprising as many treatment devices as regulated pollutants. Currently, a conventional post-treatment line includes: a wet- or dry-FGD for SO_x removal, an ESP for particulate removal and a SCR or SNCR for NO_x reduction (when regulated). Future regulations on mercury and CO_2 emissions will necessitate the addition of an activated carbon injection device (Hg removal) and CO_2 separation installation (amine sorption and regeneration technique). Such a pollutant control method comes along with several drawbacks:

- Most of these installations are flue gas flow rate dependent. Therefore, they are very expensive when applied to conventional air-combustion systems, the inert nitrogen playing a “ballast” role in the process.
- In general these installations control one independent pollutant, thus requiring the addition of a new device (and financial burden) each time a new pollutant is restricted.

It is easy to imagine that a nitrogen-free process would benefit from a highly reduced flue gas flow rate. This can be achieved by replacing the combustion air with pure oxygen in the combustion process. The resulting five-fold decrease in oxidant volume into the boiler leads to reduced flue gas treatment costs. In addition, by removing the nitrogen from the process, the flue gas is highly enriched in carbon dioxide. This characteristic allows its relatively straightforward capture for eventual sequestration without any need for expensive and energy consuming separation systems.

The oxy-combustion technology development could take different routes. For new plants, the oxy-combustion strategy would include advanced, compact oxy-fired boilers, resulting in significant reductions in boiler dimensions. To develop a retrofit technology applicable to existing boilers, the solution consists of recirculating a portion of the flue gas, so that the nitrogen is basically replaced with CO_2 and the boiler characteristics remain close to the air-fired base-case. Figure 1a shows an air-fired system including the present/future emission control devices, while Figure 1b shows the reduced-size devices and/or absence of these devices

when oxy-combustion technology is implemented. This project will attempt to demonstrate the retrofit concept and test it at a pilot scale, and will investigate the feasibility of the new boiler design through preliminary design.

Figure 1: Boiler schematic including flue gas post-treatment. a) Existing air-fired operation. b) Oxygen-fired operation using flue gas recirculation.

The main objectives of the project are:

- ⇒ To demonstrate the feasibility of the full-oxy combustion with flue gas recirculation on Babcock & Wilcox's 1.5MW pilot boiler,
- ⇒ To measure its performances in terms of emissions and boiler efficiency while selecting the right oxygen injection strategies,
- ⇒ To perform an economical feasibility study, comparing this solution with alternate technologies, and
- ⇒ To design a new generation, full oxy-fired boiler.

In order to accomplish the first two tasks, the project will perform tests on the B&W's 1.5MW coal-fired pilot boiler described below.

2 EXISTING SYSTEM: B&W SMALL BOILER SIMULATOR (SBS)

2.1 SBS Description

The experimental part of this project will be performed in the Small-Boiler Simulator (SBS) (Figure 1). This facility accurately replicates the combustion and convection heat transfer characteristics of a full-size boiler. The SBS, located in the B&W Research Center in Alliance (Ohio), is a totally integrated, small-scale combustion and fuel handling facility that allows engineers to evaluate various fossil fuels, combustion processes, and environmental controls for potential use by Babcock & Wilcox's customers. Equipment at the facility includes a test furnace, two fuel subsystems, a dry scrubber for SO₂ control, two fabric filter houses, a condensing heat exchanger and the supporting instruments for combustion and solids-grinding characterization and emissions characterization.

The SBS unit has a nominal heat input capacity of 1.5MW (5-million Btu/hr), and is typically fired in a pulverized coal (PC), wall-fired mode. Numerous tests have shown excellent scale-up of pilot results to performance at full-scale. In particular, NO_x simulations on the SBS have scaled to commercial scale very well.

The vertical design of the water-cooled SBS furnace is a scaled-down version of B&W's commercial units. It measures 1.37m (4.5 feet) wide by 1.83m (6.0 feet) deep by 4.27m (14 feet) high, and has a calculated residence time of about 2 seconds from the PC burner centerline to the furnace exit when operated at its design capacity. The inside surface of the SBS furnace is insulated with 3-inch thick refractory to yield a furnace exit gas temperature (FEGT) of 1204°C (2200°F). The gas temperature profiles are preserved accurately, as are ash characteristics (carbon content and size distribution), NO_x emissions, residence times, and FEGT values. The furnace is designed with five water-jacketed modules. They are located in the ash hopper, lower furnace, middle furnace, upper furnace, and steam drum. The lower furnace jacket also includes the burner block – a removable wall section containing the burners, burner throat, and windbox as a complete assembly.

