Report Title: Quarterly Report for the Conceptual Design Assessment for the Co-Firing of Bio-Refinery Supplied Lignin Project

Type of Report: Quarterly Report, Second Quarter of 2001

Reporting Period Start Date: April 1, 2001

Reporting Period End Date: June 31, 2001

Principal Author(s): Ted Berglund, Jeffrey T. Ranney, Carol L. Babb, Jacqueline G. Broder

Date Report Was Issued: July 2001

DOE Award No.: DE-FC26-99FT40670

Name of Submitting Organization: Masada Resource Group, LLC, and Harris Group Inc.

Address of Submitting Organization:

Masada Resource Group, LLC
2170 Highland Avenue, Suite 200
Birmingham, AL 35205

Harris Group Inc.
1000 Denny Way, Suite 800
Seattle, WA 98109-5338

TVA-PPI
Reservation Road, PPI-1A
Muscle Shoals, AL 35662

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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 design, equipment selection, and modification were completed during the fourth quarter of 2000. Initial pilot facility shakedown was completed during the fourth quarter. After some unavoidable delays, a suitable representative supply of MSW feed material was procured. During this first quarter of 2001, shredding of the feed material and final feed conditioning were completed. Pilot facility hydrolysis production was completed to produce lignin for co-fire testing.

During this quarter, TVA completed the washing and dewatering of the lignin material produced from the MSW hydrolysis. Seven drums of lignin material were washed to recover the acid and sugar from the lignin and provide an improved fuel for steam generation. Samples of both the lignin and bio-solids fuel materials for co-fire testing were sent to the co-fire facility (EERC) for evaluation. After sample evaluation, EERC approved sending the material and all of the necessary fuel for testing was shipped to EERC. EERC has requested and will receive coal typical of the fuel to the TVA-Colbert boilers. This material will be used at EERC as baseline material and for mixing with the bio-fuel for combustion testing. EERC combustion testing of the bio based fuels is scheduled to begin in August of 2001.

The TVA-Colbert facility has neared completion of the task to evaluate 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 have been completed and a cost estimate for steam supply system was completed. The cost estimate and the output and heat rate impacts will be used to determine a preliminary price for the exported steam. The preliminary steam price will be determined in the next quarter.

REPORT NO. 00-10734/05

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 27, 2001

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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 most 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 National Energy Technology Laboratory (NETL) or 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 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 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. A representative sample was procured during the fourth quarter of 2000. Feed conditioning, including shredding and drying, was completed in preparation for lignin production.

Task 5 is the production of lignin in the TVA pilot facility. The pilot plant production operation occurred in the forth quarter of 2000 and the first quarter of 2001. The lignin production activity has been completed. TVA processed approximately 20 mix 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 was largely completed this quarter and is described in the results and discussion section.

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 each case 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 will be accomplished at EERC. EERC will perform 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 will perform 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 will be standard procedures used by EERC for fuel analysis and test unit operations. A brief summary of these procedures from EERC can be found in Appendix A, EERC Combustion Test Facility.

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 cost estimate for the system modifications has been completed. TVA pilot facility modifications have been completed with further modifications to be undertaken as needed. The pilot plant has successfully completed lignin production. Some delays had occurred due to difficulty in procuring a suitable representative MSW feed supply. A feed supply was procured and lignin production completed. TVA has completed the lignin washing and dewatering aspects of this project.

NETL has expressed reservations with respect to the co-fire of the lignin/sewage sludge mixed material in the NETL test boiler. EERC has agreed to perform the co-fire portion of the testing and has indicated that co-firing of this type of material should be easily accomplished. 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.

3.2 Engineering Impact Analysis

During the second quarter of 2001 no significant changes were identified from the previous engineering impact analysis. The previously issued design criteria and site identification allow the TVA-Colbert power facility to complete the investigations into the impacts and facility modifications that would be required for this project. TVA-Colbert is completing an investigation of the impacts on the 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 discussed in previous reports, an unavoidable delay in the acquisition of a representative MSW supply caused a delay in pilot plant operations for lignin production and washing. A representative MSW supply was procured and delivered to an equipment vendor testing facility for feed conditioning. Feed conditioning was completed and all the MSW material was shipped to TVA for processing.

