FETC/EPRI BIOMASS COFIRING COOPERATIVE AGREEMENT

Quarterly Technical Report

Reporting Period:04/01/98 to 07/31/98

Author: E. Hughes and D. Tillman

Report Issue Date: August, 1998

DE-FC22-96PC96252 -09

Electric Power Research Institute (EPRI)
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304-1344

ABSTRACT

During April 1st, 1998 to June 31st, 1998, significant work was done in preparation for a series of test involving cofiring at power plants. A biomass material handling system was designed for the Seward testing, a gasification system was designed for the Allen Fossil Plant, and a test program plan was developed for testing at NIPSCO's Bailly Station. Also completed this quarter was a cyclone combustion model that provides a color visual representation of estimated temperatures within a plant.

This report summarizes the activities during the second quarter in 1998 of the FETC/EPRI Biomass Cofiring Cooperative Agreement. It focuses upon reporting the results of testing in order to highlight the progress at utilities.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Seventh Quarter of the FETC-EPRI contract, April 1, 1998 through June 31, 1998, was characterized by engineering activities pursuant to the upcoming demonstrations: the Seward cofiring demonstration of GPU Genco, the Bailly Unit #7 demonstration of NIPSCO, and the proposed gasification demonstration at the Allen Fossil Plant of TVA. All three technologies for cofiring, shown in Figures 1, 2, and 3, have applications. Selection of the appropriate technology for cofiring depends upon developing demonstration data concerning these approaches.

Technical work that proceeded during the seventh quarter of the contract included the following:

- Design of the Seward cofiring materials handling system, including identification of major systems and pieces of equipment
- Conceptual design of the TVA gasification system, to be installed as a demonstration at the Allen Fossil Plant, including preliminary selection of the gasifier
- Development of the Test Program Plan for the Bailly Station boiler #7 as the follow-up demonstration site for biomass cofiring at NIPSCO
- Completion of a cyclone combustion spreadsheet for field applications

