Advanced, Low/Zero Emission Boiler Design and Operation

Quarterly Technical Progress Report

Reporting Period from April 1st, 2003 through June 30st, 2003

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ABSTRACT

This document reviews the work performed during the quarter April – June 2003.

The main focus of this quarter has been the site preparation (task 1) for the test campaign scheduled in September/October 2003. Task 3 (Techno-economical assessment) has also been initiated while selecting the methodology to be used in the economics analysis and specifying the plants to be compared:

In Task 1 (Site Preparation), the process definition and design activities have been completed, the equipment and instruments required have been identified, and the fabrication and installation activities have been initiated, to implement the required modifications on the pilot boiler. As of today, the schedule calls for completion of construction by late-July. System check-down is scheduled for the first two weeks of August.

In Task 2 (Combustion and Emissions Performance Optimization), four weeks of testing are planned, two weeks starting second half of August and two weeks starting at the end of September.

In Task 3 (Techno-Economic Study), the plants to be evaluated have been specified, including baseline cases (air fired PC boilers with or without CO_2 capture), O_2-fired cases (with or without flue gas recirculation) and IGCC cases. Power plants ranging from 50 to 500MW have been selected and the methodology to be used has been described, both for performance evaluation and cost assessment. The first calculations will be performed soon and the first trends will be reported in the next quarter.

As part of Task 5 (Project Management & Reporting), the subcontract between Babcock&Wilcox and American Air Liquide has been finalized. The subcontract between ISGS and American Air Liquide is in the final stages of completion.

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PROJECT OBJECTIVES FOR THE QUARTER

The main effort of this quarter was primarily dedicated to **Task 1** of the project (Site Preparation) with the following objectives:

- Completion of the process definition
- Design of new or modified devices
- Identification of new or modified equipment and instruments
- Purchase of required components
- Initiation of fabrication and installation activities
- Off site preparation of modified control system (O_2-supply)

An additional objective of the quarter April-June 2003 was the initiation of **Task 3** of the project (Techno-Economic Study) with the selection of the oxy-fired and air-fired plants to be compared (type, size, equipment) and the definition of the methodology to be applied.

INTRODUCTION

The present reports summarizes the work performed by the participants from April 1, 2003 through June 30^{th}, 2003 (Q2 2003).

In the previous quarter (Q1 2003), the main achievements were related to the site preparation (Task 1), and mostly consisted in the analysis of the existing pilot boiler and the definition of the modifications to be implemented to adapt the experimental facility to the requirement of the current project. The test performance task (Task 2) was also initiated while developing a preliminary set of test series to be performed.

In the current quarter (Q2, 2003), the site preparation (Task 1) was also the most time- and budget-consuming task since the participants purchased some of the components and instruments needed for the boiler upgrade and they initiated the installation of the modified process. Detailed of the modifications already implemented or being currently implemented at the test facility are given in this report, along with the schematics of the upgraded process. The tests schedule (in Task 2) is also given, in addition to the first data of Task 3 (Techno-Economic) since this last task was initiated during that period.

Some discussion are also reported related to the benefit/drawback of different options, including the selection of technical solutions in the site preparation, such as the coal-feeding system or the oxygen control system (to increase the feasibility, the safety and the results of the tests campaign), or the selection of plants characteristics to be assessed in the economic study.

The operation of the boiler will be initiated in the following quarter (Q3, 2003), leading to the first experimental results. In the same period, the participants will have performed some first calculations in the economic task of the project and will be able to provide some preliminary results and trends.

This report also provides an update of the financial status of the project along with an update of the planning.

EXPERIMENTAL

During this reporting period, the participants have worked primarily on Task 1 (Site Preparation), and have initiated Task 3 (Techno-Economic Assessment) of the project.

No experimental data have been collected so far, as tests are scheduled to begin Q3 2003.

1 TASK 1: SITE PREPARATION

1.1 Process Design on Pilot Boiler

A process design schematic incorporating major equipment and instruments was developed. Appendix A shows the small boiler simulator (SBS) and wet scrubber in an oxygen-fired mode. Appendix B illustrates the new equipment and ductwork (in red). Appendix C shows the last update of the oxygen supply system (the oxygen skid), as on June 2003.

