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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 have been completed and issued for review. Processing of bio-solids was completed, providing material for the pilot operations. Pilot facility design, equipment selection, and modification were completed during the fourth quarter. Initial pilot facility shakedown was completed during the fourth quarter. During pilot plant shakedown operations, several production batch test runs were performed. These pilot tests were coupled with laboratory testing to confirm pilot results. In initial batches of operations, cellulose to glucose conversions of 62.5% and 64.8% were observed in laboratory hydrolysis. As part of this testing, lignin dewatering was tested using laboratory and vendor-supplied filtration equipment. Dewatering tests reported moisture contents in the lignin of between 50% and 60%. Dewatering parameters and options will continue to be investigated during lignin production.

After some unavoidable delays, a suitable representative supply of MSW feed material was procured. Shredding of the feed material was completed and final drying of the feed is expected to be completed by late January. Once feed drying is completed, pilot facility production will begin to produce lignin for co-fire testing. Facility modifications are expected to continue to improve facility operations and performance during the first quarter of 2001.

The TVA-Colbert facility continues to make progress in evaluating the 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 continues.

REPORT NO. 00-10734/03

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: JANUARY 29, 2001

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Appendix

- A PROPRIETARY INFORMATION
(Material in this appendix is proprietary, confidential, and the property of Masada Resource Group, LLC and shall not be revealed to a third party without the written consent of Masada Resource Group, LLC.)

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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 fuel 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) 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 several of the specific tasks in the preparation for the pilot production run. 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 National Energy Technology Laboratory (NETL). Design modifications of the pilot facility at the TVA-PPI laboratory included the development of process flow diagrams, sizing of key equipment, and identification of equipment requiring purchase or rental. Initial pilot facility modification has been completed and pilot plant shakedown testing has begun.

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

- Identify facility design criteria.
- Identify potential facility location and preliminary site layout.
- Evaluate 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 will identify

- 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 will be used to develop a price for the steam to be supplied from the Colbert plant to the Masada facility.

Tasks 3 and 4 involve the pilot plant facility design, modification, and shakedown for the production of lignin. Pilot plant design and modification were completed during the quarter with the pilot plant production operation tentatively scheduled for February. Several shakedown trial runs were completed during the quarter. Transitioning from the pilot facility shakedown phase to the operations phase has been delayed due to difficulties in obtaining a representative MSW feed material. A representative sample was procured during the fourth quarter. Feed conditioning, including shredding and drying, is expected to be completed by the end of January.

Tasks 5, 6, and 7 are the production of lignin, lignin dewatering, and co-fire testing at the NETL facility. These tasks await the completions of Tasks 3 and 4, which are expected to be completed by mid-February 2001.

2. EXPERIMENTAL

TVA has considerable experience in the acid hydrolysis process and its experimental experience has and will be applied to the lignin production. The lignin dewatering and conditioning will be studied in conjunction with dewatering equipment vendors and with the input of NETL. The hydrolysis process used during these tests to produce lignin samples is the proprietary Masada CES OxyNolTM process.

During the third quarter of 2000, TVA prepared 5-gal samples of unfiltered processed sewage sludge and hydrolyzate to be shipped to NETL (George Wen) for dewatering tests. Five gallons of unfiltered processed sewage sludge and five gallons of unfiltered hydrolyzate were shipped to NETL. Information on TVA's pilot plant safety procedures was also sent to NETL. The project team awaits results of the NETL testing.

Dewatering and hydrolysis testing completed during the fourth quarter of 2000 are part of continuing tests. These tests are still in progress and final reporting will include non-proprietary experimental descriptions.

3. RESULTS AND DISCUSSION

3.1 General

Progress on the major tasks of this project continues. Engineering impact of the co-fire concept appears favorable. TVA-Colbert continues to evaluate steam supply options and impacts with all indications that supply options exist. Pilot facility modifications have been completed with further modifications to be undertaken as needed. The pilot plant has successfully completed a partial shakedown operation. Some delays have occurred due to difficulty in procuring a suitable representative MSW feed supply. A feed supply has been procured and lignin production awaits feed conditioning to be completed early in the first quarter of 2001.