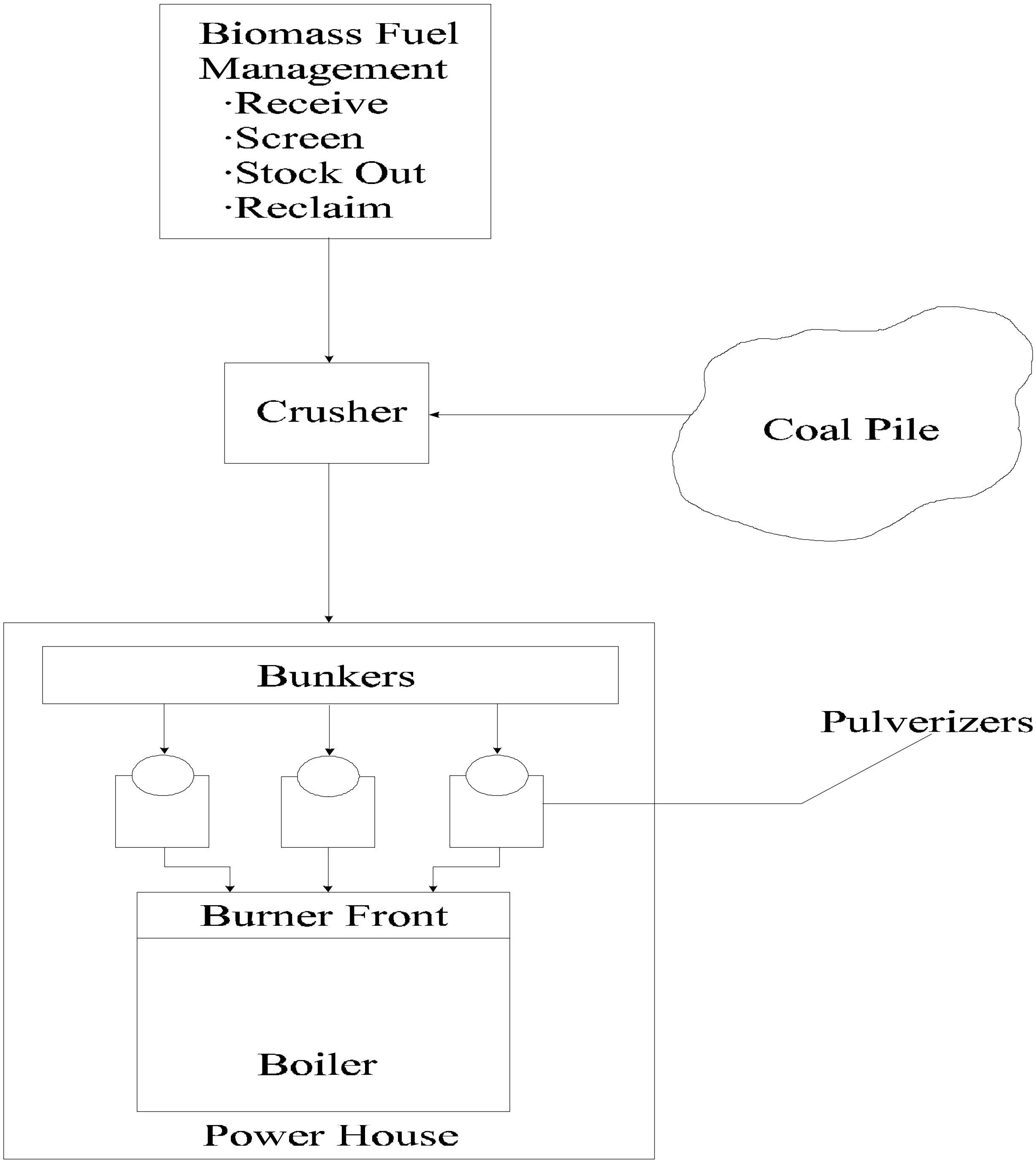

Figure 1. Simultaneous Feed Cofiring

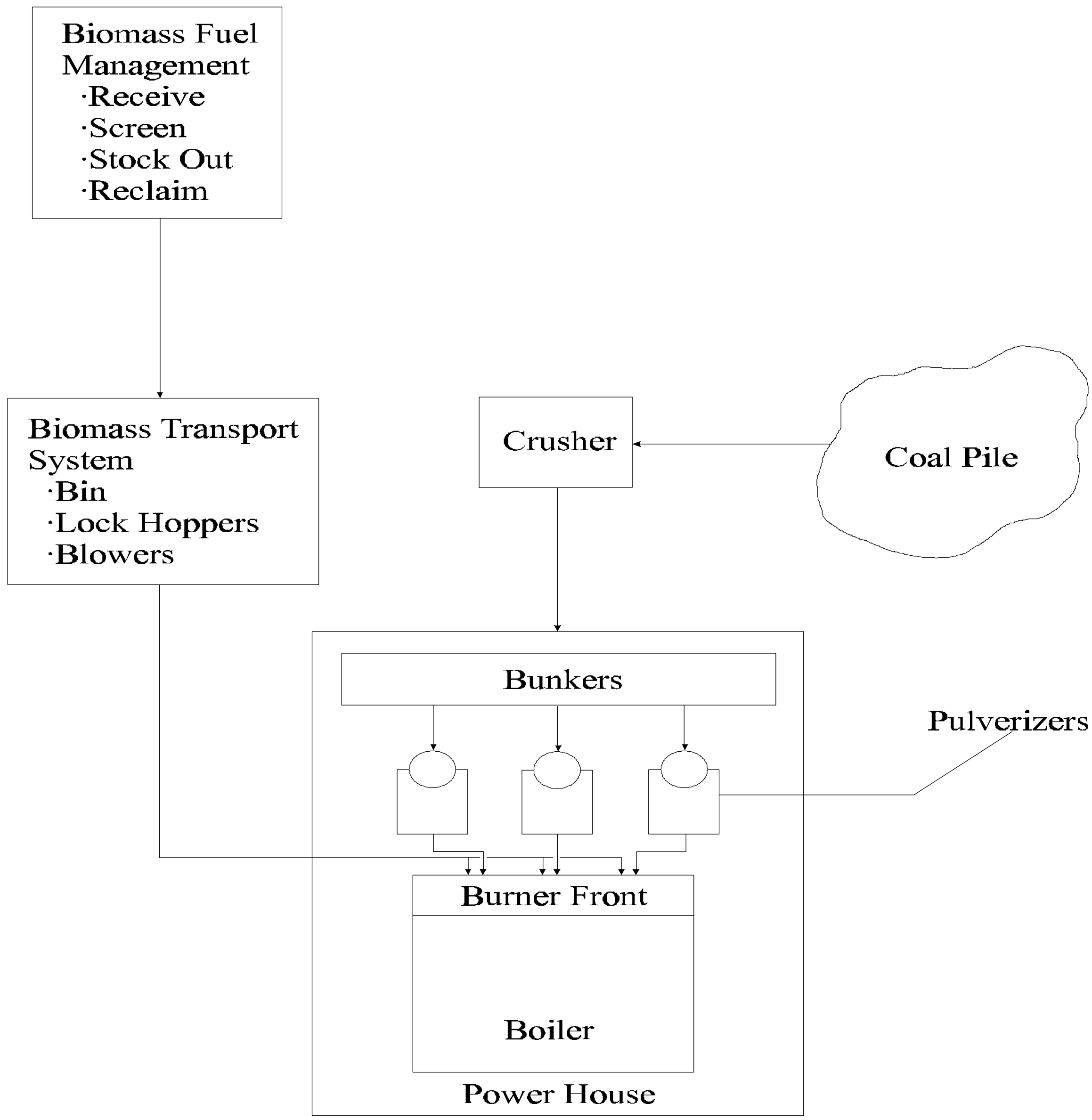

Figure 2. Cofiring With Separate Feeding

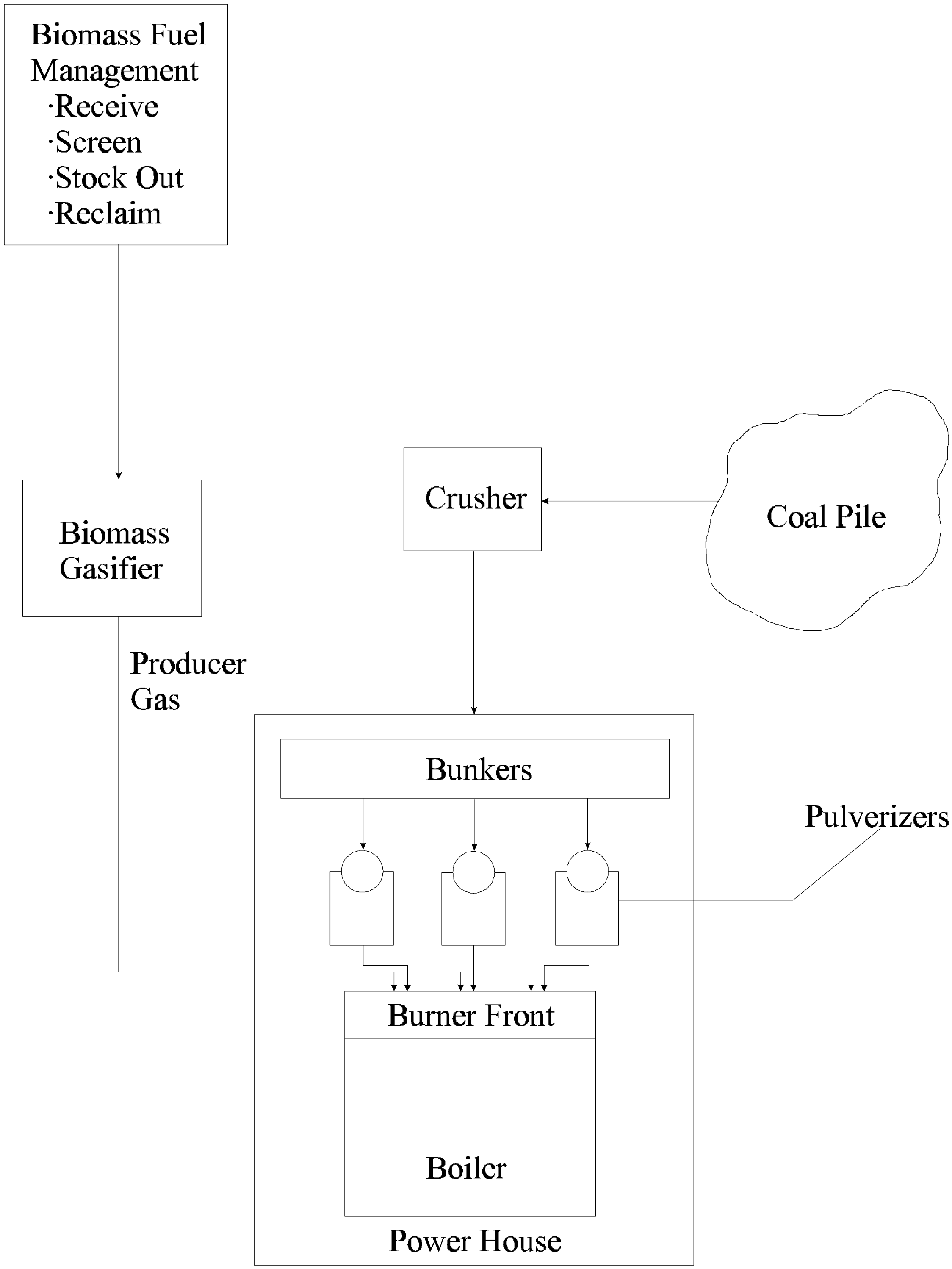

Figure 3. Gasification-based Cofiring

INTRODUCTION

Cofiring has been developed to accomplish the following economic and environmental objectives:

1. Mitigate fossil CO_2 emissions from coal-fired boilers
2. Reduce NO_x and SO_2 emissions from cyclone and PC boilers
3. Provide a mechanism for generating cost-effective green power
4. Provide customer service to utility clients, maintaining loads
5. Increase fuel diversity for utilities

The practice of cofiring is generally considered to be the least cost method for getting utilities into the biomass arena; and biomass is considered to be the most cost-effective solar energy system for cloudy climates. Further, biomass is dispatchable renewable power or "green power." The generation of green power has taken on additional significance. Utilities such as Wisconsin Electric Power Company have issued Requests for Proposals (RFP's) to obtain significant blocks of this power. Other utilities have described green power as a product line for specific customers in a deregulated environment. While many utilities are obtaining their green power by purchase from other entities (including other utilities), an increasing number of integrated utilities are seeking to generate their own green power.

In response to the diverse forces promoting the use of biomass as a fuel for electricity generation, FETC and EPRI have developed a significant program. This program focuses upon cofiring, and also includes related CO_2 capture and disposal projects. Some 16 projects have been developed as part of this program, as summarized below.

