FETC/EPRI BIOMASS COFIRING COOPERATIVE AGREEMENT

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ABSTRACT

Cofiring is considered to be the most promising near-term approach to fossil CO₂ emissions mitigation through biomass usage. Consequently FETC and EPRI have entered into a cooperative agreement: “Cofiring Biomass and Waste-Derived fuels in Electric Utility Coal-Fired Boilers.” This agreement supports sixteen (16) EPRI research projects, each contributing to the commercialization of systems to address greenhouse gas emissions. These projects include: 1) cofiring combustion testing at the Seward Generating Station of GPU Genco; 2) fuel preparation testing at the Greenidge Generating Station of NYSEG; 3) precommercial testing of cofiring at the Allen and Colbert Fossil Plants of TVA; 4) testing of switchgrass cofiring at the Blount St. Station of Madison Gas & Electric; 5) high percentage biomass cofiring with Southern Company; 6) urban wood waste cofiring at the supercritical cyclone boiler at Michigan City Generating Station of Northern Indiana Public Service Co. (NIPSCO); 7) evaluation of switchgrass cofiring with Nebraska Public Power District at Sandia National Laboratories in Livermore, CA; 8) waste plastics cofiring with Duke Power in a tangentially-fired pulverized coal (PC) boiler; 9) cofiring a mixture of plastics, fiber, and pulp industry wastes with South Carolina Electric and Gas; 10) urban wood waste cofiring evaluation and testing by the University of Pittsburgh in stoker boilers; 11) assessment of toxic emissions from cofiring of wood and coal; 12) development of fuel and power plant models for analysis and interpretation of cofiring results; 13) analysis of CO₂ utilization in algal systems for wastewater treatment; 14) combustion testing and combustor development focusing on high percentage cofiring; 15) analysis of problems and potential solutions to the sale of flyash from coal-fired boilers practicing cofiring; and 16) analysis of CO₂ capture and disposal systems.

During the second quarter of this contract, from January 1, 1997 through March 31, 1997, significant progress has been made on these projects. This progress focuses upon analysis of data from the cofiring tests, construction of systems to promote additional cofiring tests, and initiation of tasks evaluating alternatives to cofiring.

This report contains a brief description of the progress made during the second quarter of the contract, focusing upon test results from the Seward Generating Station, where parametric testing at a wall-fired PC boiler was used to evaluate cofiring using separate feeding of wood and coal to the energy generation system.

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EXECUTIVE SUMMARY

The practice of cofiring, which is an extension of fuel blending and switching, offers utilities with coal-fired boilers a technique for reducing fossil CO₂ emissions with low capital and operating costs; it is a low-cost greenhouse gas mitigation measure for utilities that own and operate baseload pulverized coal (PC) and cyclone boilers. Numerous utilities have evaluated, tested, and engineered cofiring systems including (not exhaustive) the Tennessee Valley Authority, New York State Electric and Gas, GPU Genco, Southern Company, Northern States Power, Madison Gas & Electric, Northern Indiana Public Service Co., East Kentucky Power Cooperative, Duke Power, Duquesne Light Co., Nebraska Public Power District, Otter Tail Power, Colorado Public Service, Kansas City Power & Light, Central & Southwest Services, Union Electric, Wisconsin Electric Power Co., Minnesota Power, and South Carolina Electric and Gas.

Utilities interested in cofiring have called for more parametric testing and precommercial testing to document the issues and opportunities associated with this practice. As a consequence, the FETC/EPRI program has focused upon cofiring testing at the following locations:

- Seward Generating Station, GPU Genco
- Allen Fossil Plant, TVA
- Colbert Fossil Plant, TVA
- Greenidge Station, NYSEG
- Blount St. Station, MG&E
- Michigan City Generating Station, NIPSCO

Additional work has focused upon fuels analysis, modeling, programs that support the cofiring initiative, and assessments of alternatives to cofiring.

The testing programs have been an unqualified success. They have demonstrated that boilers can be operated without capacity degradation, with modest efficiency penalties, and with benefits for emissions control. The fuels and modeling programs have supported these conclusions. This report presents progress at several power plants in testing and demonstrating cofiring; and it presents the progress made in supporting activities.

