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ABSTRACT

The major aspects of this project are proceeding toward completion. Prior to this quarter, design criteria, tentative site selection, facility layout, and preliminary facility cost estimates were completed and issued. Processing of bio-solids was completed, providing material for the pilot operations. Pilot facility hydrolysis production has been completed to produce lignin for co-fire testing and the lignin fuel was washed and dewatered. Both the lignin and bio-solids fuel materials for co-fire testing were sent to the co-fire facility (EERC) for evaluation and co-firing. EERC has received coal typical of the fuel to the TVA-Colbert boilers. This material was used at EERC as baseline material and for mixing with the bio-fuel for combustion testing.

All the combustion and fuel handling tests at EERC have been completed. During fuel preparation EERC reported no difficulties in fuel blending and handling. Preliminary co-fire test results indicate that the blending of lignin and bio-solids with the Colbert coal blend generally reduces NO_x emissions, increases the reactivity of the coal, and increases the ash deposition rate on superheater surfaces. Deposits produced from the fuel blends, however, are more friable and hence easier to remove from tube surfaces relative to those produced from the baseline Colbert coal blend. The final co-fire testing report is being prepared at EERC and will be completed by the end of the second quarter of 2002.

The TVA-Colbert facility has neared completion of the task to evaluate co-location of the Masada facility on the operation of the power generation facility. The TVA-Colbert fossil plant is fully capable of providing a reliable steam supply. The preferred steam supply connection points and steam pipeline routing have been identified. The environmental review of the pipeline routing has been completed and no major impacts have been identified. Detailed assessment of steam export impacts on the Colbert boiler system have been completed and a cost estimate for the steam supply system was completed. The cost estimate and output and heat rate impacts have been used to determine a preliminary price for the exported steam. TVA is further evaluating the impacts of adding lignin to the coal fuel blend and how the steam cost is impacted by proximity of the Masada biomass facility.

REPORT NO. 00-10734/08

QUARTERLY REPORT FOR THE CONCEPTUAL DESIGN ASSESSMENT FOR THE CO-FIRING OF BIOREFINERY SUPPLIED LIGNIN PROJECT

PROJECT NO. 00-10734
MASADA DOE LIGNIN STUDY

MASADA RESOURCE GROUP, LLC
BIRMINGHAM, AL

DATE: APRIL 17, 2002

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1. INTRODUCTION

The development of renewable domestic fuel sources is a desirable goal with positive economic and environmental impacts. Masada Resource Group (MRG) has developed a proprietary process for the conversion of municipal solid waste (MSW) and sewage sludge (SS) into ethanol (CES OxyNol™ Process). One of the byproducts of this process is a solid lignin product. MRG has developed a method for using this MSW-derived lignin as a solid fuel for steam generation. In this joint research project, a conceptual design will be developed that joins a CES OxyNol™ facility with a Tennessee Valley Authority (TVA) coal-fired power plant (the TVA-Colbert facility).

MRG is working with Harris Group Inc. (HGI), TVA, and the Department of Energy (DOE) to develop a conceptual design for the co-firing of bio-refinery-derived lignin and acidified bio-solids ("bio-solids") fuels in a coal-fired steam boiler. This project will research the dewatering and fuel properties of the CES OxyNol™-derived fuel. The project will evaluate the technological feasibility and cost/benefit analysis of co-locating a CES OxyNol™ facility with the TVA-Colbert facility. In this configuration the bio-refinery supplies boiler fuel (lignin and bio-solids) to the Colbert facility and the Colbert facility provides the process steam needed for the CES OxyNol™ process. The co-location has the benefit of providing a low-cost renewable biomass fuel source that can be co-fired with coal. Co-location also reduces the capital and operating costs of the CES OxyNol™ process and provides environmental gains by reducing the impact of coal combustion and providing an environmentally acceptable method for the disposal of solid waste.