1. <u>Combustion Tests at GPU's Seward Plant (30 MWe, PC)</u>

   EPRI and GPU (an EPRI member utility operating the Seward power plant near the Johnstown, Pennsylvania headquarters of GPU's Penelec system) will arrange for other cofunding to augment PETC's cofunding and will conduct a test of mid-level cofiring in a wall-fired PC unit using separate feed for the wood (i.e., not fed through the pulverizers along with the coal, as was done in the recent test cosponsored by PETC, EPRI, GPU and the State of Pennsylvania at Penelec's Shawville plant in November 1995). This program also includes a long-term demonstration of cofiring at the

Seward Generating Station, as a logical extension of the parametric performance testing.

2. <u>Fuel Preparation Tests at NYSEG's Greenidge Plant (100 MWe, PC)</u>

EPRI is cosponsoring New York State Electric and Gas Company (NYSEG) in a test program that focuses on the preparation of wood fuel for cofiring in a tangentially fired PC unit with separate feed for the prepared wood fuel. Size reduction equipment, such as wood "grinders" or hammermills, and drying equipment will be evaluated, and the suitability of the prepared product tested in full-scale com-bustion in the 100 MWe boiler at NYSEG's Greenidge plant. Mid-level, i.e., about 10% by heat, cofiring is planned.

3. <u>Pre-commercial Test Runs at TVA (~200 MWe)</u>

EPRI is cosponsoring the next testing program at TVA, this one being the long-term "pre-commercial" test runs to cofire wood at levels up to 10% by heat, starting at the cyclone plant (Allen) in Memphis, and continuing at one of TVA's pulverized coal plants. This program includes considering gasification as a basis for cofiring, using the producer gas from biomass as additional fuel injected in the primary furnace.

4. <u>Switchgrass Cofiring with Madison Gas & Electric (50 MWe)</u>

EPRI is cofunding the University of Wisconsin at Madison in a test program being conducted by the University and the local utility (Madison Gas and Electric) at MG&E's Blount Street Station, where an existing retrofit to burn refuse-derived fuel (formerly) and shedded paper waste (currently) in a wall-fired PC unit is to be used to conduct the first U.S. test of cofiring switchgrass along with coal in a full-size utility boiler.

5. <u>High-level Cofiring with Southern Company (50 MWe)</u>

Southern Company Services has discussed with EPRI a potential cosponsored project to do long-term testing of high-level (i.e., up to 40% by heat) cofiring of wood with coal, perhaps with some natural gas overfire, in a tangentially-fired PC boiler in Savannah, Georgia. This project would be a follow-up to an initial set of short test runs there in 1993, which indicated that separate feed of this much wood was possible. This test will provide the opportunity to explore the upper limits of cofiring wood with coal in an existing PC boiler.

6. Study and Testing with NIPSCO (~500 MWe, Cyclone)

EPRI is completing a study, cofunded by EPRI and Northern Indiana Public Service Company (NIPSCO), to evaluate the fuel supply and the power plant operations for cofiring wood in a full-size cyclone boiler as one of NIPSCO's voluntary measures to reduce emissions of fossil CO_2 under the Climate Challenge program of the federal government. The next phase, assuming the expected favorable findings that cofiring is a low-cost CO_2 mitigation measure, is to be a cofunded test at, perhaps, NIPSCO's Michigan City plant, where manufacturing process waste wood is the expected source of relatively dry wood already at small size and with potential for a 5% by heat cofiring operation in an urban area outside of the normal wood products regions of the South, Upper Midwest or Pacific Northwest. This program also includes demonstrating the results of cofiring testing, over a longer term, at a NIPSCO cyclone boiler.

7. Switchgrass Test with Nebraska Public Power District

One of EPRI's members, the Nebraska Public Power District (NPPD), has expressed interest in a preliminary evaluation of switchgrass cofiring, an evaluation that can be performed without commitment to a full-size unit test. EPRI has suggested to NPPD an evaluation based on laboratory testing at the Sandia National Laboratory's Combustion Research Facility in Livermore, California. With PETC cofunding this would test the ability of the well-controlled, well-monitored test facility at Sandia to provide data and analysis capable of predicting the potential for the fouling of superheater tubes by the cofiring of high-alkali biomass, namely switchgrass, with coal. Combined with (1) the Madison test (Item 4, above), in which NPPD will participate, and (2) the series of tests done by Sandia on both biomass fuels and coals for DOE, NREL, PETC, EPRI and industry during the past three years, and (3) PETC's in-house testing of switchgrass/coal cofiring at CERF, this new project is expected to reveal the potential and the limits of laboratory testing as a facilitator of decisions on biomass cofiring.

8. Waste Plastics Cofiring with Duke (50-200 MWe, PC)

EPRI, Duke Power Company (Duke), and the National Plastics Council have cosponsored a laboratory test and engineering analysis of the cofiring of clean plastic manufacturing wastes with coal in a PC boiler. The next step is a unit test at full-size in a PC boiler, perhaps at 50 MWe or perhaps up in the 200 MWe range, approximate size. While actual biomass cofiring, i.e., waste wood cofiring, may or may not be part of the first unit tests, this project is important for the future of biomass cofiring because it involves a major investor-owned, coal-firing utility, located in a region of a major wood-products industry as well as major, and changing, agricultural and meat/poultry industries, as well as textile industries. It is an excellent test of waste cofiring justified on purely business grounds (fuel savings and customer service) but with potential to move toward environmental grounds, if warranted.

9. Plastic/Fiber/Pulp Wastes with SCE&G (~100 MWe, PC)

EPRI has discussed possible follow-on testing with South Carolina Electric and Gas Company (SCE&G), tests that would be a follow-on to a test run in 1993 where mixed plastic and wood fiber were fired with coal to determine technical feasibility for disposal of an industrial customer's manufacturing residues. Other residues, consisting primarily, or entirely, of pulp wastes rather than plastic may be tested next. Or, a second test, longer and with more variations, using the same plastic/ fiber residue may be the prime focus. The rationale for this as a biomass cofiring test is similar to that for Duke (a neighboring utility in the same wood industry region), but the scope is more directly on biomass, as well as plastic, as fuel, and the options for boiler retrofit may be different.

10. Urban Wood-Waste Study and Test in Pittsburgh

PETC has suggested that EPRI join an evaluation of the urban wood waste resource in the industrial/commercial/residential region of Pittsburgh and environs. Course, low-cost or no-cost wood wastes would be fired with coal in a stoker boiler at the Bellefield Boiler Plant owned by a consortium that includes the University of Pittsburgh. The University would oversee and monitor a long-term test of low-level (about 2% by heat) cofiring of urban wood wastes (including tree trimmings) together with coal. The key elements of the test would be off-site wood processing, assessment of the urban wood supply and cost by means of actual fuel procurement, and, perhaps, assessment of fines separation and separate cofiring of fines in a normal utility boiler (i.e., PC or cyclone).

11. <u>Toxic Emissions</u>

Both EPRI and PETC have measured trace emissions and effluents from the combustion of coal and from ash resulting from coal combustion. In this new project, EPRI and PETC will combine their respective data sources, test facilities and expertise in an effort to determine the extent of trace emissions or effluents from the cofiring of wood or other biomass wastes with coal. After an evaluation of data on fuels and control processes, including data on fuel chemistry, ash chemistry, emissions, emission control systems, liquid waste streams and solid waste streams, EPRI and PETC will plan and conduct a test to measure and/or predict the emissions, if any, of toxic species that may arise from cofiring bio-mass with coal. This project will explicitly consider a test at the ECTC (Environmental Control Test Center) at the Kintigh power station operated by NYSEG near Buffalo, New York. The best site and fuel combination for a test will be identified and a test will be conducted, if the evaluation indicates that a useful measurement of toxic emissions can be obtained.