INTRODUCTION

EPRI initiated a program focusing on cofiring of biomass with coal in 1992, based upon its prior work cofiring refuse-derived fuel (RDF) in utility boilers. The initial work evaluated cofiring at TVA boilers, using site walks, combustion modeling, conceptual engineering, and economic evaluations to determine the conditions under which this technology would be cost-effective as a CO₂ mitigation strategy. Additional drivers associated with cofiring, at the inception of the EPRI program, included:

- Reduced SO₂ emissions
- Customer service in residue disposal
- Fuel diversification
- The development of biomass infrastructure to get to energy crops

The original work was completed in 1993, and it led to further activities by EPRI and Foster Wheeler Environmental. This work involved detailed fuel characterization studies, cold flow bunker studies to determine the flow characteristics of wood waste/coal blends, and related support activities. At the same time TVA funded cofiring safety studies focusing upon issues of spontaneous combustion. TVA also funded some low percentage cofiring experiments at two PC plants: Kingston Fossil Plant, with tangentially fired boilers, and Colbert Fossil Plant, with wall-fired boilers.

Other utilities were experimenting with cofiring at this time. Southern Company experimented with cofiring at Plant Hammond and Plant Yates of Georgia Power, and Plant Kraft of Savannah Electric. Delmarva conducted a small experiment in cofiring, as did East Kentucky Power Cooperative.

In 1994, EPRI and TVA conducted the first cofiring parametric tests at the Allen Fossil Plant in Memphis, TN. This unit, with three 275 MW cyclone boilers, was fired with Illinois basin coal. The cofiring tests demonstrated that green sawdust could be fired successfully in a cyclone boiler at levels up to 20 percent by mass. Such cofiring would result in lost boiler efficiency and, simultaneously, reduced NO_x formation.

In 1994, also, significant low percentage parametric cofiring tests were conducted by TVA at the Kingston and Colbert facilities. These tests, coupled with the Allen Fossil Plant tests, documented a standard approach to wood waste receiving, screening, and blending with coal on the belts to the crushers.

In 1995, the Allen Fossil Plant switched from Illinois Basin coal to Utah Bituminous coal. This switch resulted in the use of a more volatile coal with a very low sulfur content. Again cofiring parametric tests were conducted in both August and December. Cofiring levels up to 20 percent by mass were employed successfully. The results included no loss in boiler capacity, some reduction in boiler efficiency, and substantial reductions in NO_x emissions.

While the experiments were being conducted at the Allen Fossil Plant, other utilities were investigating cofiring or initiating testing. Duke Power experimented with various waste fuels, as did other utilities. One major cofiring test program was conducted at the Shawville Generating Station of GPU Genco. These parametric tests documented the capacity problems of PC boilers fired with blends of wood waste and coal. At Shawville, tests were conducted in Boiler #2, a wall-fired unit, and in Boiler #3, a T-fired unit. In both cases, a 3 percent wood/97 percent coal blend caused capacity limitations as a function of pulverizer performance. The ball-and-race mills of Boiler #2 experienced capacity limitations due to feeder speeds (see Figure 1), while the bowl mills of Boiler #3 experienced capacity limitations due to mill exit temperatures (see Figure 2). Further, in both cases, the energy required for grinding the coal increased (see Figure 3).

The impact of cofiring at low percentages, then, was associated with pulverizer performance. There were no appreciable impacts on boiler performance or emissions formation per se. The pulverizer limitations occurred because mills are the capacity limiting factor at Shawville; FD and ID fans and back end temperatures are not capacity limiting.

The NYSEG program at Greenidge Station was initiated in 1994-1995, and it employed separate feeding of the biofuel. By using separate feeding, this program avoided the problems associated with the Shawville tests. Further, this program focused upon the material handling aspects, and upon actions required to commercialize cofiring.

Figure 1. Impact of Wood Cofiring on Feeder Speeds at the Shawville Cofiring Tests.

Figure 2. Impact of Wood Cofiring on Mill Outlet Temperatures at the Shawville Cofiring Tests

Figure 3. Impact of wood Cofiring on Energy Requirements for Pulverizing Fuel at Shawville Cofiring Tests on Boiler #2

A significant body of experience was gained, then, regarding cofiring of woody biomass with coal. This body of experience included engineering studies, modeling, and cofiring testing. This body of experience provided a foundation for the subsequent work funded by the FETC/EPRI Cofiring Cooperative Agreement. The 16 projects associated with the FETC/EPRI program draw extensively from the experience described above. It is against this background that the progress of the 16 projects can be evaluated.

TECHNICAL PROGRESS

Project 1. Combustion Testing at the Seward Generating Station

The combustion tests at the Seward Generating Station were completed in the previous quarter. The results of those tests were analyzed during the first quarter of 1997, the second quarter of the project. The results of those tests are summarized below.