The main parts of the system are:

1) Flue Gas Recycle (FGR) line to the Primary Air (PA) fan, including an orifice, a pressure transducer, a thermo couple (TC), a control valve, and a remote controller to control and measure the flow rate and temperature of the FGR flow,

2) Air inlet modifications to the PA fan, including measurement and control equipment similar to Item 1,

3) Condensing Heat Exchanger (CH_x) bypass line with an on/off manual valve, to enable the to switch from dry recirculation process to wet recirculation process,

4) Oxygen supply to the boiler, including primary, secondary and tertiary injection zones. The oxygen valve skid is all but finalized; most of the new components (all of them cleaned for oxygen service) have been purchased and some have already been assembled and installed. The required additional piping is being installed, as well as the new oxynator in the PA line. The control system is currently being developed off-site in order to be installed on-site in the next quarter,

5) Two oxygen sensors to measure oxygen concentration in the primary air/oxidant and recirculated flue gas, to account for air infiltration.

1.2 Detailed Design

The following activities were performed:

- Completed the detailed drawings for the flue gas recirculation (FGR) to primary air line and CH_x by-pass line.
- Determined oxygen supply requirements to the primary air zone. Materials have been selected, purchased, and stored at the SBS on June 30th.
- Reviewed electrical drawings and determined instrument and safety interlock changes to the unit to receive oxygen in the primary air zone.

- Ordered long-lead equipment and instruments required.
- Initiated fabrication of the FGR lines.
- Negotiated and issued a sub-contract for the oxygen system piping. The schedule for this activity is July 1 – 11, followed by electrical wiring. Oxygen system tuning and control will be performed from July 21 through July 24.
- Ordered and received approximately ~20m^3 (~5,000) gallons of oxygen on site.
- Reviewed a total system analysis and decided to modify the coal feed system to reduce air inlet to the unit. The unit is using an air aspirator for feeding pulverized coal to the burner. During the proposal, the participants had planned to operate the aspirator with compressed air. In order to minimize the air inlets into the boiler and thus to maximize the CO_2 content in flue gas, the participants are now considering three options to eliminate the compressed air: 1) operating the aspirator with compressed CO_2, 2) changing the aspirator to a venture, and 3) using a pressurized coal-feed system. The last option has been successfully used in the operation in a larger facility and could be scaled-down to the SBS. The Venturi option remains an alternative, and the compressed CO_2 is considered as the last option. Trial and adjustments will be required during the start-up to optimize this new coal feed system.

2 TASK 3: TECHNO-ECONOMIC STUDY

The techno-economic study has been initiated during the current reporting period.

The objective of this techno-economic study is to compare the performance and cost of the O_2-enriched combustion (OEC) process in pulverized coal (PC) boilers, to the conventional air-fired process in PC Boilers and to the IGCC process. Consistently with the experimental part of the project, the coal considered in this economic study is a PRB coal (low-sulfur coal).

The following sub-sections describe a preliminary selection of cases to be evaluated in this study (plant size, equipment, type…) and some specificities of the methodology to be applied for plant performance simulation and cost evaluation.

2.1 Case Study Definition

Five “types” of cases will be investigated: the air-fired PC Boiler, with or without CO_2 capture system, the proposed O_2-based technology with flue gas recirculation (for retrofit application) or without recirculation (in new compact O_2-boilers), and the IGCC (new plant only).

For each case, the post-treatment equipment has been selected in order for the plant to comply with existing and future emission regulations, including the following pollutants: particulates, sulfur, NO_x and mercury. The cost of CO_2 capture will be assessed for CO_2 sequestration.

This study primarily focuses on **retrofit applications** (series 3: O_2-retrofit), using as much as possible of the existing plant to reduce the cost its conversion to a “cleaner” operation. In particular, the boiler (designed for air operation) will not be replaced, but used in O_2-retrofit application due to the flue gas recirculation system, which enables to maintain the same flow pattern inside the boiler. These O_2-retrofit solutions are compared with air-baseline series, with or without CO_2 capture.

In addition, additional technologies for "**new plants**" are investigated in Series 4 (O_2-new), and compared with air baseline and IGCC.

Table 1 summarizes the specification of the case study selected for the economic assessment.