Figure 2: B&W Small Boiler Simulator (SBS).

The SBS combustion air supply uses a forced draft system with the capacity to deliver up to 150% of full-load total air requirements. The secondary air preheat is provided by use of a gas-fired indirect air heater to yield temperatures up to 427°C (800°F). Capabilities for up to 50% overfire air and 30% flue gas recirculation (FGR) are included in the air supply system. The total secondary air flow as well as air flows to the overfire system are measured by use of orifices.

The SBS was set up for the possibility of direct firing of coal from its MPS-32 pulverizer. The direct feed system consists of a live-bottom bin designed to handle crushed coal, a weight belt feeder, and MPS-32 pulverizer with externally controlled rotating classifier, and a primary air heating and supply system for the pulverizer. A small crusher is available upstream to pre-size the solids before the bin.

The MPS-32 pulverizer is a scaled-down version of the large-scale MPS mills used in the field. It is rated at 363kg/hr (800 pounds per hour) of solid feed. The coal fineness (particle size distribution) can be varied by adjusting the air/coal ratio to the mill, the pulverizer and classifier rotational speed. The coal flow to the pulverizer is measured and controlled at the weigh feeder, which is calibrated to within 2% accuracy. The primary air flow is dampered at the fan and measured at the orifice ahead of the electric air heater. The air heater is capable of supplying primary air up to 427°C (800°F) to the pulverizer at the pulverizer's rated capacity. The air heater is controlled to maintain the desired fuel/air temperature leaving the mill, usually between 54°C and 66°C (130-150°F).

In order to control the air/coal ratio to the burners, independent of the supplied air/coal ratio from the mill, a bag filter is included downstream of the pulverizer to dispose of a

controlled amount of air from the stream. The bag filter can also be used to provide a full capacity catch of the pulverizer output for pulverizer characterization with a particular fuel.

The SBS is equipped with temperature, pressure and flow measuring devices to facilitate mass and energy balance calculations. Measured gas flows include primary air to the pulverizer, primary air discharged at the bag filter vent, the total secondary air to the furnace, the overfire air, the secondary air to the windboxes, and the stack gas flow.

The SBS has a complete gas analysis system consisting of Beckman gas analyzers for O₂, NO_x, CO, CO₂, and SO₂ measurements. The flue gas is drawn from the stack by a vacuum pump, filtered, transported in a heated sample line to the refrigeration unit, and passed to the appropriate analyzers. For the measurement of local in-furnace gas species, the gas analyzers can be switched to a remote heated line that is connected to a gas-sampling probe.

In addition to the Beckman gas analysis system, a Lear Siegler transmissometer is available for opacity measurements. The Lear Siegler Model RM41 transmissometer is installed downstream of the Beckman analyzers to provide the optical density measurement of the flue gas in the stack, or indication of the particulate concentration in the stack.

The bottom ash is removed manually from the SBS furnace. The stack fly ash can be collected from the stack using an Andersen Manufacturing Emission Parameter Analyzer. The particulate sample is withdrawn isokinetically so that the stack dust loading can be determined. The fly ash can be analyzed for carbon content to determine carbon utilization in the system.

The SBS furnace is equipped with viewing and sampling ports that can be used for in-furnace sampling and temperature traverses. Several sampling probes are included with the SBS. These include a water-cooled gas probe for in-furnace gas probing, a high velocity thermocouple in a water-cooled probe for in-furnace temperature probing, a pulverized coal sampler for isokinetic sampling of pulverized coal in the coal duct, and a straight through water-quenched char probe for in-furnace particulate sampling. A video camera is available for recording flame pictures and a FlameviewTM imaging system is available for temperature mapping of the flame.

The convective pass section is designed to duplicate the time/temperature history of the flue gas in a utility boiler. It consists of four different sections simulating secondary superheater, reheater, primary superheater, and economizer containing 42, 40, 100, and 216 tubes, respectively. All four sections are connected to a common atmospheric steam drum that recirculates cooling water to the tube banks and walls. Deposits on the tubes and the walls are removed by sootblowers that are located in front of each section.