NETL has expressed reservations with respect to the co-fire of the lignin/sewage sludge mixed material in the NETL test boiler. The project team is currently investigating other options with the likely outcome that co-fire testing will be completed at an alternate facility.

3.2 Engineering Impact Analysis

During the fourth quarter of 2000 no significant changes were identified in the engineering impact analysis from the previous quarterly report. During the third quarter of 2000 preliminary design criteria for the Masada Colbert facility were issued to the team members. A preliminary site for the Masada facility was identified to the west of the TVA-Colbert power plant in an industrial park development area. This site selection is preliminary for purposes of this study. Final site selection will be predicated on community approval and economic viability. The design criteria and site identification allow the TVA-Colbert power facility to make the initial investigations into the expected impacts and facility modifications that would be required for this project. TVA power is currently investigating the impacts on the plant steam cycle and power plant operations. Results of the TVA-Colbert study to date are reported below in paragraph 3.8.

3.3 MSW Feed Procurement and Conditioning

As previously commented on, an unavoidable delay in the acquisition of a representative MSW supply caused a delay in pilot plant shakedown and operations. A representative MSW supply was eventually procured and delivered to an equipment vendor testing facility for feed conditioning. Due to a large quantity of plastics in the MSW, a manual sort of the feed material was required prior to feed conditioning. This involved the hand sorting of over 3000 lb of material. Hand sorting was completed during November 2000.

After sorting was complete, the material was shredded using a vendor-supplied hammer mill rental unit. The rental machine configuration as supplied had incorrect sizing of the hammer mill screens, resulting in delays in MSW shedding. The correct screens were procured and the MSW was shredded. Approximately 50% of the material was dried in a vendor-supplied steam tube dryer. During feed conditioning, an alternative style dryer was also identified at TVA and the opportunity was taken to test this dryer. A portion of the sorted and shredded MSW was dried in the steam tube dryer with the rest of the material set aside for test drying in the alternate dryer. Some modification of the TVA dryer is required to test the applicability of this type of dryer and to compare to the steam tube dryer. All the MSW material has been shipped to TVA for processing. The remainder of the undried material will be dried at TVA with hydrolysis/lignin production to follow.

3.4 Pilot Plant Modifications

In preparation 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. TVA's pilot facility provided several tanks and pumps that are used. Several pieces of equipment required rental or purchase for the completion of this project. Rented or purchased equipment included a suitable vessel for the hydrolysis reaction, an acid pump, a mixer effluent tank, and an industrial mixer. Each of these pieces of equipment has been procured and was incorporated into the pilot facility. A schematic drawing of the pilot facility is shown in Appendix A (proprietary information). A filtration equipment vendor was also identified as the preferred equipment provider for lignin dewatering equipment. Filtration equipment was rented and used in initial shakedown testing of the pilot facility.

3.5 Pilot Facility Shakedown and Hydrolysis Operations

During this quarter the hydrolysis pilot facility at TVA went through initial shakedown operations. These operations were accompanied by laboratory scale process verification by TVA-PPI. Briefly summarized here are the results for the shakedown testing.

As described previously, TVA's pilot facility was set up to operate the OxyNol™ process in a batch mode. A proprietary flow diagram of the process is shown in the appendix.

After initial modifications of the TVA pilot facility were completed, a shakedown test of the facility was begun. Because the supply of the specified MSW feed material had been delayed, the pilot testing was completed using a substitute feed material available at TVA which is expected to be similar to the proposed facility feed material. The MSW (RDF) feed material analysis is summarized in Table 1.

Table 1. Composition of RDF on a Dry Basis

Component	Amount (%)	Amount Adjusted to 100 (%)
Glucose	56.21	53.49
Xylose	8.05	7.66
Acid soluble lignin	1.07	1.02
Klason lignin	30.55	29.07
Ash	9.20	8.76

Two test runs of the pilot facility were completed using the alternate feed. In the initial shakedown test of the pilot facility, 101.5 lb MSW feed was processed. Moisture analysis of the RDF used in the initial test gave an average feed moisture content of 7.6% as shown in Table 2.