1. Air-fired PC Boiler w/o CO_2 capture	**("Air-Baseline")**
Plant Size	100, 500 MW
Flue Gas Treatment	ESP, dry FGD, SCR, PACI
Application	New or Retrofit Plant
2. Air-fired PC Boiler with CO_2 capture	**("Air-Baseline + CO_2cap")**
Plant Size	100, 500 MW
Flue Gas Treatment	ESP, dry FGD, SCR, PACI, MEA
3. O_2-fired PC with FG recirculation for retrofit application	**("O_2-retrofit")**
Plant Size	50, 100, 300, 500 MW
Flue Gas Treatment	ESP, dry FGD, PACI
4. O_2-fired PC w/o FG recirculation for new plant	**("O_2-new")**
Plant Size	100, 500 MW
Flue Gas Treatment	ESP, dry FGD, PACI
5. IGCC	**("IGCC")**
Plant Size	250, 500MW
Flue Gas Treatment	ESP, dry FGD, SCR, PACI, MEA

Table 1: Case Study Definition of the economic assessment

2.2 Process simulation

The process simulation can provide important information of mass and energy streams through the power plant, as well as for cost estimation. A computer software package, CHEMCAD, is being used to perform process performance simulations. In CHEMCAD, unit operations involved in the power generation process are available, such as the compressor, mixer, reactor, heat exchangers, columns, vessels, valves, etc.

The CHEMCAD simulation consists of flowcharts of each of the important sections in the OEC and conventional PC plants. Each flowchart is composed of unit operation blocks and may also include the design specifications. The flowchart in each section is connected with other sections by the mass, energy and/or work stream. Mass and energy balances of the unit block and flowchart can be thermodynamically calculated using CHEMCAD.

The performance simulation will be conducted both for the PRB coal-fired OEC process and conventional PC process over the plant sizes specified in table 1. In the OEC process (Series 3 and 4) different sections will be modeled, including the air separation unit (ASU), boiler, steam turbine generator, flue gas circulation, flue gas cleaning system such as the ESP, dry FGD and mercury removal (See Figure 1). In the conventional PC plant (Series 1 and 2), the AEM process for CO_2 separation and SCR for NO_x removal will also be considered (See Figure 2).