This project has been divided into six separate but related tasks to reach the aforementioned goals of the project. Progress has been made on all of the specific tasks. The goal of the pilot run is both to evaluate dewatering options and to generate lignin to be used in the co-fire evaluation at the Environmental Energy Research Center (EERC). Pilot facility modification, shakedown, and lignin production were completed in preparation for the co-fire testing.

The first task is the overall feasibility analysis for co-location of the Masada facility with a TVA power facility. Task 1

- Identified facility design criteria.
- Identified potential facility locations and preliminary site layout.
- Evaluated the economic impact associated with co-location.

The second task is the assessment of the impacts on the TVA facility. TVA's Fossil Engineering Organization is performing a preliminary engineering assessment for delivering steam from the TVA-Colbert fossil plant to the proposed Masada waste processing facility. The study identified

- Steam supply connection point in the Colbert plant steam cycle
- Steam pipe routing from the steam cycle connection to the Colbert plant boundary
- Capacity and heat rate impacts on the Colbert plant resulting from the steam supply
- Environmental review of the steam pipe installation
- Capital cost of the steam supply design, materials, and installation
- Operation and maintenance cost impacts on the Colbert plant resulting from the steam supply

This information has been used to develop a price for the steam to be supplied from the Colbert plant to the Masada facility.

Tasks 3 and 4 involved the pilot plant facility design, modification, and shakedown for the production of lignin. Pilot plant design and modification have been completed and shakedown testing of the facility was completed. Transitioning from the pilot facility shakedown phase to the operations phase was delayed due to difficulties in obtaining a representative MSW feed material.

Task 5 is the production of lignin in the TVA pilot facility. The lignin production activity has been completed. TVA processed approximately 20 batches in the hydrolysis pilot facility to generate sufficient lignin for co-fire testing. The mother liquor was filtered from the lignin and the resulting lignin was prepared for washing and dewatering.

Task 6 is lignin washing and dewatering. This process is employed to maximize the recovery of both sugar and acid from the lignin cake and to improve the characteristics of the lignin fuel. This task has been completed.

Task 7 is the co-fire testing of the lignin and bio-solids. In this testing of the material, the bio-fuel is combusted as a mixture with coal in a test boiler to estimate the combustion parameters and how the addition of this material to a coal-fired boiler will impact boiler operation. Both the lignin and bio-solid materials are tested in individual mixtures with coal and as a composite mixture with coal. In most cases, the target mixture is a 10% bio-fuel, 90% coal blend. This blending is well above the expected blending ratio for the TVA-Colbert facility but rich enough in bio-based fuels to allow detection of potential changes and improvements in boiler operations as a result of the bio-fuel addition. This testing was completed at EERC. EERC performed a series of tests designed to evaluate the following:

- Fuel value
- Slagging and fouling
- Corrosion
- Fly ash properties
- Gas emissions
- Trace element analysis and emissions

To accomplish these objectives, EERC performed a series of combustion tests in its combustion test facility accompanied by analysis of the fuels and combustion products. These tests include combustion of the baseline coal as well as mixtures of coal with lignin and bio-solids.

2. EXPERIMENTAL

TVA has considerable experience in the acid hydrolysis process and its experimental experience has been applied to the lignin production, washing, and dewatering. The lignin dewatering and conditioning were studied in conjunction with dewatering equipment vendors and with input from the test burn facility. The hydrolysis process used during these tests to produce lignin samples is the proprietary Masada CES OxyNol™ process.

Experimental procedures for the test burn are the standard procedures used by EERC for fuel analysis and test unit operations, as presented previously.

3. RESULTS AND DISCUSSION

3.1 General

Progress on the major tasks of this project continues. Engineering impact of the co-fire concept is favorable. TVA-Colbert completed the evaluation of steam supply options and impacts, indicating that supply options exist. A preliminary cost estimate for the system modifications has been completed. TVA-Colbert has also evaluated the cost of steam supply. This cost is being updated to reflect additional considerations as outlined in paragraph 3.6. TVA pilot facility modifications have been completed. The pilot plant has completed lignin production.

