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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. Processing of biosolids and pilot facility hydrolysis production have been completed to produce lignin for cofire testing. EERC had received all the biomass and baseline coal fuels for use in 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 cofire test results indicate that the blending of lignin and biosolids 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. A draft of the final cofire technical report entitled "Effects of Cofiring Lignin and Biosolids with Coal on Fireside Performance and Combustion Products" has been prepared and is currently being reviewed by project team members. A final report is expected by mid-third quarter 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 environmental review, preferred steam supply connection points and steam pipeline routing, and assessment of steam export impacts have been completed without major issue. A cost estimate for the steam supply system was also completed. 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. TVA has provided a draft final report that is under review by team members.

REPORT NO. 00-10734/09

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: JULY 23, 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 cofiring of biorefinery-derived lignin and acidified biosolids (“biosolids”) 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 collocating a CES OxyNol™ facility with the TVA-Colbert facility. In this configuration the biorefinery supplies boiler fuel (lignin and bi-solids) to the Colbert facility and the Colbert facility provides the process steam needed for the CES OxyNol™ process. The collocation has the benefit of providing a low-cost renewable biomass fuel source that can be cofired with coal. Collocation 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 related tasks to reach the aforementioned goals of the project. The goals of the pilot runs are to evaluate dewatering options and generate lignin to be used in the cofire evaluation at the Environmental Energy Research Center (EERC).

The first task is the overall feasibility analysis for collocation 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 collocation.

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 cofire 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 cofire testing of the lignin and biosolids. In this testing of the material, the biofuel was 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 biosolid materials were tested as mixtures with coal. In most cases, the target mixture is a 10% biofuel, 90% coal blend. This blending is well above the expected blending ratio for the TVA-Colbert facility but rich enough in biobased fuels to allow detection of potential changes and improvements in boiler operations. 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 biosolids.

2. **EXPERIMENTAL**

TVA has considerable experience in the acid hydrolysis process and its experimental experience has been applied to lignin production, washing, and dewatering. 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 as summarized below.

- Task 1 – Engineering impact of the cofire concept is favorable. Status: Substantially completed.
- Task 2 – 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. Status: Draft of final TVA-Colbert report under review.
- Task 3 – Design and modification of the TVA pilot facility to operate under Masada process has been completed. Status: Substantially completed.
- Task 4 – TVA pilot facility modifications and shakedown testing have been completed. Status: Substantially completed.
- Task 5 – The pilot plant has completed lignin production. Status: Substantially completed.
- Task 6 – Dewatering/washing of lignin has been completed. Status: Substantially completed.
- Task 7 – Cofire testing has largely been completed at EERC. NETL expressed reservations with respect to cofire of the lignin/biosolids mixed material in the NETL test boiler. EERC agreed to perform the cofire portion of the testing. The lignin and biosolids cofire feed materials were shipped to the EERC cofire test site for feed characterization and preparation for cofire test runs. Cofire testing at EERC is completed. Status: A draft final report from EERC will be provided for team review. EERC is wrapping up some final sample analysis as part of this project.

Further details are provided in the sections below.

3.2 **Engineering Impact Analysis**

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 will be required for this project. 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 OxyNoI™ process in a batch mode. This process included the hydrolysis of a conditioned MSW feed material to produce a lignin fuel for cofire testing. Approximately 1000 lb of lignin were produced to meet cofire testing requirements.

3.4 Lignin Dewatering Testing

Lignin washing and dewatering occurred at TVA, providing washed feed for cofire testing at EERC. Seven drums of lignin material were washed and dewatered. The biofuel was shipped to EERC along with the biosolids for Task 7 of this project, the combustion testing of the biofuels.

3.5 Combustion Testing

Lignin, derived from MSW and renewable biosolid feedstock using Masada Resource Group's patented CES OxyNoI™ process, and acidified biosolids were evaluated as supplemental fuels with coal for producing steam and electricity. Tests were conducted in EERC's pilot-scale (550,000-Btu/hr [580 MJ/hr]) combustion system to evaluate the effects of coal characteristics, blend mixture (on a dry wt % basis), and furnace exit gas temperature (FEGT) on boiler heat-exchange surface slagging and fouling, NO_x and SO_x production, fly ash characteristics, and combustion efficiency. The effects of blending lignin and acidified biosolids with coal on fuel handling and pulverization characteristics were also addressed.

An 80 wt % Colorado–20 wt % subbituminous Power River Basin coal blend from the TVA-Colbert steam plant, hereafter referred to as the Colbert coal, and a bituminous Pittsburgh No. 8 coal were tested. The lignin and acidified biosolids were characterized by higher moisture contents and lower carbon, hydrogen, and heating values relative to the coals. Ash contents of the fuels were similar. The lignin also possessed higher concentrations of TiO₂, CaO, and SO₃ and lower concentrations of SiO₂, Al₂O₃, Fe₂O₃, K₂O, and N relative to the coals. The sulfur content of lignin is known to be higher than normal due to inefficiencies associated with the dewatering process at the pilot scale at TVA. The sulfur content will be reduced through a more thorough washing and drying of the lignin in the more efficient commercial-scale dewatering equipment identified by Masada. Acidified biosolids were distinguished by higher concentrations of P₂O₅ and MgO and lower SiO₂ and Al₂O₃ relative to the other fuels.