For fouling (deposition) studies, an air-cooled deposition probe is placed in the convective section to represent a superheater tube. This probe is equipped with thermocouples for measuring the wall and inlet/outlet air temperatures. The probe wall temperature is maintained at values typical to boiler tubes to ensure meaningful ash deposition results. Ash deposition effect on heat transfer is determined by energy balance calculation for the probe. In addition, a simulated commercial sootblower is available to determine the required pressure for removing the deposits and restoring maximum heat flux potential.

Analog data from pressure transducers, thermocouples, and gas analyzers are sampled every 15 seconds and averaged over a preset time span. Macro programs and commercially available software including Stars Labview, and Microsoft Excel are used for data acquisition and post-processing.

2.2 Oxygen System

For the duration of the tests, liquid oxygen will be delivered to the test facility and stored in a 34m³ (9,000 gallon) tank, provided by Air Liquide. To comply with safety guidelines, the tank is located at an appropriate distance from all electrical and combustible sources, and will have easy road access. The liquid oxygen is vaporized in an ambient vaporizer, sized for winter operating conditions (-7°C/20°F air temperature). The tank and vaporizer are supported on a concrete foundation pad, while a second pad will be laid for the off-loading area. The oxygen is regulated to an appropriate pressure and delivered to the test area via a copper line.

Air Liquide provides a valve skid to control and monitor flow of oxygen to the SBS. This skid is similar to equipment used in other oxy-combustion applications. Appendix A shows the existing skid installed at B&W, and used in 2002 for a previous project, including two oxygen “legs”. One supplies oxygen to a sparger inserted either in the secondary air duct or recycled flue gas duct, while the other supplies oxygen to injection devices placed in the SBS overfire air ports. Each leg has a flow control valve, and metering device (orifice plate and pressure transducer). The control system is integrated with the SBS, allowing oxygen flows to be controlled and monitored from a central location. It is also integrated into the SBS safety interlock system.

Appendix B presents the modifications of the skid which are currently underway in order to meet the project objectives. Thus, an additional oxygen leg will be added, dedicated to providing oxygen to the primary air stream, for complete oxy-combustion.

Finally, Appendix C presents the existing SBS/oxygen delivery/piping system (in black), and the preliminarily envisioned modifications (in red). These modifications are further explained below.

2.3 Limitations/problems of the existing system

2.3.1 Limitation of experimental systems

To date, no full oxygen retrofit of a coal-fired boiler has been reported. The tests carried out by Air Liquide and B&W in 2002 using Illinois coal had certain limitations listed below. In addition, the coal used during the current project is Power River Basin coal, low sulfur and high elemental mercury, poses a different set of challenges, several identified below. Thus, the main limitations during previous tests include:

- The inability (to-date) to enrich the primary air stream with oxygen and/or flue gas recirculation. In the previous tests only the secondary and tertiary oxidants were enriched in oxygen or replaced by flue gas and oxygen. This project will eliminate this limitation, by appropriately re-designing the oxygen flow skid and the piping into the SBS.
- Air infiltrations are difficult to control. They occur in different locations (ID fans, baghouse, dry scrubber, boiler...) and for this process will have to be minimized to increase CO₂ concentration in flue gas for carbon sequestration purpose.
- To-date, only dry recirculation of flue gas was performed. Wet recirculation, which is more likely to represent the future industrial solution, has not yet been tested.

- The impact of oxygen enrichment and flue gas recirculation on mercury emissions will be assessed. For Illinois coal, a reduction of around 50% in mercury emissions has been noted. The issue is more stringent for PRB coal, as it contains more elemental mercury.

2.3.2 Knowledge Gap

The overall issue of oxygen enrichment/full oxy-firing in coal fired systems, particularly in boilers, is not yet well understood and handled. It is considered that the retrofit of coal-fired boilers to full oxy-firing could dramatically reduce the overall emissions originating in power generation, including the greenhouse gases (through capture/sequestration). The implementation of full oxy-firing in boilers will significantly reduce the flue gas post-treatment equipment such as mercury, sulfur, very likely eliminating the need for NO_x control, as demonstrated during the previous tests.