NETL has expressed reservations with respect to the co-fire of the lignin/bio-solids mixed material in the NETL test boiler. EERC has agreed to perform the co-fire portion of the testing. The lignin and bio-solids co-fire feed materials have been shipped to the EERC co-fire test site for feed characterization and preparation for co-fire test runs. Co-fire testing at EERC is completed. EERC is wrapping up sample and data analysis with a final report to follow shortly.

3.2 Engineering Impact Analysis

During the first quarter of 2002 no significant changes were identified from the previous engineering impact analysis. The previously issued design criteria and site identification allowed the TVA-Colbert power facility to complete the investigations into the impacts and facility modifications that would be required for this project. TVA-Colbert has completed a preliminary investigation of the impacts on the power plant operations. This evaluation is being updated to include fuel value credit for the bio-fuel and investigating issues associated with proximity and infrastructure costs. Results of the TVA-Colbert study to date are reported below in paragraph 3.6.

3.3 Pilot Facility Modification, Feed Conditioning and Hydrolysis Operations

For lignin production, TVA's pilot facility was modified for Masada's proprietary process. TVA, Lizan, and Harris worked with Masada to identify equipment needed for the lignin production pilot run. As described previously, TVA's pilot facility was set up to operate the OxyNol™ process in a batch mode. This process included the hydrolysis of a conditioned MSW feed material to produce a lignin fuel for co-fire testing. Approximately 1000 lb of lignin were produced to meet the co-fire testing requirements.

3.4 Lignin Dewatering Testing

Lignin washing and dewatering occurred at TVA, providing washed feed for co-fire testing at EERC. Seven drums of lignin material were washed and dewatered. The bio-fuel was shipped to EERC along with the bio-solids for Task 7 of this project, the combustion testing of the bio-fuels.

3.5 Combustion Testing

Lignin, derived from municipal solid waste and bio-solid feedstocks using MRG's patented CES OxyNol™ process, is being evaluated as a supplemental fuel with coal for producing steam and electricity. The co-firing of relatively small proportions of lignin and/or sludge with coal may affect (in either a positive or negative fashion) combustion efficiency, boiler heat exchange surface slagging and fouling, NOx and SOx production, and fly ash and trace element emissions. These potential effects are being evaluated in a pilot-scale (550,000-Btu/hr [580 MJ/hr]) combustion system. The effects of blending lignin and sludge with coal on fuel handling and pulverization characteristics are also being addressed.

An 80 wt % Colorado–20 wt % subbituminous Power River Basin coal blend from the TVA-Colbert power plant (referred to as the Colbert coal blend) and an eastern bituminous coal alternative (Pittsburgh #8) were tested. The eastern coal, Colbert coal blend, lignin, and bio-solids have been analyzed for proximate and ultimate analysis. The bio-solids and lignin are characterized by possessing higher moisture and lower heating values relative to the coal blend. Ash contents of the fuels are very similar. Proximate analysis results are presented in Table 1, below.

Table 1
Fuel Proximate Analysis Results, as Received wt %

Analysis Parameters	Colbert Coal Blend	Pittsburgh No. 8	Lignin	Biosolids
Moisture	8.10	2.10	40.9	68.8
Volatile matter	38.6	35.9	34.7	17.1
Fixed carbon	41.2	50.0	11.0	2.73
Ash	12.2	12.0	13.4	11.3
Higher heating value, Btu/lb	10,700	13,320	4,130	1,810

Table 2, below, summarizes the combustion testing matrix completed at EERC. The table provides the blends of material being tested along with the target furnace exit gas temperature for each experiment. Nine co-fire pilot tests were completed.