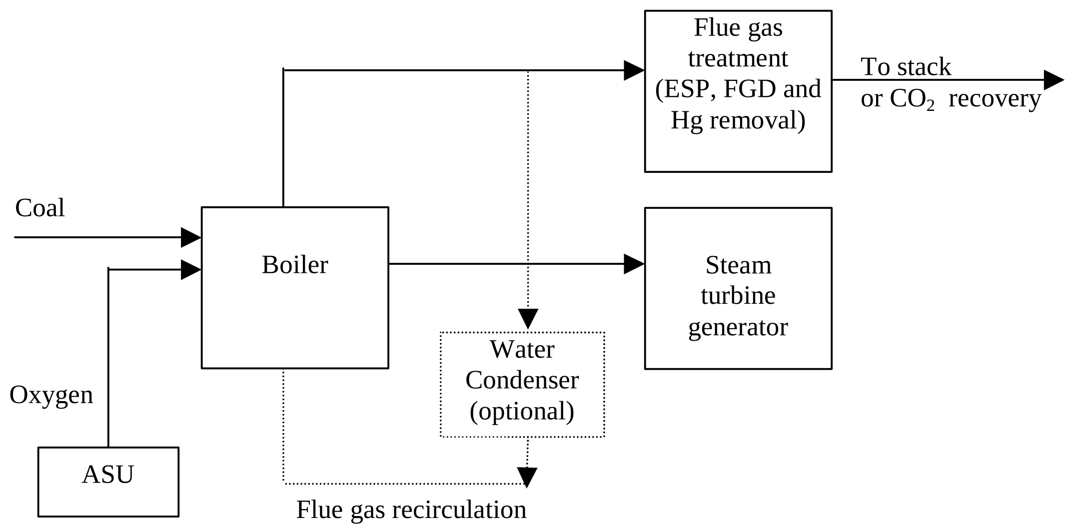

Figure 1: Process systems of an oxygen-fired pulverized coal power plant

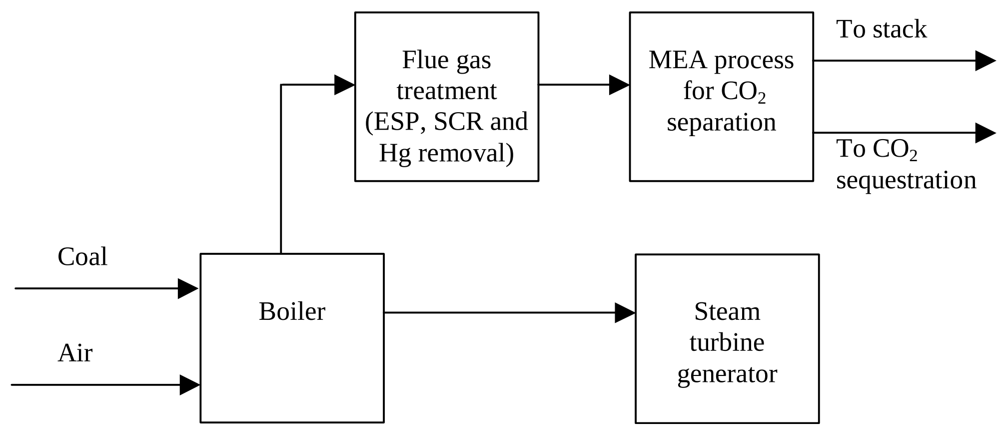

Figure 2: Process systems of a conventional air-fired pulverized coal power plant

The flow diagrams and operating conditions of the sections required in the simulation are being collected from existing data. The basic inputs for the combustion, steam generation and related auxiliaries, such as conditions of steam system, water system, and heaters can be found in a previous reports and handbooks [1,2,3,4]. The process descriptions of the flue gas cleaning, including the FGD, SCR, Hg removal and CO_2 separation are available in a number of references, and some are listed below [5,6,7,8]. In this study, the carbon injection process will be adopted for mercury removal, and the MEA process will be adopted for separation of CO_2 from the conventional PC boiler.

2.3 Cost model

The cost model includes the capital, operation & maintenance (O&M) and levelized costs. EPRI technical Assessment Guide methodology will be implemented.

The capital cost, specially referred to the total plant cost (TPC), consists of bare erected cost (equipments, bulk materials, labor and sales tax), engineering & home office overheads and fee, and contingencies (process and project contingencies). It can be determined by estimating the cost of every significant piece of equipment, component and bulk quantity. The results from process simulation, such as the mass/energy flow and equipment size, will be used in the cost estimation by scaling up/down the costs reported in literature for specific sections of a plant. In this regard, the effects of plant and equipment sizes are being collected from literature to obtain reliable scaling factors over the plant size range considered in this study.

The Total Plant Investment (TPI) and Total Capital Requirement (TCR) will also be determined. TPI includes escalation of construction costs and interest during construction. TCR covers all other capital costs to complete the entire plant, such as the pre-production and royal allowance and so on. Table 2 shows the main items of the capital cost.

Total plant cost (TPC)	
Bare erected cost	Equipment Materials Labor (direct and indirect) Sales tax
Engineering cost	12% of erected cost
Contingencies	Process contingency Project contingency
Total plant investment (TPI)	
TPC	
Total cash expended	
AFDC (escalation and interest in construction period)	
Total capital requirement (TCR)	
TPI	
Royal allowance	
Pre-production costs	
Inventory capital	
Initial catalyst & chemicals	
Land cost	

Table 2: Items in capital cost estimation

The operating and maintenance costs (O&M) are associated with those charges for operating and maintaining the plant over the expected lifetime. It includes both the fixed and variable costs. Fixed operating costs include the operating labor, maintenance labor and materials, and administrative and support labor. The cost of operating labor will be based on reference plants in literature. Maintenance costs are estimated as a percentage of TPC, and can be determined for major sections by using the corresponding TPC values and the representative percentages. Variable operating costs include the consumables, fuel and wastes disposal. The estimation of variable costs is based on the results of mass balance from the process simulation, and on the unit prices of consumables, coal and waste disposal. In addition, the potential ash recovery from the OEC process will be analyzed, and its credit for the use in the cement industry will be considered. Table 3 shows the main items of the capital cost.

Operating & Maintenance costs	
Operating labor	
Maintenance (% of TPC, diff. for each section)	Labor Materials
Administrative and support labor	
Consumables	
Fuel cost	
Waste disposal (water, ash)	

Table 3: Items in O&M costs estimation

The cost of electricity is composed of the levelized TCR and O&M costs. Levelized factors are applied to the TCR, and the first year fuel, operating and consumable costs to yield levelized costs over the life of plant. A levelized value can be computed using the "present worth" concept of money.