12. <u>Fuel/Powerplant Models, Analysis and Interpretation</u>

In order to interpret results from this entire set of projects and to facilitate the transfer of the results to the industry, EPRI will develop a SOAPP ("State-of-the-Art Power Plant") module for evaluating wood cofiring situations. SOAPP already has modules for combustion turbine power systems, and SOAPP modules for conventional utility PC and cyclone plants, and also FBC and coal gasification systems, are under development. By July 1996, the first SOAPP cofiring module will be completed, for natural gas as the cofired fuel in a reburn or other mode. This new project

(No. 12 of the PETC/EPRI cofiring program) will add wood cofiring to SOAPP, and also will add a fuels database capable of putting the properties of each new cofiring fuel into a context for comparison to some 50 other fuels and for prediction of slagging/ fouling/agglomeration potential in comparison to those other fuels. The result will be a model that will make possible the interpretation of test results from all the cofiring experiments in terms of the performance and cost impacts on a state-of-the-art coal-fired powerplant. Currently, but separate from this proposal, EPRI and PETC are cooperating on the EPRI-developed CQIM computer model by doing tests to obtain data on slagging/fouling for blends of coals. This work will be used and expanded under this PETC/EPRI biomass cofiring project. EPRI's fuels database for biomass and other alternative fuel properties (including slagging indices, etc.) will be incorporated into CQIM, SOAPP and other analytical frameworks as appropriate. EPRI's biomass resource assess-ments and tools for developing supply/cost curves will be applied as appropriate to address regional or local biomass resource issues important to PETC.

13. CO_2 Utilization in Algal Systems for Wastewater Treatment

EPRI and PETC have independently done experiments and studies of systems that can take advantage of the high rates of capture of CO_2 by aquatic biological systems such as seaweed (kelp), microalgae (ocean and land-based) and halophyte species (both in water and on dry land). This new project under this PETC/EPRI cofiring project will assess what appears to be one of the few near-term options for an algae-based system to contribute to reductions of CO_2 emissions: the use of CO_2 to speed the growth of algae in water treatment facilities. This approach adds a coproduct value, namely the improved performance of the water (i.e., sewage) treatment plant, that may make the system one of the low cost options for near-term CO_2 mitigation. Two forms of fossil CO_2 reduction are involved: (1) capture of CO_2 into a biomass form, i.e., a process similar to carbon sequestration in forest biomass, but in this case coupled directly to use of a CO_2-enhanced stream like powerplant fluegas; and (2) replacement of a fossil fuel by a biomass fuel, as the algae grown with the enhanced CO_2 stream replace fossil fuel, i.e., a process similar to the CO_2 recycling inherent in all uses of biomass fuels replacing fossil fuels.

14. Combustion Tests and Combustor Development

EPRI and TVA have sponsored an initial assessment of slagging combustion as a way to use high-alkali biomass as fuel in power generation without having to solve the problems associated with gas cleanup to meet the purity required by the gas turbines in biomass gasification combined cycle power systems. PETC has completed the first in a planned series of bench-scale tests of the cofiring of high-alkali fuels with coal in CERF (Combustion Environment Research Facility) at PETC. This new project in the PETC/EPRI cofiring program will use test systems at PETC to obtain data to predict performance and guide design for use of high-alkali biomass fuels in mid- to high-level fractions (approximately 20% to even 100% of the heat into a coal-fired power system). The new project will start with follow-up design and fuel/ash studies that apply and interpret relevant work already completed. Tests will be planned and performed as appropriate, in accord with assessments and plans prepared by EPRI and PETC staff and contractors, and in accord with an implementation plan approved by PETC.

15. Ash Sales

An immediate barrier to the cofiring of biomass with coal in existing coal-fired powerplants is the potential that the flyash from the cofired operation of the plant will not be purchased by the cement industry, which is now the best market for flyash from coal-fired utility boilers. This project will develop and communicate an action plan that will enable a cement industry standards board to make as early as possible a finding that cofired ash is acceptable for purchase from utility powerplants.

16. CO_2 Capture and Disposal

This project will conduct a series of feasibility studies of various pro-posed options for capture and disposal of carbon dioxide from U.S. coal-fired power plants. Consideration will be given to both land and ocean-based disposal options in an effort to determine which options would be most amenable to fossil carbon sequestration for both existing and future U.S. power generation capacity. This effort will build on the results of studies previously performed by the International Energy Agency (IEA) Greenhouse Gas Research and Development Program with joint DOE and EPRI funding.

TECHNICAL PROGRESS

Project 1 – Combustion Testing at the Seward Generating Station

The combustion testing demonstration program at the Seward Generating Station experienced significant progress during the seventh quarter. A materials handling design was developed for the facility, as described below.

Design Basis For The System

The design basis for the biofuel injection system includes the following:

- The battery limits for the system are from truck receiving of the biofuel to the Unit #12 furnace front wall burner ports.
- Interface points between this system and the existing plant include the burner ports, electrical power feed from the station, boiler feedback control signals, and the station's service air system.
- The biofuel injection feed rate must have a capacity of 5 tons/hr.
- the biofuel can only be fed when the unit is operated above 50% of capacity, or when the flame scanners do not cause a boiler trip when cofiring wood waste and coal
- The system must be controlled from the existing boiler control room, with local controls for start up and shut down.
- The fuel receiving/processing area must provide for dust management.

Given that design basis, Foster Wheeler Development Corporation and its sister company, Foster Wheeler Energy Services, have developed a design for implementing the biomass initiative of Seward Station, as described below:

Biofuel Receiving, Processing And Storage

Biofuel is delivered by truck to the biofuel processing area. There is no provision for a truck dump; trucks supplying fuel must be self-unloading walking floor vans.

A fuel barn, constructed as a pole barn, approximately 120 ft. x 70 ft. x 18 ft. high (wall height) houses a POWERSCREEN Model 615 truck-mounted trommel screen with receiving hopper and conveyor, and a receiver bin with rotary airlocks and fan for pneumatic transfer of the biofuel to storage.

The trommel screen is electric powered and has a capacity to process 10-15 tons per hour of biofuel screened to a ¼” to 0 size. Rejected material is conveyed to a dumpster for disposal.

Storage is accomplished in a HARVESTORE brand glass-lined silo 25 ft. diameter x 55 ft. high, which will enable a 2-day storage capacity to be attained. This silo is equipped with a top mounted cyclanet for dust control, with a bin vent filter located at ground level for easy access for maintenance. The cyclone is also equipped with a bottom of pile reclaim system, or discharge auger.

Biofuel Injection

Biofuel is removed from the storage silo by a discharge auger, which transfer the fuel onto an incline conveyor. This conveyer in turn dumps the fuel into a surge bin designed for a 2-hr storage capacity.

Biofuel then flows onto a THAYER Model MD-48TM.1 weigh belt feeder for accurate control of the feed rate. The weigh belt feeder dumps the regulated amount of biofuel into an injection vessel for pneumatic transfer to the Unit #12 furnace.

The injection vessel is a surge bin capable of holding 20 minutes of fuel. It is equipped with three metering screws at the bottom of the bin. Each screw feeds a rotary airlock which transfers the biofuel to pressurized pneumatic lines.