Table 2
Combustion Test Matrix

Test No.	Coal:Lignin:Bio-Solids, dry wt %	FEGT[a], °F (°C)
1	100[b]:0:0	2200 (1200)
2	90[b]:10:0	2200 (1200)
3	95[b]:5:0	2200 (1200)
4	90[b]:5:5	2200 (1200)
5	90[b]:0:10	2200 (1200)
6	100[c]:0:0	2350 (1290)
7	90[c]:10:0	2350 (1290)
8	90[b]:10:0	2350 (1290)
9	100[b]:0:0	2350 (1290)

[a]Furnace exit gas temperature
[b]80 wt % Colorado–20 wt % subbituminous Powder River Basin coal blend
[c]Eastern U.S. coal, Pittsburgh #8

The combustion tests described in Table 2 have been completed. Compositional analyses of the fuels, deposits, and fly ashes have been completed and are being tabulated and interpreted by EERC. Preliminary analyses of the test data indicate that the blending of lignin and bio-solids with the Colbert coal blend generally reduces NO_x emissions but increases the ash deposition rate on superheater surfaces. Deposits produced from the fuel blends, however, are more friable and hence easier to remove from tube surfaces relative to those produced from the baseline Colbert coal blend.

The fuels, fly ashes, and fouling deposits associated with each test have been analyzed in detail using wavelength-dispersive x-ray fluorescence spectrometry, computer-controlled scanning electron microscopy, and x-ray diffraction. These analyses evaluated the following:

- Mineral content and composition of the four fuel materials
- Mineral size analysis within the fuel
- Effect of blending on the relative mineral concentrations
- Effect of blending on the mineral composition of the fly ash produced
- Improved combustion reactivity with fuel blending (less carbon in the ash)
- Effect of blending on the mineral composition of the tube deposits
- Evaluation of initial ash layer enrichment in certain mineral content from the tube deposits

This data will be reported in more detail in the final EERC co-fire evaluation report.

In addition to completing the fuel, fly ash, and deposit mineralogical and chemical analyses, the viscosities of slags produced from melting the fuel ashes were predicted using the Facility for the Analysis of Chemical Thermodynamics (FACT) and a modified form of the Urbain equation. Comparisons of predicted liquid phase viscosities for the Colbert parent coal and fuel blends suggest that the blending of lignin and/or bio-solids at relatively low proportions (<10 wt %, dry basis) does not significantly affect liquid phase viscosity, especially at $\geq$1275°C.

TVA and Masada had representatives present for several of the co-fire tests to witness and evaluate the co-fire process. TVA's Jonathon Patterson, HGI's Jeff Ranney, and Lizan's Larry Russo witnessed several of the tests. Mr. Patterson and Mr. Russo witnessed Test 2. They observed the mixing of the lignin with the coal. This is a simple process that involved a tumbler mixer and a Hammermill. Approximately 500 lb of coal was added to the tumbler; then a proper amount of lignin (to get a 10% mixture by dry weight) was added to the coal. After tumbling for 60 minutes, the mixture was passed through a Hammermill and transferred to a vessel that would be used to feed the pilot combustion unit. Mr. Patterson and Mr. Russo then witnessed the combustion testing in the EERC test burner and reported no problems associated with the test burn.

Mr. Ranney witnessed Test 4. Fuel blending was completed prior to this test and EERC reported that this processing presented no difficulty. During the test burn, deposits were witnessed forming on the test probes in the boiler. These deposits were loosely connected to the probes and fell from the probes during probe extraction. EERC indicated that while the deposits appear larger for the blended fuel than for the base coal, the material was generally easily removed and would be handled by standard soot blowing in a utility scale boiler.

EERC's efforts in the next few weeks will be to focus on reducing the gas analyzer, multicyclone, and ash mass balance data recorded during the combustion tests. Results from this data reduction activity will enable EERC to quantify the effects of lignin and acidified bio-solids blending on flue gas composition (e.g., CO, SO_2, and NO_x), fly ash particle size, and ash fouling. We anticipate that a draft final report will be made available for review by team members by the end of April 2002.