There is a clear knowledge gap in the impact of oxy-combustion on heat transfer and overall efficiency in a utility boiler. The modified flame shape and temperature and flue gas mass flow rate will perturb the original heat transfer patterns in the boiler, including the radiative and convective sections. This project aims at investigating these issues.

3 PROPOSED SCOPE OF WORK

The project tasks are presented below.

3.1 Task 1 – Site preparation

Appendix A and B show the existing, and the proposed oxygen delivery skid. Thus, the present skid is being modified in order to allow oxygen flow in three different regions of the boiler, namely the primary, secondary and tertiary oxidant streams. For this, the piping has to be modified, additional valves and meters need to be installed (in blue in Appendix B). The modifications have to be re-programmed in the system Human Machine Interface (HMI). In addition, Appendix C shows the simplified existing and proposed implementation of the oxygen delivery system in the SBS system. This work is in progress.

3.2 Task 2 – Combustion and Emissions Performance Optimization

The main objective of the tests to be performed during the DOE program is to demonstrate the feasibility, and to optimize the combustion process in a coal-fired boiler, using oxygen enrichment and flue gas recirculation.

The proposed work includes a test campaign as presented in Table 1, subject to future amendments as decided by Air Liquide and the DOE project manager.

Burner Hardware and Nominal Operating Conditions							
Load (10 ⁶ Btu/hr)	PC Fineness (% thru 200 mesh)	Oxidizer		O ₂ Level (Vol %)		Burner Stoichiome try (% overall)	Overall Excess O ₂ at Stack (Vol % dry)
				Coal Nozzle/ Windbox	OFA Port		
5	70	Air		21	NA	100	2.5, 3.5, 4.5
5	70			21	21	80,90,100	3.5
5	70			21	21	Optimum	3.5
5	70	RFG/O ₂	Wet	25	NA	100	2.5, 3.5, 4.5
5	70	RFG/O ₂	Dry	25	NA	100	2.5, 3.5, 4.5
5	70	RFG/O ₂	Optimum	23	NA	100	2.5, 3.5, 4.5
5	70	RFG/O ₂	Optimum	25	25	80,90,100	3.5
5	70	RFG/O ₂	Optimum	25	25	Optimum	3.5
5	70	RFG/O ₂	Optimum	25	100	Optimum	3.5
5	60	RFG/O ₂	Optimum	25	100	Optimum	3.5
3	70	RFG/O ₂	Optimum	25	Opt.	Optimum	3.5
5	70	RFG/O ₂	Optimum	Optimum	Opt.	Optimum	Optimum

Table 1: Preliminary test matrix as described in proposal. 3MBtu/hr=0.88MW, 5MBtu/hr=1.47MW

The accomplishment of these major objectives requires the following prerequisites:

- ⇒ Maximizing the CO₂ content in flue gas, by minimizing air infiltration and removing all air streams with FGR/oxygen. This can be better achieved by:
 - ID fan sealing
 - Appropriate O₂ sensor installation
 - Replacement of primary air by O₂ and flue gas
 - Possible replacement of compressed air (entraining coal) by compressed CO₂ or air aspirator redesign to decrease compressed air inlet.
- ⇒ Minimizing the oxygen consumption, by:
 - Minimizing the O₂ content in the flue gas
- ⇒ Minimizing emissions by:
 - Improved burner (low NO_x)
 - Optimizing oxygen injection strategy: where, how much O₂, injection method
- ⇒ Assess impact of technology on mercury by:
 - Hg measurements on one baseline and the optimized full-oxy case
- ⇒ Assess impact on boiler efficiency by:
 - Fly ash sampling and analysis (LOI)
 - temperature and flowrate measurements of each oxidant streams (primary, secondary, tertiary, lances) + heating value measurements of inlet coal + flue gas exhaust temperature measurement
 - flame temperature mapping (optical system).