Pneumatic transfer occurs by way of three separate 3” pipes, each served by independent rotary airlock and blower. The blowers are sized to supply a constant stream of air, ~290 actual cubic feet/minute (ACFM) to the boiler. This stream of air equates to a fuel velocity at the burner tip of 5,000 ft/min. This speed exceeds the flame speed of woody biomass. The biofuel enters the Unit #12 furnace through each of three existing front wall burner ports.

This system, then, provides for separate feeding of the biomass to the Seward #12 boiler. This feeding is accomplished using the existing interface between the wood waste handling system and the existing coal burners. The interface consists of firing the wood down the

3” centerpipe of the burners. The sawdust is then diffused into the coal flame as shown in Figure 4.

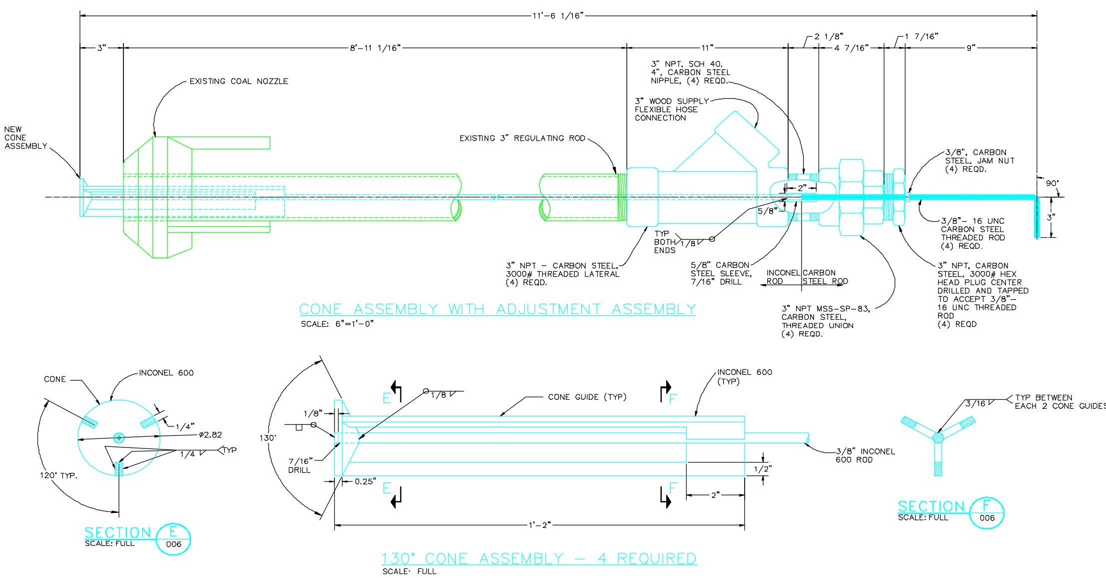

Figure 4. Seward Wood Waste Injection System.

Because the biofuel is injected into the center of the coal flame, it creates conditions supporting early ignition of the coal while decreasing the stoichiometric ratio at the point of fuel injection. This technique is essential to the optimization of biomass firing at the Seward site.

Project 2 – Fuel Preparation Tests at Greenidge Generating Station

The cofiring program at Greenidge Generating Station proceeded as commercial activity during this quarter.

Project 3 – Precommercial Testing and Gasification Investigation at TVA Fossil Plants

Foster Wheeler Development Corporation conducted conceptual design studies for implementing gasification-based cofiring at the Allen Fossil Plant of TVA. Gasification-based cofiring was viewed as the second generation cofiring technology.

Gasification Rationale

The rationale for gasification-based cofiring, demonstrated by Foster Wheeler at the Lahti project in Finland, is presented below.

In the gasification approach, coarse biofuels are processed in a thermal gasifier, with the product being fired in a boiler or other application. The gas may be unconditioned and fired at elevated temperatures (e.g., 1,000°F - 1,600°F). If conditions require, the gas may be cleaned and partially quenched prior to use. Gasification-based cofiring has numerous inherent advantages. It increases the market potential of biomass cofiring. Not only is it applicable to both PC and cyclone boilers, but it is also applicable to many natural gas-fired boilers. If used in conjunction with a duct burner between a combustion turbine and a heat recovery steam generator (HRSG) it is applicable to combined cycle technology as well.

If this technique is used in coal-fired boilers, then separate gas burners are required. Similarly, if this technique is used in natural gas-fired boilers, separate burners designed for low Btu gas would be necessary. Air-fuel ratios for natural gas combustion and for low Btu gas combustion are sufficiently different, and gas volumes are sufficiently different, to make this adjustment necessary.

The concept of gasification-based cofiring has the potential to accomplish the following objectives for boiler cofiring:

- Maintain the ability to increase boiler capacity when firing wet coal by adding more Btu's to the feed to the primary furnace

- Minimizes the particle size reduction requirement for the biofuel as produced, with gasifiers typically capable of using ¾" x 0" particles, rather than the ¼" x 0" particles associated with cofiring

- Broadens the range of biofuels that can be successfully cofired with coal or with natural gas, including the use of zero cost and negative cost fuels

- Permits deployment with natural gas-fired reburn systems for possible dramatic NO_x reductions (e.g., >50 percent).

- Minimize efficiency losses in the boiler by taking those moisture-related losses in the gasifier

- Continuing the reduction of emissions by reducing the sulfur content of the fuel, modifying the operating combustion mechanism with gas firing for NO_x control, and reducing the impact of cofiring on opacity

- Keeping the biofuel ash separate from the coal ash by gasifier design, thereby protecting the ability of the plant to make ash sales.

Gasification-based cofiring has not been practiced in the USA However it is the basis for the Lahti project in Finland, where a fluidized bed gasifier accepts solid biofuels, produces a hot and unconditioned gas, and fires that gas in a PC boiler. Gasification, then, can be viewed as a material preparation technique for PC boilers.

Equipment Selection

The gasification conceptual design studies evaluated fixed bed gasification, entrained flow gasification, and fluidized bed gasification. Four types of gasifiers were evaluated as discussed below.

Four primary types of biomass-gasification reactor systems have been developed: fixed bed reactors, bubbling-fluid bed reactors, and entrained flow reactors. Gasification reactors operate under much of the same principles as comparable combustors. Following this review, gasification system selection was performed.

Updraft Fixed Bed Gasifiers

The simplest air gasifier is the updraft (counterflow) gasifier, in which air is introduced to the biomass through grates in the bottom of the shaft furnace. Rather high temperatures are generated initially where the air first contacts the char, but the combustion gases immediately enter a zone of excess char, where any CO_2 or H_2O presented is reduced to CO and H_2 by the excess carbon. As the gases rise to lower temperature zones, they meet the descending biomass and pyrolyze the mass in the range of 400 F to 900 F. Continuing to rise, they contact wet, incoming biomass and dry it. The counterflow of gas and biomass exchanges heat so that the +gases exit at low temperatures.