3.6 Preliminary Engineering Interface Assessment and Design for TVA Coal-Fired Facility

The Colbert fossil plant consists of five pulverized coal-fired electricity generating units. Units 1 through 4 are identical and have the following characteristics:

- Capacity 200 MW
- Main steam flow 1,287,000 lb/hr
- Main steam pressure 1815 psig
- Main steam temperature 1050°F
- Reheat steam flow 1,122,000 lb/hr
- Reheat steam pressure 402 psig
- Reheat steam temperature 1050°F
- Steam turbine extractions eight at various pressures

Units 1 through 4 began commercial operation in 1955. Unit 5 is a unique, larger capacity (500 MW) unit and was not considered as a steam supply source. HGI provided TVA with the design case steam requirements of the Masada facility. The requirements include the following:

- Steam pressure 150 psig
- Steam quality saturated
- Base demand 217,420 lb/hr
- Peak demand 229,420 lb/hr

The peak demand is the basis for the TVA engineering assessment. Of the steam exported to the waste processing facility, 82% would be returned to the Colbert plant as condensate.

The design of the steam supply system is complete. For reliability reasons, the steam supply arrangement would be configured so that steam would be supplied from one unit or equally divided from two units. Main steam from the steam generators would be the source. The steam conditions required by the waste processing facility would be met by attemperation and throttling. Steam export would reduce electrical generation from the plant and increase plant heat rate. Analysis of these impacts on the turbine cycle has been completed.

The steam pipe routing has been finalized and the environmental review completed. The selected route had no significant environmental impacts. The selected pipeline route includes 7,345 ft of pipeline with four road crossings and one crossing of Cane Creek.

A preliminary steam price has been determined based upon the cost estimate for the steam supply system, the output and heat rate impacts resulting from the potential steam export, and steam supply system maintenance costs. A preliminary report from TVA-Colbert has been received and is being updated to include some additional items. These items include the following:

- A BTU credit for the value of bio-fuels is being included in the steam cost. This evaluation awaits the report from EERC on the co-fire results.
- Evaluation of the impact of reducing the distance between the TVA-Colbert steam system and the Masada facility.
- Modifying the estimate for the more general power facility; i.e., not including infrastructure improvement costs specific to Colbert in the general cost of co-location and of steam supply.

4. CONCLUSION

The design criteria of the MSW-to-ethanol facility for this study have been completed. Hydrolysis operations and lignin production in the TVA facility were completed. Lignin washing and dewatering were completed and the fuel supplied to EERC for co-fire testing, along with baseline coal from the TVA-Colbert facility. Coal processing was completed at EERC to facilitate combustion testing. EERC completed preliminary fuel analysis and co-fire testing. Co-fire tests indicate no significant problems associated with bio-fuel co-firing. Both fuel handling and combustion tests were successful. Test fire runs indicate that, while tube deposition may slightly increase with the addition

of bio-fuels, the depositions are more friable and hence easier to remove from tube surfaces relative to those produced from the baseline Colbert coal blend. EERC continues with data analysis.

The TVA-Colbert fossil plant is fully capable of providing a reliable steam supply for the proposed Masada waste processing facility. The steam supply connection point in the Colbert plant steam cycle has been identified. The pipeline routing from the Colbert powerhouse to the Colbert plant boundary has been identified. The environmental review of the pipeline routing has been completed and no impacts have been identified. The cost estimate for the steam supply system is under review and will be updated by TVA.

5. LIST OF ACRONYMS AND ABBREVIATIONS

DOE	Department of Energy
EERC	Environmental Energy Research Center
HGI	Harris Group Inc.
MRG	Masada Resource Group, LLC
MSW	Municipal Solid Waste
NETL	National Energy Technology Laboratory (also FETC, Federal Energy Technology Center)
PFD	Process Flow Diagram
RDF	Refuse Derived Fuel (also MSW)
SS	Sewage Sludge
TVA	Tennessee Valley Authority
TVA-PPI	TVA Public Power Institute
WWT	Waste Water Treatment