3.3 Task 3 – Techno-economical assessment

The project will conduct a techno-economic study of O₂-enriched combustion, conventional air-blown pulverized coal boiler equipped with a dry FGD, and an IGCC. The objective is to compare and determine the benefits of O₂-enriched combustion for generating power from the burning of PRB coal (without FGD) to the other two technologies. Techno-economic studies will be performed using a comprehensive computer software package called CHEMCAD. It is an ideal technique to compare alternative power generation technologies before implementing a new process. Experimental data obtained during the combustion testing of the PRB coal will be used to evaluate in detail the characteristics of O₂-enriched combustion for PRB coal. This study will define potential technical and economical advantages or disadvantages of the proposed technology compared to an IGCC technology and air-blown pulverized coal boiler. The results from this task will help identify future R&D activities required for wider implementation of the technology and for commercialization. As a part of this task, a preliminary process flow sheet will be provided for each process. All major equipment in each process will be sized based on a selected plant scale, and a cost estimation will be developed. The results of the cost estimation will be used in economic analysis and in identifying the benefits and shortcoming of the O₂-enriched combustion as compared to the IGCC and air blown PC combustion equipped with wet FGD for power generation using PRB

coal. For each power generation technology, the total cost of electricity generation will be estimated.

3.4 Task 4 – Preliminary Design of New Generation Boiler

The project will conduct a preliminary design of a new generation boiler, fired with oxygen but without FGR. The conceptual design will incorporate multi-pollutant control systems and the inherent means to produce a concentrated CO₂ stream for use or sequestration. This task will entail detailed fluid dynamics and heat transfer modeling, using state of the art tools, such as ASPEN and Fluent. From these modeling results, optimum oxygen staging techniques and geometric configurations will be determined.

EXPERIMENTAL

During this quarter, the participants have worked on task 1 of the project, dedicated to the site preparation for the future experimental tests: the list of modifications to be implemented on the boiler site to overcome previous limitations of the system has been defined, including some adaptation to the oxygen supply delivery system (O₂-skid).

In addition, the participants started working on task 2 (“Combustion Performance Emission Optimization”) of the project, not yet on test performance but on test matrix preliminary definition.

No experimental data have been collected so far, as tests are scheduled to begin Q4 2003.

1 TASK 1: SITE PREPARATION

1.1 List of modifications to be implemented on SBS

Following is a list of changes to be implemented on SBS to be able to perform the tests and to measure their performances:

- O₂ injection system to primary oxidant (PO): oxynator, lance, O₂ skid modification
- Flue Gas recirculation to PO
- Wet recirculation
- Additional O₂ sensors
- Air infiltration limitation and measurements (ID Fan sealing, baghouse, dry scrubber etc...)
- Limitation of compressed air inlet (along with coal): air aspirator may redesigned or compressed air replaced with compressed CO₂...
- Heat transfer measurements (Temperature in inlet and outlet streams, flame mapping system ...)

1.2 Oxygen skid adaptations

Appendix B shows the modifications to be performed on the oxygen skid. The purpose is to generate an additional “leg” supplying oxygen to the primary air stream and/or flue gas recirculation. Valves, pipes, oxygen mixers and/or lances will be installed in order to achieve this objective. The changes are underway, and most of the hardware pieces were identified and are in process to be purchased. The control strategy, and system integration have also been commissioned, and are in progress. The operation safety is also addressed, using the extensive experience of Air Liquide in handling oxygen delivery systems.

2 TASK 2: COMBUSTION AND EMISSIONS PERFORMANCE OPTIMIZATION

2.1 Preliminary definition of tests series to be performed

In order to comply with the experimental objective of the project (Task 2 – Combustion and Emissions Performance Optimization) as described in the proposal, four test series to be performed have been identified (Table 2).

The key tests are included in test series 3 referred to as FULL OXY-COMBUSTION WITH RECIRCULATION. This series includes all performances and emissions measurements as described in the proposal in order to characterize the oxy-coal combustion with recirculation.

As a preparation for the main test series 3, two short previous test series have been selected, so that the specificities of oxygen injection method in two specific locations are investigated: Test series 1 “PRIMARY AIR REPLACEMENT” will enable to optimize the oxygen injection in the coal conveying stream, and Test series 2 “TERTIARY INJECTION OPTIMIZATION” will aim to select the best injection strategy (nozzle, amount of O₂...) in the overfire air ports.

Finally, a short test series 4 will enable to test some configurations where not the whole amount of air is replaced by pure oxygen and flue gas, in order to find an economical optimum of a retrofit technology when there is no CO₂ capture involved.