3.4 Pilot Plant Modifications

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 much of the equipment that was used. Additional equipment required rental or purchase for this project. This equipment has been procured and was incorporated into the pilot facility as needed.

3.5 Pilot Facility Hydrolysis Operations

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.

During lignin production approximately 20 batch runs of MSW hydrolysis were processed to produce lignin material for co-fire testing. Each batch was approximately 100 to 200 lb of MSW. The analytical data is being processed and conversions and yields calculated. Preliminary estimations of conversion efficiency in the pilot facility indicate that conversions above 70% were achieved for the hydrolysis of cellulose to glucose. The hydrolyzate liquor was filtered from the lignin cake using a TVA pilot scale plate and frame filter. This hydrolyzate was set aside for further testing and processing beyond the scope of this project.

The lignin residue from the filter press was loaded into drums. Approximately 1000 lb of lignin were produced to meet the co-fire testing requirements. Seven drums of residue were obtained. Moisture analysis of samples from the drums showed that the lignin residue averaged about 55% moisture. The lignin was further analyzed to determine the sulfuric acid content of the lignin material. A summary of the acid content (on a dry solids basis) is summarized in following table.

Based Samples, Average Solid Content at 45°C			
Sample	**Calc Solids, g**	**Calc Moisture, g**	**H_2SO_4/solids, g/g**
Drum 1	6.80	4.80	0.22
Drum 2	8.05	2.85	0.29
Drum 3	6.34	4.57	0.22
Drum 4	6.68	3.91	0.21
Drum 5	5.97	5.03	0.18
Drum 6	5.67	5.20	0.18
Drum 7	6.46	3.86	0.20

This data was used to determine the amount of wash water needed for the lignin residue to recover the bulk of the sugar and acid in the lignin material and prepare the lignin for combustion testing.

3.6 Lignin Dewatering Testing

Lignin washing and dewatering occurred at TVA during May and June of 2001. This process both increases the recovery of sugar and acid from the lignin material and improves the fuel quality of the lignin by removing much of the sulfur present in the lignin fuel. Based on the analysis of the prewashed lignin and the anticipated commercial wash performance, a sulfur target in the washed and dewatered lignin was set at 3% sulfur (dry basis). This target was used to estimate the amount of wash water for lignin washing.

Modification of the pilot facility was required to facilitate the lignin washing process. These modifications included installation and wiring of a pump connected to the tank where the lignin could be mixed with water prior to dewatering. The general procedure for the washing and dewatering was as follows.

- The lignin was mixed with the desired amount of water in the tank, then circulated through the pump to facilitate mixing. The target amount of water was set for each drum of solids based on the acid content of the lignin material.
- The mixture was pumped to the TVA plate and frame filter for dewatering.
- After pumping to the plate and frame, the lignin material was allowed to dry. When the desired moisture content was reached, the solids were removed and placed in drums.

Seven drums of lignin material were washed and dewatered using this procedure. After drumming of the lignin material, 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.

3.7 Combustion Testing

EERC will be performing the combustion testing. This testing will evaluate the fuel properties and potential impacts of co-firing lignin fuel with coal in the TVA-Colbert facility. The lignin and bio-solids material has been shipped to and received by EERC. TVA-Colbert will be providing approximately 5000 lb of the standard TVA-Colbert coal for EERC to use as a baseline material for the combustion testing. EERC plans to perform combustion testing in early to mid-August with a potential second phase of testing scheduled for September. The dates have not been finalized because the test unit is currently being reconfigured to accommodate a grate feed system. Work on the test unit should be completed by the end of July 2001.

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 with 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. 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.

The cost estimate for the steam supply and steam pipe is complete. The cost estimate and the output and heat rate impacts will be used to determine a preliminary price for the exported steam. The preliminary steam price will be determined in the next quarter.