Table 2. Weight and Moisture Contents of RDF Fed to Mixer in Batch 1

RDF Bag Number	Weight (lb)	Moisture Content (%)
1	15.5	8.0
2	25.0	8.1
3	28.0	7.2
7	33.0	7.3
Total	101.5	7.6

After mixing with acid the resulting mixture was mixed with hot SS Centrate. The mixture was then transferred to a reaction vessel and heated to the reaction temperature. After the hydrolysis reaction was completed, the material was transferred to the filter feed tank. About 3 gal of the hydrolyzate was sampled and fed to the rental filtration unit for dewatering (see lignin dewatering, paragraph 3.6).

A total of 113 lb MSW was fed to the pilot facility in Test Batch No. 2. After reaction this material was combined with the hydrolyzate from the initial test and used for further testing of lignin dewatering using the filtration rental equipment.

In both Test Batches 1 and 2, samples of the hydrolysis gel produced were sampled for laboratory scale hydrolysis testing in the TVA laboratory. The measured cellulose-to-glucose conversion efficiency in the lab tests was calculated to be 62.5% and 64.8% in Test Batches 1 and 2, respectively.

Late in the fourth quarter of 2000, a representative sample of feed material was procured and delivered to a vendor's test facility for feed processing. After partial processing of the feed, the dried material was shipped to TVA. After 500 lb of dried RDF were delivered several additional facility shakedown tests were run in the TVA pilot facility. The analysis of this material is presented in Table 3. The RDF had been shredded through a 3-in. screen and was larger than material used previously (1-in. screen). The vendor had dried the material through its steam-tube dryer to a moisture content of 1.5% to 4.3% moisture. The RDF was divided into five batches for processing.

Table 3. Compositional Analysis of Three Samples of RDF

RDF Sample	Glucose (%)	Xylose (%)	Total Sugars (%)
RDF 1	48.89	6.20	55.09
RDF 2	46.72	6.15	52.87
RDF 3	47.98	6.45	54.43
Average	47.86	6.27	54.13

During initial testing of the material, the larger size resulted in some minor line plugging. As a result, the material was shredded to a smaller size using TVA's hammer mill. The further hydrolysis testing of this material resulted in calculated conversions in excess of 65% in the pilot operation. TVA continues to confirm these encouraging results.

The material generated in this second batch of testing was dewatered using the TVA filter press. Results of this method of dewatering will be compared to the vendor-supplied filtration equipment results when testing on the filter press is completed. Lab scale dewatering tests were also begun at TVA.

3.6 Lignin Dewatering Testing

Lignin dewatering and filtration testing were performed during the pilot facility shakedown at TVA. Tests were performed both in TVA's laboratory and using vendor-supplied pilot filtration equipment.

3.6.1 Laboratory Testing at TVA

Several samples of hydrolyzate slurry were collected during the TVA pilot facility shakedown for use in dewatering testing in the TVA laboratory. Hydrolyzate slurry samples were dewatered both as is and after removal of large particles by prefiltration with a large mesh screen.

TVA tested lignin dewatering utilizing several different flocculent materials. One flocculation material proved superior as the flocculent in the filtration of the hydrolyzate under the conditions tested in the laboratory. The addition of the polymer reduced filtration time at all dilution levels. The addition of optimum polymer concentration was determined as a function of the dilution rate of the slurry.

Testing is likely to continue using samples generated during the scheduled lignin production phase of the program.

3.6.2 Vendor Equipment Dewatering Testing

During the TVA pilot facility shakedown, a rental pilot scale test filtration unit was tested for lignin dewatering. The vendor initially tested flocculent for applicability as a filter aid and observed that a suitable dose of flocculent to the undiluted hydrolysis slurry “flocculated very well.” In subsequent pilot equipment testing, a similar flocculent level was employed for hydrolyzate slurry filtration.