TEST SERIES 1: PRIMARY AIR REPLACEMENT

<u>Main objective</u> : Selecting the best O ₂ injection method (oxynator and/or lance) in Primary Oxidant, based on operability (selection of the optimal method) and performance (low emission level).

TEST SERIES 2: TERTIARY INJECTION OPTIMIZATION

<u>Main objective</u> : Selecting the best O ₂ injection method (selection of lance nozzle) in Tertiary Oxidant, based on system performance (low LOI, CO, etc.).
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TEST SERIES 3: FULL OXY-COMBUSTION WITH RECIRCULATION
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<u>Main objective</u> : Replacing the maximum amount of air by O ₂ and recycled flue gas. Demonstrate the feasibility of the process and measure its performances.

TEST SERIES 4: EMISSION OPTIMIZATION

<u>Main objective</u> : Testing some configurations with air, flue gas and oxygen enabling low NO _x , CO, LOI levels (no SCR needed) while minimizing the total cost (oxygen + flue gas treatment).
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Table 2: Four experimental test series to be performed

2.2 Test matrix definition

From the four test series described above, the preliminary test matrix described in Table 1 will be updated in the next few months to provide an accurate specification of the tests to be performed in this project.

RESULTS AND DISCUSSION

As described in the “Experimental” section of this report, the previous quarter was dedicated to the preparation of the experimental campaign of the project. Experimental results will be available Q4 2003.

The economical analysis (Project task 3) will be initiated during Q2 - 2003.

The project is so far progressing as expected, and the following sub-sections, “Project Planning” and “Financial Status” provide data related to the project management.

1 PROJECT PLANNING

The planning for the entire project is presented in Table 3.

1.1 Current quarter sub-tasks

The sub-tasks currently or soon to be ongoing are, together with their deadlines:

		<u>Deadline</u>	<u>Status</u>
Task 1.1:	List of required modifications	March 30, 2003	- Completed
Task 1.2:	Conceptual design of SBS adaptations	April 15, 2003	- In Progress
Task 1.2:	Technical design of SBS adaptations	April 30, 2003	- In Progress
Task 1.3:	Implementation of SBS adaptations	July 30, 2003	- In Progress
Task 1.4:	System shake-down	August 1, 2003	- Future
Task 2.1:	Test matrix definition	Sept. 15, 2003	- In Progress
Task 2.2:	Tests performance	Dec. 15, 2003	- Future
Task 2.3&2.4:	Test analysis & report	March 15, 2004	- Future

1.2 Next quarter sub-tasks

During the next quarter (April 1st to June 30th 2003), the following activities will be performed:

- Site Preparation on B&W's location (task 1) will continue, including the O₂ skid modifications (components ordering, assembling and update of control system)
- The technico-economical study (task 3) of oxy-coal boilers will be initiated with ISGS

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DOE AMENDMENT FEB 2003		

✕ Deadlines as scheduled on DOE "Performance Metrics"

✕ DOE Task Deadline

Q Quarterly report

FG Final report

O Once after award

Table 3: Planning of the project.

2 FINANCIAL STATUS

Tables 4 and 5 show the financial status of the report to-date. An amount of \$69,650.10 has been spent by the contractor (including ~ \$30,000 of direct labor, ~ \$8,000 to subcontractors, and ~ \$30,000 of indirect charges), and no invoice to DOE to date was issued. The project proceeds according to the planning.

10. Transactions:		I Previously Reported	II This Period	III Cumulative
a. Total outlays		\$ 0	\$ 69,650.10	\$ 69,650.10
b. Recipient share of outlays		\$ 0	\$ 69,650.10	\$ 69,650.10
c. Federal share of outlays		\$ 0	\$ 0	\$ 0
d. Total unliquidated obligations				\$ 0
e. Recipient share of unliquidated obligations				\$ 0
f. Federal share of unliquidated obligations				\$ 0
g. Total Federal share (Sum of lines c and f)				\$ 0
h. Total Federal funds authorized for this funding period				\$ 285,268
i. Unobligated balance of Federal funds (Line h minus line g)				\$ 285,268
11. Indirect Expense	a. Type of Rate (Place "X" in appropriate box) ☐ Provisional ☒ Predetermined ☐ Final ☐ Fixed			
	b. Rate see attachment	c. Base see attachment	d. Total Amount \$ 30,598.76	e. Federal Share \$ 0

Table 4: Financial situation to-date.