The cost information in literature is being collected, such as from the DOE, EPA and EPRI studies as listed below. The basic economic assumptions such as the inflation rate, interest, plant life, material unit price and so on will refer to the EPRI Technical Assessment Guide. For the combustion and steam generator systems, the reference plants [9,10,11] are available for the cost estimation by the scaling approach. However, to acquire the reliable scaling factors or regression models for major process sections, further efforts will be made to get more information of plants or equipment with different sizes [12,13]. A cost analysis of the FGD process will be based on a recent EPA report [14]. Another EPA report will be used for estimating the cost of SCR [15]**.** The cost of the carbon injection process for Hg removal will refer to an EPA report [16]. The cost of the MEA process will be based on an EPRI report [17].

RESULTS AND DISCUSSION

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

The economical analysis (Project task 3) has been initiated while defining the case study to be performed and the methodology to be applied. Some first results will be available during Q3 - 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 SCHEDULE

The previous report presented the planning related to the entire project, along with specific deadlines. The current status of the project tasks and sub-tasks is displayed below, followed by a short description of the work to be performed in the next quarter (July-Sept. 2003).

1.1 Status of the project tasks and sub-tasks

The sub-tasks completed in the current reporting period, currently in progress or soon to be ongoing, together with their deadlines, are:

		Deadline		**Status**
Task 1: Site Preparation				
Task 1.1:	List of required modifications	March 30, 2003	-	**Completed**
Task 1.2:	Conceptual design of SBS adaptations	April 15, 2003	-	**Completed**
Task 1.2:	Technical design of SBS adaptations	April 30, 2003	-	**Completed**
Task 1.3:	Implementation of SBS adaptations	July 30, 2003	-	In Progress
Task 1.4:	System shake-down	August 1, 2003	-	Future
Task 2: Test Performance				
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
Task 3: Techno-Economic Study				
Task 3.1:	Cases Specification	Sept. 15, 2003	-	In Progress
Task 3.2:	Methodology Definition	Aug. 30, 2003	-	**Completed**
Task 3.3:	Process Simulation & Cost Estimation	March 30, 2004	-	Future
Task 3.4:	Results analysis & Report	June 30, 2004	-	Future

1.2 Next quarter sub-tasks

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

- Site Preparation on B&W's location (task 1) will be completed.
- Tests Performance (task 2) will be initiated with the first two weeks of tests scheduled in August/September 2003.
- The technico-economical study (task 3) will continue and provide some first trends.

2 FINANCIAL STATUS

Tables 4 and 5 show the financial status of the report to-date. An amount of $84,078.05 has been spent by the main contractor in the reporting period (Q_2, 2003), including ~ $32,000 of direct labor, ~ $15,000 of material & equipment related to the upgraded oxygen supply system, and ~ $36,000 of indirect charges. The $67,225 amount will be billed in the next quarter, as the bill was issued after the end of the quarter. To date, $153,728.14 has been spent by the project. The project proceeds according to the planning. No invoice to DOE was yet issued, the first one will be issued very soon.

10. Transactions:	I Previously Reported	II This Period	III Cumulative
a. Total outlays	$ 69,650.10	$ 84,078.05	$ 153,728.14
b. Recipient share of outlays	$ 69,650.10	$ 84,078.05	$ 153,728.14
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 **$ 36,174.30**	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	$ 32,160.00	$ 28,281.50	$ 0
General&Administrative	10.36%	Total Direct Project Costs and Overhead Costs	$ 76,185.25	$ 7,892.79	$ 0
Total Indirect Expenses				**$ 36,174.30**	**$ 0**

Table 5: Indirect Expenses (details)

3 TASK 5: PROJECT MANAGEMENT & REPORTING

The sub-contract between American Air Liquide and Babcock and Wilcox has been finalized in June 2003.

CONCLUSION

The project is to-date advancing according to the plan, technically and financially.

At the end of the current reporting period, two quarters have been mostly dedicated to site preparation, namely adapting the coal-pilot boiler to the oxygen-fired combustion process, including the required instruments needed to measure the combustion characteristics. The major issues have been addressed, primarily related to technical solution selection and safe operation, so that the system will be ready for a detailed shakedown and on-time operation. Some options (like the oxygen injection system and the modified coal pick-up system) will be further investigated in the next quarter, through preliminary tests and the first series of full-scale tests, to select the optimized process.

In the next quarter, the focus of the project will be to start the first series of tests, followed by data analysis. In addition, the preliminary results of the economical assessment will be reported.