Simplicity is a major advantage of these systems, and countercurrent gasification has long been employed both for biomass and coal. The original Lurgi gasification system is an updraft gasifier. However, the updraft gasifier has several drawbacks. It requires a feedstock that is relatively coarse. Further, the gasification zones, while maximizing mass transfer, produce a gas sufficiently low in temperature to contain a wide variety of chemicals, tars, and oils produced in the pyrolysis zone. Because of the low gasifier exit temperatures, these can be allowed to condense in cooler regions. Alternatively, the producer gas can be partially oxidized to elevate its temperature above the tar condensation region. For this reason, this gas is generally used in the "close-coupled" mode in which it is mixed immediately with air and burned completely to CO_2 and H_2O. The close-coupled mode is quite suitable for supplying a biomass gas to existing coal, oil or gas furnaces. The high temperature at the grate may melt the ash and produce slagging on the grates with feedstocks such as rice hulls and corn cobs. Indeed, in the Andco-Torrax solid municipal waste (SMW) gasifier, the incoming air is preheated to give slagging temperatures on the grate, which then convert the high mineral content of SMW to a clean glass fit that can be used in road building. The Purox™ process of Union Carbide used oxygen to achieve sufficiently high temperatures (e.g., 3,000^{o}F) to melt minerals.

Primenergy, of Tulsa, OK, currently is a leading supplier of updraft or countercurrent gaisifers. They have been applied to a wide variety of biofuels including wood waste, rice hulls, switchgrass, and other products. They have been installed in a variety of applications throughout the world, including a significant number of cogeneration applications.

Downdraft Fix Bed Gasifiers

The downdraft (co-flow) gasifier is designed specifically to eliminate the tars and oils from the gas. Air is introduced to the gasifier through a set of nozzles called "tuyeres" and the products of gasification are reduced as they pass through a bed of hot charcoal, where they are cracked to simpler gases or char. An important result of this cracking is an effect called "flame stabilization" in which the temperature is maintained in the range from 1500 F to 1800 F by these cracking reactions. If the temperature tends to rise, the endothermic reactions predominate, thus cooling the gas. If the temperature drops below this range, the exothermic reactions predominate, keeping the gas hot.

The tars and oils are reduced to less than 10% of the value produced in updraft gasifiers, and these gases can then be used with minimal filtering. Typically, the gas velocities are low in updraft and downdraft gasifiers, and the ash settles through the grate, so that very little is carried over with the gas.

Downdraft gasification was prominent in Europe before and during World War II, when up to 1 million cars, trucks, buses, and tractors were fueled with producer gas from such devices. The capacity of these systems is limited by the grate, and the need to draw the product gas through the incandescent char bed. Further, the gasification system relies upon the bulk of its fuel being coarse particles. Cocurrent gasification lends itself to small systems.

Twin-Fire Gas Producer

The advantage of co-current and counter-current gasifiers are combined in a so called twin-fire gasifier. It consists of two defined reaction zones. Drying, low temperature carbonization, and cracking of gases occur in the upper zone, while permanent gasification of charcoal takes place in lower zone. The gas temperature lies between 860 to 968° F. Twin-fire gasifier produces fairly clean gas.

Crossdraft Gas Producer

Crossdraft gas producers, although they have certain advantages over updraft and downdraft gasifiers, they are not of ideal type. The disadvantages such as high exit gas temperature, poor CO_2 reduction and high gas velocity are the consequence of the design. Unlike downdraft and updraft gasifiers, the ash bin, fire and reduction zone in crossdraft gasifiers are separated. This design characteristics limit the type of fuel for operation to low ash fuels such as wood, charcoal and coke. The load following ability of crossdraft gasifier is quite good due to concentrated partial zones which operates at temperatures up to 3600° F. Start up time (5-10 minutes) is much faster than that of downdraft and updraft units. The relatively higher temperature in the crossdraft gas producer has an obvious effect on gas composition such as high carbon monoxide, and low hydrogen and methane content when dry fuel such as charcoal is used. Crossdraft gasifier operates well on dry air blast and dry fuel.

Fluidized Bed Gasifiers

Fluidized beds have been developed over the last few decades to provide uniform temperatures and efficient contact between gases and solids in process industries. Because of its higher throughput, it is more compact, but the higher velocities carry the ash and char out with the gas and they must be separated in cyclones or bag houses.

Fluidized beds usually contain either inert material (such as sand) or reactive material (such as limestone or catalysts). These aid in heat transfer and provide catalytic or gascleaning action. The material is kept in suspension, simulating a "fluid," by a rising column of gas. In a true fluidized bed, the solids mix very rapidly and provide high heat transfer between all parts of the bed. In "spouted" beds and other modified gasifiers, there may be temperature gradients established and less mass exchange between the lower and upper parts.

Fluidized bed technology represents the most advanced gasification technology today, significantly outperforming fixed bed gasifiers in several areas: fuel flexibility, excellent combustion efficiency, minimum emissions, excellent heat transfer, and maximum throughput. Two basic designs are used today, the circulating fluidized bed (CFB) and the bubbling fluidized bed (BFB). As the unit size grows the CFB's better performance becomes clearly apparent. Since the entire bed is circulating though the gasification zone, CFB offer the best mixing performance and the longest particle residence times. In contrast, as the BFP bed diameter grows, complete and uniform fluidization becomes more and more difficult.

Gasification Technology Selection

The gasification technology selected for the conceptual design studies was the fixed bed updraft gasifier of Primenergy. This gasifier provided simplicity, U.S. experience, and cost advantages essential to a project where gasification is used as an alternative to extensive materials preparation—essentially as a means for increasing the fuel supply base and thereby decreasing the cost of biofuels to the Allen Fossil Plant.

Following technology selection, conceptual design studies commenced on implementing gasification at the Allen Fossil Plant.

Project 4 – Switchgrass Testing at Blount St. Station of Madison Gas & Electric

No activity occurred on this project.

Project 5 – High Percentage Cofiring with Southern Company

No activity occurred on this project.

Project 6 – Cofiring Testing at Michigan City Generating Station of NIPSCO, and Demonstration of Cofiring at that utility

During the Seventh Quarter of the FETC/EPRI contract, a program plan was developed for NIPSCO in implementing its demonstration of firing biomass with petroleum coke and coal at Bailly Generating Station, #7 boiler. The essential elements of the program are summarized below.

Utilities such as NIPSCO have considered cofiring for several of these reasons. Cofiring of biomass with coal becomes a technology that may have immediate potential; alternatively it may be considered as a ***bankable technology,*** positioning NIPSCO to meet the needs of such concepts as the portfolio standard or CO_2 regulations when or if they become law.

The fundamental elements of the program include:

- Engineer, procure, and construct modifications to the generating station materials handling system; these modifications include a trommel screen and blending area to mix the opportunity fuels, an apron reclaim conveyor and an associated 400 ton/hr opportunity fuels reclaimer and conveyor to mix the wood waste and petroleum coke and to blend such fuels with the coal
- Perform 2 – 3 weeks of baseline (coal only) tests at full load, minimum load, and various operating conditions typically experienced by the unit. Baseload tests will be performed using only coal. Typically the unit will run at 2.8% O_2 (dry basis) with an air heater inleakage of about 7% and with an air heater exit temperature of 300°F. These tests will provide performance data about the boiler focusing upon the following parameters
    - main steam pressure, temperature, and flow
    - feedwater pressure, temperature, and flow
    - cold and hot reheat pressure and temperature
    - fuel and air flows to each cyclone (if possible)
    - air distribution within each cyclone (if possible)
    - economizer exit temperature
    - air heater exit temperature
    - gas composition (O_2, CO_2) entering and leaving the air heater
    - airborne emissions data including SO_2 and NO_x

The program will also include sampling of all of the fuels being burned, sampling the slag from the cyclones to determine partitioning and speciation of vanadium and nickel as a means for measuring the relative changes associated with petroleum coke firing, sampling the flyash from the plant to determine the concentration, fate and partitioning of vanadium and nickel during combustion, and the impact of this biomass initiative on unburned carbon in the flyash. Temperatures may also be measured using optical pyrometry if appropriate locations can be identified. Sampling of the gypsum produced will be used to measure and determine the impact of the biomass initiative on gypsum quality and the gypsum specification, and other tests as defined. All of these test initiatives will commence with baseline testing.