4. CONCLUSION

The design criteria of the MSW to ethanol facility for this study have been completed along with preliminary site identification and layouts for the processing facility. These items were the first step in evaluating the feasibility of this co-located facility. The delay of suitable feed material delayed the lignin production operations; however, a suitable MSW feed material was delivered and feed conditioning was completed. Hydrolysis operations and lignin production in the TVA facility were completed. Lignin washing and dewatering were tested on a small laboratory sample and the sample sent to the co-fire facility for fuel evaluation. Once evaluation was completed, the remaining lignin fuel was washed and dewatered and both fuel materials were shipped to the EERC testing facility for co-fire evaluation. A baseline coal from TVA-Colbert will be supplied to EERC and co-fire testing is scheduled to begin during the upcoming quarter.

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 steam supply system is underway and this task in the project is nearing completion.

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

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APPENDIX
EERC COMBUSTION TEST FACILITY (CTF)
DESCRIPTION OF FACILITIES AND PROCEDURES

Research programs have been under way at EERC for more than 25 years to study ash fouling of boiler heat-transfer surfaces in coal-fired utility boilers. A 550,000-Btu/hr pulverized-coal pilot plant test furnace was constructed in 1967 to evaluate the influence of variables, including ash composition, excess air, gas temperature, and tube wall temperatures on ash fouling. Results from this work have shown a strong correlation between ash characteristics and degree of fouling.

The research capabilities of the combustion test facility (CTF) have been enhanced and expanded to provide information on a wide range of combustion-related issues. The many research applications of this pilot-scale combustion equipment over the years have included the following:

- Determining ash-fouling rates and the strength, composition, and structure of fouling deposits.
- Applying sophisticated analytical methods to characterize input coal, ash, and deposits and to correlate coal and ash properties with deposit growth rates and strength development.
- Evaluating the effectiveness of ash-fouling additives.
- Studying particle-size distribution and velocity prior to deposition on convective section heat-transfer surfaces.
- Evaluating combustion characteristics of coal–water fuels.
- Studying high-temperature baghouse operation and performance.
- Evaluating sorbent injection for SO_x control.
- Assessing integrated particulate and SO_x–NO_x control.
- Studying NO_x control using selective catalytic reduction and disposable catalysts.
- Evaluating slagging potential in a simulated wet-bottom firing mode.
- Performing flame stability tests for comparing a particular fuel at full load and under turndown conditions.

COMBUSTION TEST FACILITY

An isometric drawing of the EERC CTF is shown in Figure A-1. The furnace capacity is approximately 75 lb/hr (550,000 Btu/hr) of pulverized lignite. The combustion chamber is 30 in. in diameter, 8 ft high, and refractory-lined for combustion testing of low-rank coals.