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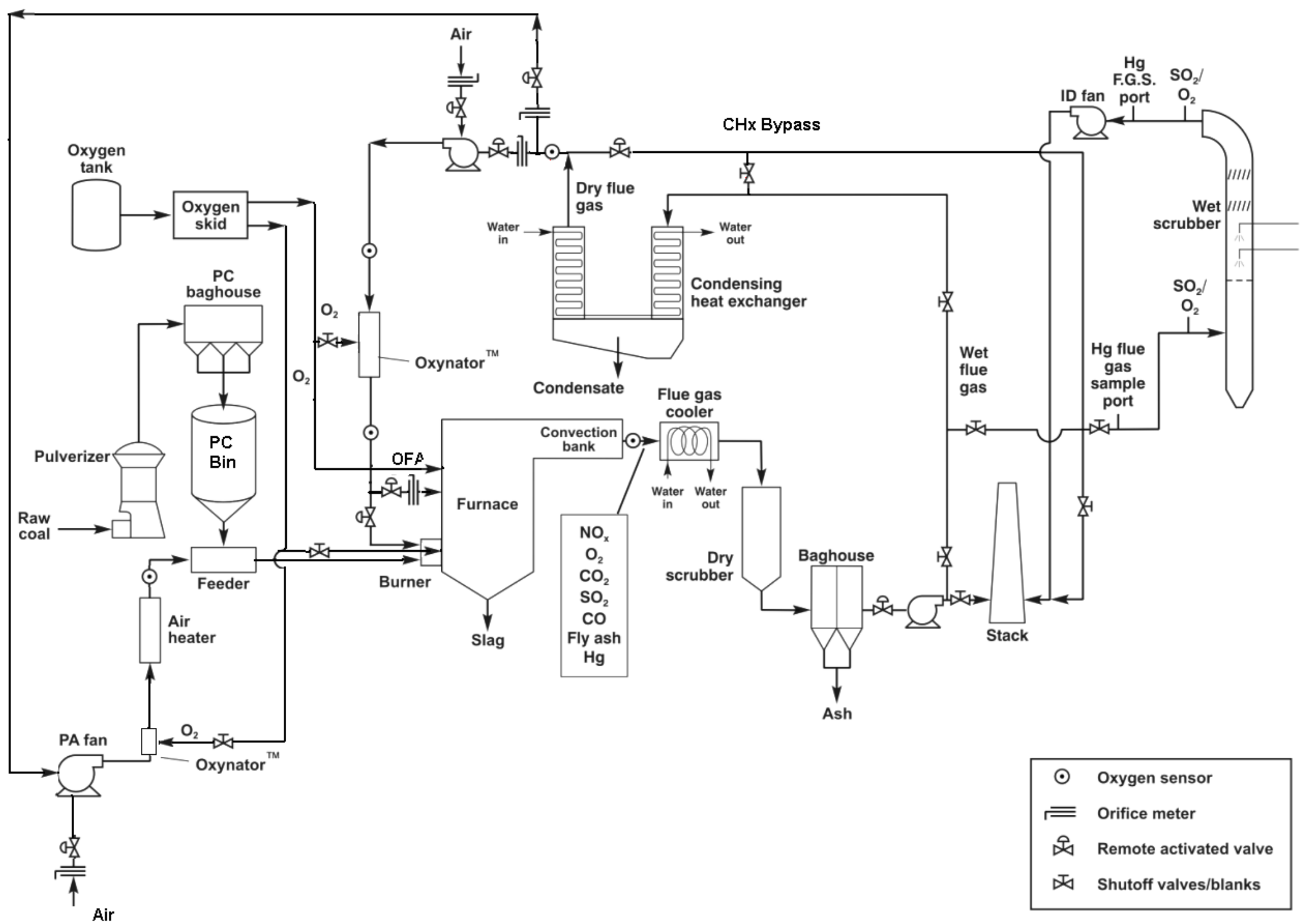
LIST OF ACRONYMS AND ABBREVIATIONS