The data will be analyzed using heat and material balance calculations about the boiler #7. Further, the data will be analyzed using the Foster Wheeler cyclone model developed for EPRI to evaluate local stoichiometries, residence times, temperatures, and combustion completeness. These calculations will address the baseline conditions with respect to capacity, efficiency, and emissions. There may be additional testing by Federal research laboratories concerning deposition and corrosion. Currently we are discussing their fabrication of probes to measure such phenomena. Successful discussions will lead to this aspect of cofiring testing.

- Perform 3 – 4 weeks of testing with petroleum coke to determine the influence of this fuel on boiler capacity, efficiency, and emissions. The control room and stack data identified above will be taken during the petroleum coke cofiring tests. The samples of fuel, bottom ash (slag), flyash, and gypsum will be taken. Temperatures will be measured if appropriate. Deposition and corrosion will also be measured depending upon the activities of the Federal laboratories.

  Testing with the petroleum coke will be based upon a range of mass ratios of opportunity fuel and coke. The original ratio will be 10% petroleum coke/90% coal. That ratio will rise until it reaches 30% petroleum coke/70% coal or until other problems set limits for the blend. Such other problems could include impacts on emissions or on the gypsum quality.

Four distinct blends will be used, varying the percentage of petroleum coke in the blend.

Testing with the petroleum coke will be designed to elucidate the specific influences of this opportunity fuel on cyclone combustion. Further, it will be designed to identify changes in combustion conditions that are required for optimum use of petroleum coke.

- Perform 3 – 4 weeks of testing with urban wood waste (sized to ½" x 0") to determine the influence of this fuel on boiler capacity, efficiency, and emissions. The control room and stack data identified above will be taken during the biofuel cofiring tests. The samples of fuel, bottom ash (slag), flyash, and gypsum will be taken. Temperatures will be measured if appropriate. Deposition and corrosion will also be measured depending upon the activities of the Federal laboratories.

  Testing with the wood waste will be based upon a range of mass ratios of opportunity fuel and coke. The original ratio will be 5% wood waste/95% coal. That ratio will rise until it reaches 15% wood waste/85% coal or until other problems set limits for the blend. Such other problems could include impacts on capacity, efficiency, or on the gypsum quality. At least 3 distinct blends will be used, varying the percentage of wood waste in the blend.

  Testing with the wood waste will be designed to elucidate the specific influences of this opportunity fuel on cyclone combustion. Further, it will be designed to identify changes in combustion conditions that are required for optimum use of wood waste.

- Perform 3 – 4 weeks of testing with urban wood waste (sized to ½" x 0") and petroleum coke at various blend percentages to determine the influence of various fuel mixtures on boiler capacity, efficiency, and emissions and fuel prices (in $/MWh generated). The control room and stack data identified above will be taken during the combined biofuel/petroleum coke opportunity fuel tests. The samples of fuel, bottom ash (slag), flyash, and gypsum will be taken. Temperatures will be measured if appropriate. Deposition and corrosion will also be measured depending upon the activities of the Federal laboratories.

Testing with the wood waste and petroleum coke will be based upon a range of mass ratios of opportunity fuel and coke. The original ratio will be 5% wood waste/10% petroleum coke/85% coal. It will be followed by 10% wood waste/10% petroleum coke/80% coal. That will be followed by 5% wood waste/15% petroleum coke/80% coal and finally 10% wood waste/20% petroleum coke/70% coal. That ratio will rise until it reaches 20% petroleum coke/80% coal or until other problems set limits for the blend. Such other problems could include impacts on emissions or on the gypsum quality. Four distinct blends will be used, varying the percentage of wood waste in the blend.

Testing with the wood waste and petroleum coke—combined as a single opportunity fuel—provides a unique perspective on the use of biomass. While biomass is expected to help with emissions, petroleum coke provides economic support for the project. This phase of the activity will be designed to elucidate the optimum opportunity fuel blend and to define specific influences of this opportunity fuel on cyclone combustion. Further, it will be designed to identify changes in combustion conditions that are required for optimum use of wood waste with petroleum coke.

- Based upon the testing, coupled with modeling and economic calculations, select an optimum blend for long-term testing. This long-term optimum blend will be calculated and selected based upon the following parameters:
  - Overall fuel cost
  - Fuel availability
  - Overall emissions (including influence on the plume color, influence on NO_x emissions)
  - Combustion influences including temperature profiles
  - Gypsum quality influences

This blend selection will be a total team effort of NIPSCO and Foster Wheeler personnel, recognizing that the participants in this selection will be Bailly Station personnel, Fuels personnel, Engineering personnel, Environmental personnel, and FWDC personnel. Other participants such as FETC and EPRI may be consulted, and may be used in an advisory role.

- Once the final blend has been selected, it will be fired in Bailly #7 boiler for a 6-month period. During this period, both periodic testing and long term testing will occur. Additionally, data will be taken on-site concerning long-term operational aspects of this opportunity fuels approach to biomass utilization. Such issues include:
  - Influence of cofiring on capacity and efficiency over time
  - Influence of opportunity fuels on sootblowing schedules
  - Influence of opportunity fuels on plume characteristics [if any]
  - Influence of opportunity fuels on long term slagging, fouling, and corrosion [if any]
  - Other influences as appropriate

  The testing will occur over the full load range at Bailly #7 boiler. Further, it will occur during 3 of the 4 seasons of operation: late winter, spring, and summer. NIPSCO, working with FWDC, has the right to change the blend after 3 months if experience and calculations demonstrates the desirability of such a change. This change will be made in consultation with EPRI and with USDOE personnel. Such a change could be caused by positive or negative influences on the Bailly plume.

- As a part of this program there will be a series of topical reports including the following:

  - Quarterly reports
  - Report concerning baseline testing
  - Report concerning petroleum coke testing
  - Report concerning wood waste testing
  - Report concerning blended fuel [blend selection] testing
  - Final report focusing upon long-term testing

Overview of Test Methodologies

The test methodologies for the initial tests are distinguished from the test methodology for the 6-month test. All of these methodologies, however, are based upon known approaches to boiler performance issues.

General Constraints on Testing

There are certain general constraints on testing at the Bailly Generating Station site. These constraints include the following:

- The need to fire at least 70% of the base fuel as coal
- The questionable reliability of the computer data acquisition system currently installed at the plant, particularly with attention to the ability to obtain data over long periods of time
- The presence of a common stack for boilers #7 and #8, making use of CEMS data, by itself, less than acceptable for evaluating emissions
- The need to operate the plant with a high availability and a high capacity factor
- The use of bucket blending for opportunity fuels mixing on-site at the Bailly station

The test methodology has been developed recognizing these inherent limitations.