The lignin and biosolids air dried to <40 wt % moisture did not present handling, pulverization, or fuel homogeneity problems. Nine combustion tests, described in Table 1, were conducted. Ash mass balance measurements were used to calculate ash deposition rates (ash deposition rate = deposit, g/total ash input, kg) to simulated superheater surfaces in the pilot-scale combustion system. Deposition rates were lowest for the baseline (100:0:0) Colbert coal tests and highest for the 90:10 Colbert coal/lignin blend tested at the higher FEGT of 2350°F (1290°C). Although combustion test results indicate that the cofiring of

lignin and/or acidified biosolids with Colbert coal will increase ash deposition, the deposits produced at a FEGT of 2200°F (1200°C) were friable and very loosely bound to simulated superheater surfaces. Therefore, these deposits should be easily removed via soot blowing in a full-scale boiler. The cofiring of relatively low proportions (≤ 5 dry wt %) of lignin and/or biosolids at a FEGT of $\leq 2200^\circ\text{F}$ ($\leq 1200^\circ\text{C}$) should not create catastrophic ash deposition problems. Benefits of cofiring relatively small proportions of lignin and/or biosolids with the Colbert coal are primarily threefold: 1) increases utilization of biomass energy, 2) reduces NO_x emissions, and 3) improves combustion efficiency resulting in reduced fly ash carbon contents.

The cofiring of 10 dry wt % lignin with the Pittsburgh No. 8 coal did not significantly affect entrained ash/bottom ash partitioning or the ash deposition rate, even though thermodynamic calculations predicted the formation of additional low viscosity silicate liquid. In contrast to the Colbert coal, the cofiring of lignin with Pittsburgh No. 8 coal at a FEGT of 2350°F (1290°C) did not reduce NO_x, but did reduce SO₂ via ash sulfation (i.e., formation of anhydrite).

Table 1 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 cofire pilot tests were completed.

Table 1
Combustion Test Matrix

Test No.	Coal:Lignin:Biosolids, 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 No. 8

The combustion tests described in Table 1 have been completed. Compositional analyses of the fuels, deposits, and fly ashes have been completed. Preliminary analyses of the test data indicate that the blending of lignin and biosolids 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 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
- Initial ash layer enrichment in certain mineral content from the tube deposits

This data is reported in more detail in the final EERC cofire evaluation report, a draft of which has been distributed to team members for review. The report is entitled “Effects of Cofiring Lignin and Biosolids with Coal on Fireside Performance and Combustion Products.” 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 biosolids at relatively low proportions (<10 wt %, dry basis) does not significantly affect liquid phase viscosity.

TVA and Masada had representatives present for several of the cofire tests to witness and evaluate the cofire process. TVA’s Jonathon Patterson, HGI’s Jeff Ranney, and Lizan’s Larry Russo witnessed several of the tests. Messrs. Patterson and 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, the mixture was passed through a Hammermill and transferred to a vessel that will be used to feed the combustion unit. Mr. Ranney witnessed Test 4. Fuel blending was completed prior to this test and EERC reported that this processing presented no difficulty. Messrs. Patterson, Russo, and Ranney witnessed the combustion testing in the EERC test burner and reported no problems associated with the test burn.

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 as follows:

- 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% will be returned to the Colbert plant as condensate.

The design of the steam supply system is complete. For reliability reasons, the steam supply arrangement will be configured so that steam will be supplied from one unit or equally divided from two units. Main steam from the steam generators will be the source. The steam conditions required by the waste processing facility will be met by attemperation and throttling. Steam export will 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 7345 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, output and heat rate impacts resulting from the potential steam export, and steam supply system maintenance costs. Several factors unique to the Colbert facility have been identified that impact system costs. The primary factor is the distance of the steam system from the TVA-Colbert reservation boundary. The distance impacts both the system costs and the extraction pressure required to provide steam for the Masada facility. 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 biofuels is being included in the steam cost. This evaluation awaits the report from EERC on the cofire 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 colocation and of steam supply.

A draft of the updated TVA-Colbert report has been received and is under review for final acceptance by team members.

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 c-fire testing, along with baseline coals. Coal processing was completed at EERC to facilitate combustion testing. EERC completed fuel analysis and cofire testing. Cofire tests indicate no significant problems associated with biofuel cofiring. Both fuel handling and combustion tests were successful. Test fire runs indicate that, while tube deposition may slightly increase with the addition of biofuels, 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 to wrap up data analysis and has provided a draft of the final cofire report for team review.

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. TVA has provided an updated final feasibility report including cost estimates for the steam supply system.

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