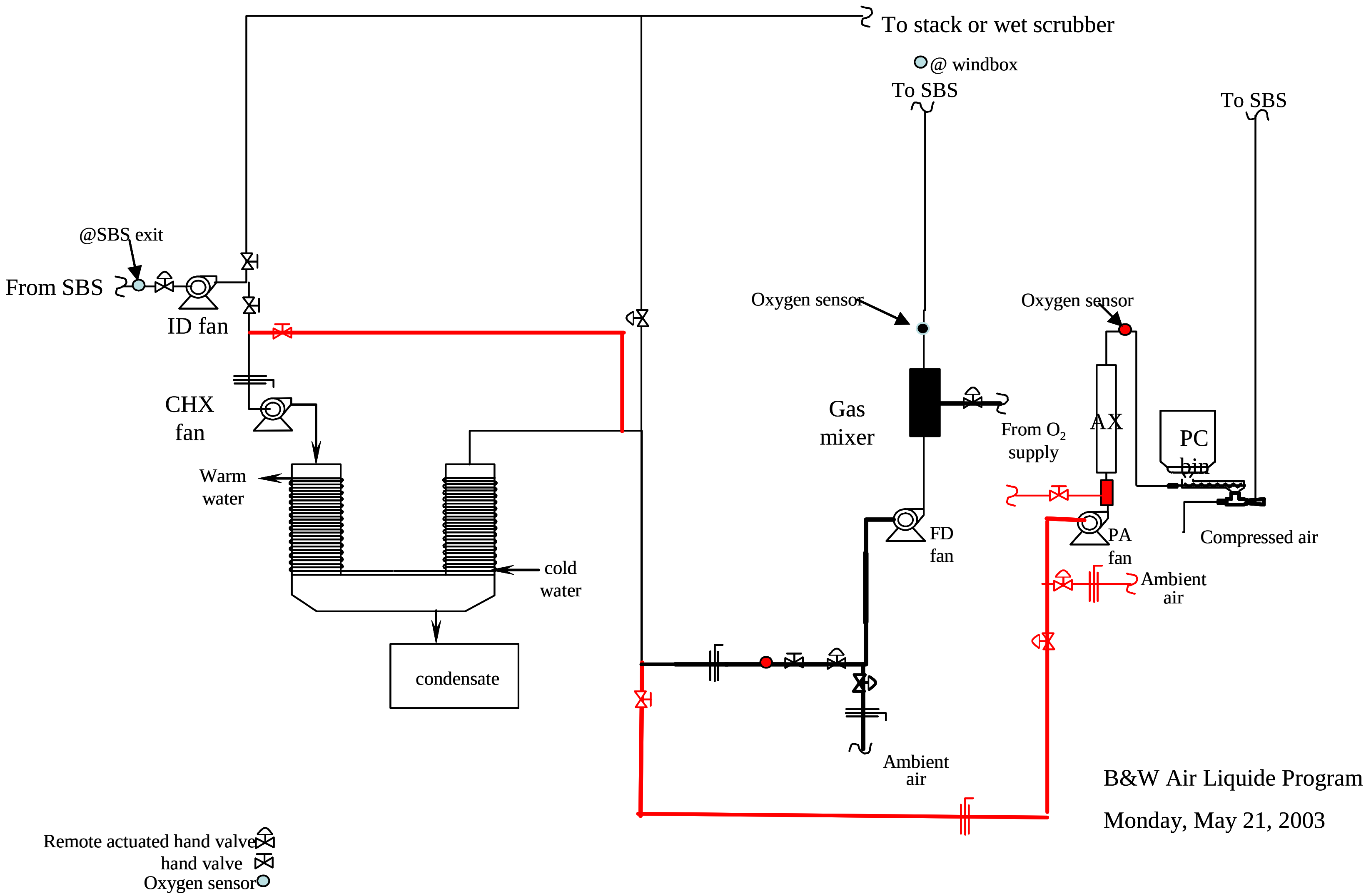
AAL	American Air Liquide
BSR	Burner Stoichiometric Ratio
B&W	Babcock and Wilcox
ESP	Electrostatic Precipitator
FEGT	Furnace Exit Gas Temperature
FG	Flue Gas
FGD	Flue Gas Desulfurization
FGR / RFG	Flue Gas Recirculation / Recycled flue gas
HMI	Human Machine Interface
IGCC	Integrated Gasification Combined Cycle
ISGS	Illinois State Geological Survey
LOI	Lost On Ignition (Unburned Carbon in Ash)
OEC	Oxygen Enriched Combustion
PA	Primary Air
PACI	Pulverized Activated Carbon Injection
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. SBS (Small Boiler Simulator) in an Oxygen Firing Mode



Appendix B. NEW EQUIPMENT AND DUCT WORK (IN RED) INSTALLED ON THE SBS



Appendix C. Updated modified Oxygen Skid as anticipated on June 30th, 2003