Test Methodologies for short term testing

The general format for tests conducted at the Bailly Generating Station involves the following activities:

- opportunity fuels are prepared for blending with the coal
- samples of wood, petroleum coke, and coal are obtained for analysis
- a blend is selected, the opportunity fuel is loaded through the Stamler feeder/reclaim hopper to be mixed with the coal at the crushers, and then the blend of fuel is loaded into the bunkers for testing
- testing will occur over a 1-week period for any blend; during the first two days data will be taken to evaluate operational considerations, but it is recognized that the boiler and bunkers will be adjusting to the changed feed [this does not occur during baseline testing]. Data from days 3-6 will be used for mathematical calculation of impacts on capacity, efficiency, emissions, and other parameters.
- During the testing on any given day, a 3 to 6 hour window of time is selected for test purposes, based upon ensuring that the target fuel is being fed from the bunkers through the stock feeders to the cyclones, based upon selecting a stable load [e.g., minimum load tests will typically be conducted

between 3:00 AM and 7:00 AM] and firing condition to be maintained by the plant

- During the testing, a Testo™ apparatus and probe will be used for combustion products calculation with the instrumentation being used at both the entrance and exit of the air heater. The Testo™ will be used to determine flue gas composition at each location. This probe will determine flue gas composition including CO_2, O_2, SO_2, NO_x, and related gaseous components. The determinations will be made by traversing the duct at Boiler #7. They will be made on a dry basis. Such instrumentation will be used to measure air heater in-leakage as well as emissions on a $lb/10_6$ Btu basis.

- Data are acquired during the test period, sufficient to evaluate the impacts of the cofiring blend, along with samples of the fuel blend and samples of the flyash and slag with both electronic and manual data being used; fuel and ash samples will be analyzed by Foster Wheeler Development Corporation laboratories.

- Data are analyzed to determine the outcome of any blend during any firing condition

The data acquired for analysis include information from the coal yard along with readings from the control room and testing at the air heater entrance and exit. The data from the coal yard relate to the handling systems associated with the wood waste. They provide insights into appropriate equipment, equipment operation, and such concerns as energy required for processing and transporting biofuel. The data acquired from the control room and from the air heater exit are used to measure boiler and plant performance directly.

Analytical and Calculation Techniques

Given the multiple data sets, several analyses will be performed. Heat and material balances will be created about Bailly station #7 boiler, using standard methodologies:

1. calculate the heat transferred to main steam and reheat steam using existing NIPSCO data for the flow of reheat steam at Bailly #7 boiler;
2. calculate the losses in the flue gas (including air heater inleakage), flyash, bottom ash, and the fixed losses;

3. calculate the fuel flow based upon the losses calculation and based upon the ultimate analyses and heating value determinations for the fuel; and

4. calculate closure based upon comparison of the O_2 data between the plant instrumentation and the Testo™ instrumentation and the plant instrumentation, and by comparing measured heat rates to expected and published heat rates for the unit. Closure will also be calculated by comparing calculated fuel flows to measured fuel flows.

The heat and material balance equations used by Foster Wheeler are designed to calculate, in sequential order:

1. The heat required by the boiler as a function of feedwater, main steam, and reheat steam pressures, temperatures, and flows; and attemporator flows;
2. The efficiency of the boiler based upon flue gas temperatures and compositions, fuel compositions, slag characteristics and flows, ash characteristics and flows, and air heater in-leakage
3. The fuel required to generate the heat produced in the form of useful steam to the turbine, with the calculated fuel flows being compared to measured fuel flows

It is recognized that the efficiencies calculated will be “relative” efficiencies, used to determine differences achieved by using various opportunity fuel blends. There will be no effort to perform a detailed ASME Power Test Code efficiency measurement; such an effort is beyond the scope of this analysis.

Following the construction of heat and material balances, the data obtained will be used to evaluate emissions formation, and other parameters. Combustion modeling, using the cyclone spreadsheet model developed by Foster Wheeler, will also be used as an analytical tool to evaluate the impacts of wood waste, petroleum coke, and coal in various combinations. Should USDOE laboratories provide deposition probes, the influence of the biomass initiative on slagging and fouling will also be analyzed.

Source Testing

In addition to the testing described above, Foster Wheeler will contract with a stack testing firm to measure the impacts of firing at full load on the following parameters, at a minimum:

- particulates

- NO_x
- SO_2
- SO_3
- CO

Source testing will be performed on a baseline test, on a single petroleum coke/coal test, on a single biomass/coal test, and on one test of the target 3-fuel blend. Such testing will provide a basis for measuring the incremental impacts of various fuel blends.

Metal Partitioning and Speciation

The critical metals to be evaluated are vanadium and nickel, found in petroleum coke. Anecdotal evidence from other testing at other plants suggests that the vanadium and nickel preferentially report to the slag, rather than the flyash. Further, such evidence suggests that the speciation of vanadium to V_2O_5 (a corrosion concern) or more benign oxidation states results from the concentration of unburned carbon in the flyash. This critical issue for use of petroleum coke will be addressed during these tests.

Samples of the flyash and slag will be obtained during the testing of the petroleum coke/coal blends, and during the testing of the biomass/petroleum coke/coal blends. These samples will be analyzed in Foster Wheeler laboratories to measure the concentrations of V and Ni in the flyash and slag. Splits of these samples will be sent to Hazen Research for microprobe testing. Microprobe testing will be used to evaluate the speciation of the two metals identified above. If appropriate, XPS (ESCA) analysis also may be used to evaluate the oxidation state(s) of these metals.

Outcomes of the Short Term Testing

The short-term testing—allocating approximately one month for the baseline, a second month for the petroleum coke cofiring, a third month for the wood waste, and a fourth month for the blended opportunity fuel—provides the basis for selecting a blend for long term testing. At the same time it provides key insights into the specific influences of each fuel, and the synergies among fuels, that can be manipulated for maximum benefit in long-term testing and operation at the Bailly station.

Test methodologies for long term testing

There are several aspects to the long term testing:

- performance of periodic short term tests which, when taken together, will establish trends in unit behavior

- acquisition of statistical data concerning fuel consumption, electricity generated, etc.
- acquisition of operational characteristics (e.g., sootblowing schedules)
- acquisition of slagging and fouling data, if supported by Federal laboratories

Project 7 – Testing Cofiring of Switchgrass by Nebraska Public Power District/Sandia

No activity has occurred on this project

Project 8 – Waste Plastics Cofiring at Duke Power

No activity has occurred on this project

Project 9 – Plastics/Fiber/Pulp Waste Cofiring with SCE&G

No activity has occurred on this project

Project 10 – Urban Wood Waste Cofiring in Pittsburgh, PA

No activity has occurred on this project

Project 11 – Toxic Emissions from Cofiring Evaluation

No activity has occurred on this project

Project 12 – Fuel/Powerplant Model Development

Foster Wheeler Development Corporation continued its work on the cyclone spreadsheet model. The basic modeling was complete. FWDC is now progressing on a users guide for the model.

Foster Wheeler Development Corporation continued its assessment of the feasibility of cofiring at the Central & Southwest Generating Stations: Northeastern #3 and Pirkey. Fuel surveys were completed for the Northeastern #3 and Pirkey stations. The fuels data indicated sufficient availability of wood waste to obviate the need for more problematic biofuels. The fuels data also included an analysis of poultry litter supplied by C&SW. The poultry litter exhibited 0.77% Cl on a dry basis, and that number is sufficiently high to warrant corrosion concerns. Because of the availability of wood waste and the corrosion potential of poultry litter, the latter fuel was excluded from further study.

Project 13 – CO_2 Utilization in Algal Systems

No activity occurred during this quarter.

Project 14 – Combustion Tests and Combustor Development

No activity occurred during this quarter.

Project 15 – Support for Ash Sales from Cofiring Plants

No activity occurred during this quarter.

Project 16 – CO_2 Capture and Disposal Options

Battelle Memorial Laboratories completed its report on this issue.