Indirect Expenses	Rate	Base	Indirect expense charged to the project	Federal share for indirect expense
Labor Overhead	87.94%	Total Direct Labor Costs \$ 27,360.00	\$24,060.38	\$ 0
General&Administrative	10.36%	Total Direct Project Costs and Overhead Costs \$ 63,111.72	\$ 6538.37	\$ 0
Total Indirect Expenses			\$ 30,598.76	\$ 0

Table 5: Indirect Expenses (details)

CONCLUSION

The oxy-combustion technology proposed by this work offers significant benefits, such as:

⇒ ***Reduced flue gas treatment costs.*** The reduced volume of flue gas will require smaller pollution control equipment. Pulverized coal-fired plants burning low-sulfur PRB coal generally utilize dry flue gas desulfurization for SO₂ removal. In a multi-pollutant control scheme, this could include mercury and particulate removal. Capital costs for dry-FGD units and baghouses are typically in the \$80-100/kW range. The costs of this equipment will decrease with the anticipated reduction in flue gas volumes when oxy-combustion is implemented. Another benefit of oxy-combustion is the fact that the elimination of nitrogen from the oxidant stream(s) will significantly reduce NO_x formation. A NO_x-reduction strategy that combines this feature with an effective combustion staging technique, such as the use of over-fire “air”, will reduce NO_x formation rates substantially, together with the reburning process of NO_x through recirculation. Oxygen enrichment could effectively replace conventional deNO_x processes such as selective catalytic reduction (SCR). With SCR capital costs running at ~\$80/kW, the capital savings will be very significant.

⇒ ***Potential for zero-emission operation.*** The flue gas resulting from a highly enriched or full oxy-combustion process will contain concentrated carbon dioxide, allowing for its capture and/or sequestration.

⇒ ***Reduced boiler costs.*** The reduced volumes of flue gas could potentially result in more compact boiler equipment. This aspect will be addressed by Task 4 of the project.

The quarter January – March 2003 was the first working period, and included the site and test preparations.

So far, technically as well as financially the project is advancing according to the plan.

REFERENCES

Marin, O., Châtel-Pélage, F., Perrin, N., Carty, R., Gary, P., Farzan, H., Vecchi, S.J., **2003**, “Low-oxygen enrichment in coal-fired utility boilers”, *The 28th International Technical Conference on Coal Utilization & Fuel Systems*, Clearwater, FL.

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Marin, O., Châtel-Pélage, F., Perrin, N., Chen, S., Lu, Y., Rostam-Abadi, M., **2003**, “Economic Analysis of Oxygen-fired Coal Boilers”, *The 28th International Technical Conference on Coal Utilization & Fuel Systems*, Clearwater, FL.

LIST OF ACRONYMS AND ABBREVIATIONS

AAL	American Air Liquide
BSR	Burner Stoichiometric Ratio
B&W	Babcock and Wilcox
ESP	Electrostatic Precipitator
FEGT	Furnace Exit Gas Temperature
FG	Flue Gas
FGD	Flue Gas Desulfurization
FGR / RFG	Flue Gas Recirculation / Recycled flue gas
HMI	Human Machine Interface
ISGS	Illinois State Geological Survey
LOI	Lost On Ignition (Unburned Carbon in Ash)
PA	Primary Air
PC	Pulverized Coal (Boiler)
PO	Primary Oxidant
PRB	Powder River Basin
SA	Secondary Air
SBS	Small Boiler Simulator
SCR	Selective Catalytic Reduction
SNCR	Selective Non Catalytic Reduction
SO	Secondary Oxidant
TA	Tertiary Air
TO	Tertiary Oxidant

APPENDICES

APPENDIX A.	OXYGEN SKID AS ON SEPTEMBER 30TH, 2002	26
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Appendix A. OXYGEN SKID AS ON SEPTEMBER 30TH, 2002

Appendix B. PROPOSED MODIFIED OXYGEN SKID

Appendix C. SBS AS OF SEPTEMBER 2002 AND PROPOSED MODIFICATIONS