The vendor reported that cake moisture contents of 50% to 60% were achieved during the testing with an average cake thickness of approximately 1/8 in. Cake washing also appeared to be effective in the removal of sugar from the lignin cake. An estimated rate of filtration (averaged over the filter cycle) of the slurry was determined by the filtration equipment vendor.

3.7 **Pilot Schedule**

The following tentative schedule represents our projected timeline for operation of the TVA pilot facility for the production of the lignin for co-fire testing. This schedule is subject to change.

Modification of RDF dryer	January 18-29
Dry RDF	January 29-February 2
Hydrolysis	January 31-February 16
Lignin Dewatering	February 19-23

3.8 **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 the design case steam requirements of the Masada facility. The requirements include the following:

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

The peak demand is the basis for the TVA engineering assessment.

A location for the Masada facility has been identified adjacent to the western boundary of the Colbert plant reservation. This location is the basis of steam pipeline routing and steam line pressure drop calculations.

There are several locations in the Colbert Unit 1 through 4 steam cycles from which steam could be taken for export to a steam user. The selected location must provide steam of sufficient temperature and pressure so that the steam user's required steam conditions can be maintained throughout the range of Colbert operating conditions. The steam export connection location should be selected so that the negative impacts (capacity, heat rate, and operation and maintenance costs) on the Colbert plant are minimized. Steam connection locations that have been investigated are

- Main steam
- Cold reheat steam
- No. 1 steam turbine extraction
- No. 2 steam turbine extraction

As previously reported, main steam is the preferred location from which to export steam for the Masada application. One of the four units can supply the steam requirement even at reduced unit loads. (Although one unit will be able to supply adequate steam, at least two and potentially all four of Units 1 through 4 will be connected to the steam supply in order to assure a reliable steam supply while accommodating planned and forced unit outages.) Main steam will be attemperated to desired conditions. A contract has been placed with the Colbert Unit 1 through 4 boiler vendor to complete a detailed boiler impact assessment of the steam export.

An environmental review of the two proposed steam pipeline routes from the Colbert powerhouse to the Colbert boundary has been completed. This review addressed potential impacts to navigation and recreation, flood plains, wetlands, archaeological resources, aquatic ecology and sensitive aquatic animals, protected plant species, protected terrestrial animal species, and visual effects. One of the proposed routes would have impacted a known

archaeological site and thus was dropped from consideration. The second proposed route had no significant environmental impacts identified during the review and became the basis for the preferred pipeline route. The preferred route includes 7,345 ft of pipeline with four road crossings and one crossing of Cane Creek.

Detailed design of the instrumentation and control system required for steam export has been started.

4. CONCLUSION

The initial design criteria of the MSW to ethanol facility have been completed along with preliminary site identification and layouts for the processing facility. These items are the first step in evaluating the feasibility of this co-located facility.

Pilot facility design and modification continue for the production and dewatering of the lignin fuel. The delay of suitable feed material has delayed the lignin production operations. Several test runs of the TVA hydrolysis pilot facility were completed initially using an alternate feed material available at TVA. Lab scale test runs using pilot generated material demonstrated conversions in the range of 62% to 65%. Subsequent testing showed encouraging pilot facility performance with conversions calculated in excess of 65%. Lignin dewatering was also testing during the shakedown testing with polymer addition concentrations studied and cake dryness analysis completed. Initial testing allowed the improvement of the facility operations in anticipation of the lignin production run.

The TVA Colbert fossil plant is fully capable of providing a reliable steam supply for the proposed Masada waste processing facility. The preferred steam supply connection point in the Colbert plant steam cycle has been identified. The preferred steam 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 major impacts have been identified. Detailed assessment of steam export impacts on the Colbert boilers continues, as does a detailed steam supply study.

5. LIST OF ACRONYMS AND ABBREVIATIONS

DOE	Department of Energy
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