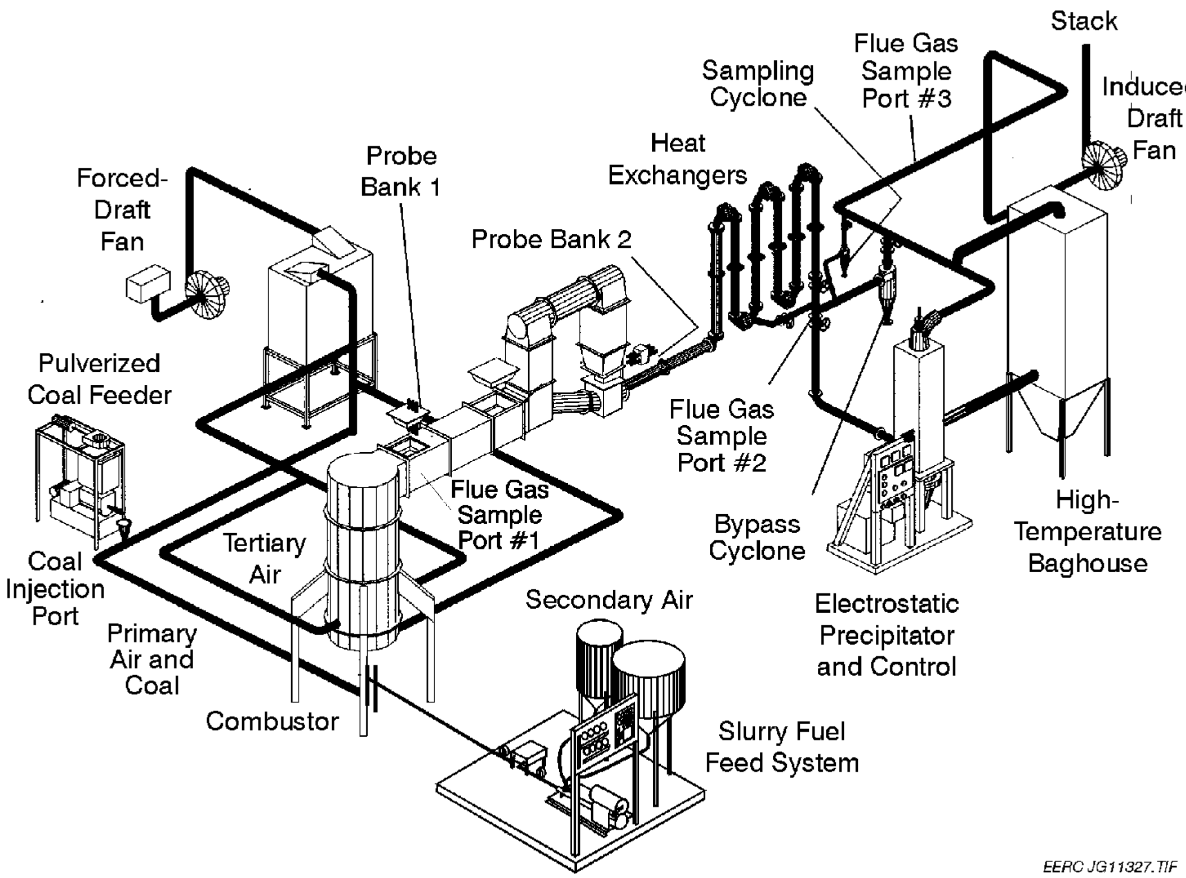

Figure A-1. Combustion Test Facility and Auxiliary Systems

The furnace diameter may be reduced to 26 in. to elevate the temperature entering the convective pass. Furnace exit gas temperatures as high as 2400°F have been achieved during combustion testing in this mode. Most tests are performed using the standard configuration (30-in. inside diameter), with the furnace exit gas temperature maintained at approximately 2000°F for each combustion test.

Coal is pulverized remotely in a hammer mill pulverizer, targeted to a size of 70% less than 200 mesh. The coal is then charged to a microprocessor-controlled weight loss feeder from a transport hopper. Combustion air is preheated by an electric air heater. The pulverized coal is screw-fed by the gravimetric feeder into the throat of a venturi section in the primary air line to the burner. Heated secondary air is introduced through an annular section surrounding the burner. Heated tertiary air is added through two tangential ports located in the furnace wall about 1 ft above the burner cone. The percentages of the total air used as primary, secondary, and tertiary air are usually 10%, 30%, and 60%, respectively. (An adjustable swirl burner, which uses only primary and secondary air with a distribution of approximately 15% and 85%, respectively, was used during flame stability testing.) Flue gas passes out of the furnace into a 10-in.-square duct that is also refractory lined. Located in the duct is a vertical probe bank designed to simulate superheater surfaces in a commercial boiler.

The ash-fouling test probe bank is located in a hinged door to facilitate inspection and cleaning. The three fouling probes used during this combustion test were constructed of 1.66-in.-outside-diameter Type 304 stainless steel pipe and were cooled with compressed air. Each probe has two thermocouples embedded in its upstream edge to measure metal temperature. One of the thermocouples on each probe is attached to a temperature recorder–controller that regulates the cooling air to the probe. The surface temperature of each probe was maintained at 1000°F. The gas velocity between the tubes is normally about 25 ft/s when low-rank coals are fired. The gas temperature entering the probe bank is normally maintained at 2000°F.

After leaving the probe duct, the flue gas passes through a series of water-cooled heat exchangers before being discharged through either an electrostatic precipitator (ESP) or a baghouse.

General Test Method

The relative fouling or other tendencies of test coals are determined by burning coal samples under specified conditions. When starting with a cold furnace, the following 13.25-hour test program is normally used:

	Hours
Preheat on gas	8.00
100% coal firing	5.25
Total	13.25

The coal feed rate is commonly adjusted to keep the flue gas temperature entering the upper duct to the probe bank at 2000°F, with 25% excess air. Coal samples are taken periodically to form a composite sample. Oxygen, carbon dioxide, nitrous oxides, carbon monoxide, and sulfur dioxide in the flue gas are continuously monitored by recording analyzers. The operating conditions and procedures described above are those normally used when the ash-fouling tendencies of low-rank western coals are studied.

The test furnace has numerous ports that permit observation of the probes and the furnace burner zone during the test run. These ports can also be used for installation of additional test probes, auxiliary measurements, photography, or injection of additives.

At the completion of the test period, the probe door is carefully opened and photographs are taken of the deposit. The deposit is then removed from the probes in two fractions, an inner and an outer layer, and each is weighed and analyzed separately. Normally, the inner white layer weighs less than 10 grams, as compared to 100 to 500 grams for the outer sintered deposit.

The weight of ash deposited on the probe bank during a standard test is used to rank the coal for its relative fouling potential. To ensure that the pilot-scale test results are meaningful for evaluation of ash-fouling potential in full-scale utility boilers, calibration tests were previously conducted with low-rank coals known to produce low and high fouling when used in utility boilers. Comparisons of ash fouling have been made from tests conducted at a number of power stations throughout the western United States: Monticello (Texas Utilities), Big Brown (Texas Utilities), Four Corners (Arizona Public Service Company), St. Clair (Detroit Edison Company), Jim Bridger (Pacific Power and Light), Big Stone (Otter Tail Power Company), Leland Olds (Basin Electric Power Cooperative), and San Miguel (San Miguel Electric Cooperative). Based on these tests, the ash deposit buildup rate on the probe bank was found to be a good indicator of fouling potential. The relationship between deposit weight and a fuel's fouling potential is generally categorized as indicated below:

Deposit Weight, Grams	Relative Fouling Potential
0–150	Low
150–300	Medium
Above 300	High

Deposit Strength Tests

The weight of the ash deposit from the probe bank has proven to be a good indicator of the fouling potential for most coals tested in the EERC CTF. Heavy deposits in the 5.25-hour test indicate high deposition rates, which can usually be related to potential ash-fouling problems in utility boilers. However, the deposition rate does not provide an indication of the ease of removal of deposits by sootblowing. Methods to measure deposit tenacity and strength have been reviewed at the EERC, and strength test methods have been developed that appear to provide reliable, reproducible results.

Deposit strength is initially assessed by means of the strength rating factor (SRF). This factor is determined from observations made by a pilot plant operator during removal of ash deposits from the probe bank. Deposit hardness and breakability is rated from 1 to 10, with "1" indicating "soft and crumbly" and "10" meaning "hard and unfragmented."

The probe deposit can also be subjected to a laboratory deposit strength evaluation procedure developed at the EERC, which utilizes a drop impactor technique. A known weight is dropped with a measured impact on the sliced face of a 1-in.-long deposit sample. After the drop test, the sample is sieved in a sonic sifter through a series of six screens ranging in size from 5.66 to 0.21 mm. The percentage of each size is determined and, using the procedure from the ASTM Tumbler Test (ASTM Method D441-45), the dust index, friability, and mass mean diameter of the crushed deposit sample are determined. The dust index is indicative of the tendency of the deposit to form dust on impaction. The mass mean diameter is the average size of the fragmented particles after the drop test. An impact resistance value (IRV) is calculated, which adjusts the results of the impactor tests for the test parameters under which they were obtained. The calculation was developed by analysis of a large body of data obtained by this procedure.

Furnace Wall Slag Probes

The combustion test facility at the EERC was originally designed for tests of fouling potential of low-rank coals. As a result, the nominal design values of heat input (550,000 Btu/hr), FEGT (2000°F), and excess air levels (25%) reflect utility industry experience on such fuels. More recently, efforts were made to evaluate slagging potential in the CTF. A slag probe was designed, constructed, and positioned close to the flame region of the furnace, just above the flame. The slagging test probe was water-cooled, to enable monitoring and maintaining surface metal temperatures between 500°F and 800°F.