Foster Wheeler Environmental Corporation (Foster Wheeler) performed an extensive cofiring test at Boiler #12 of the Seward Generating Station of GPU Genco. Boiler #12 is a wall-fired boiler built by Babcock & Wilcox, and has a nominal steaming capacity of 300,000 lb/hr of 675 psig/850°F steam. The furnace of Boiler #12 has a volume of 20,000 ft³, and has a volume in the primary combustion area of 12,700 ft³. The boiler has two rows of burners, with three burners installed on each row. Figure 4 is an elevation view of this boiler.

Typically the unit consumes about 14 ton coal/hr when firing at 100 percent of capacity. This boiler, along with Boiler #14, supply steam to a 64 MW_e Westinghouse turbine. The net station heat rate (NSHR) for Boilers #12 and #14, and the associated turbine, is 14,200 Btu/kWh. Boiler #14 has been used to test coal water slurry (CWS), and that experience contributed to the design and execution of this sawdust cofiring test.

Foster Wheeler designed and procured a cofiring system used for the testing. This system included a trommel to screen the wood to <1/4" inch particle size, a large tent for fuel storage, a metering bin with the capacity to feed three lock hoppers. Those lock hoppers, in turn, fed three pneumatic transport systems. Each transport system had the capacity to deliver up to 4,000 lb/hr of sawdust to the face of the boiler. Each transport system was connected to an individual burner on the top row of burners. The sawdust was injected down the center pipe of each burner on the top row, and diffused into the coal flame.

Foster Wheeler also procured two types of sawdust: a coarse sawdust produced by a sawmill with a circular saw headrig, and a finer sawdust produced by a sawmill with a bandsaw headrig. Both types of sawdust contained significant percentages of moisture. Both types were fine, with the majority of the material being <1/4" inch particle size and a significant fraction being <1/16 inch particle size.

Figure 4. Elevation View of the Seward Generating Station #12 Boiler.

Ten tests were conducted during December, 1996. These tests were established to determine the influence of cofiring on the following parameters:

- boiler steaming capacity
- boiler efficiency
- boiler stability
- combustion temperatures
- heat release rates and residence times in the furnace and primary combustion area
- combustion completeness
- formation of airborne emissions, particularly NO_x

Cofiring tests were conducted with up to 20.7 percent sawdust (mass basis), or up to 9 percent sawdust (heat input basis). The results of the test program were significant, and generally favorable although certain problems were uncovered.

Because of the fuel delivery system, cofiring increased the capacity of the boiler, particularly when firing wet coal. Because wet coal limits the steaming rate of the boiler to <300,000 lb/hr, and because the cofiring system had the potential to increase the delivery of fuel to the furnace, cofiring increased the potential capacity of the unit.

Cofiring decreased boiler efficiency, but not severely. Three tests conducted without sawdust in the unit had calculated boiler efficiencies of 85.4 percent, 83.9 percent, and 84.3 percent. Efficiencies when cofiring wood waste ranged from 83.7 percent to 85.1 percent depending upon the percentage wood cofiring, the type of wood, and the excess O₂ of the boiler. This modest decrease was within the range of acceptability. Boiler stability was not at issue.

Combustion temperatures decreased, but only slightly, when cofiring was practiced. Heat release rates increased as a function of the firing rate of the boiler. Residence times in the furnace, and in the primary combustion zone did not decrease significantly when cofiring was practiced.

Potential problems with combustion completeness may have occurred when cofiring was practiced. Visual evidence also exists of some embers being in the flyash at the mechanical collectors, although the extent of this problem is not documented. Carbon monoxide formation increased when cofiring was practiced, however this increase was within acceptable limits.

SO₂ emissions are a function of fuel sulfur content. Cofiring reduces fuel sulfur content and, consequently, SO₂ emissions. NO_x emissions also decreased as a function of cofiring and the ability to reduce NO_x emissions proved substantial. Although there were few tests

with acceptable NO_x data, and some uncertainties existed with the data due to the sampling location, these data led to the creation of the following NO_x management equations:

$$\text{NO}_x, \text{lb}/10^6 \text{ Btu} = 0.59 + 0.001(\text{HI}) - 0.924(\text{W}) \quad [1]$$

$(r^2 = 0.97)$

$$\text{NO}_x, \text{lb}/10^6 \text{ Btu} = 1.245 - 2.75(\text{V}/\text{FC}) + 0.25(\text{FN}) \quad [2]$$

$(r^2 = 0.87)$

Where:

HI is heat input to the boiler in 10⁶ Btu/hr

W is the percent wood cofired, expressed on a mass basis

V/FC is the volatile/fixed carbon ratio

FN is the fuel nitrogen content in lb/10⁶ Btu

Essentially, the wood reduces the fuel nitrogen content and, because of the combustion technique, reduces the stoichiometric ratio at the center of the flame, leading to increased combustion staging in that location. The volatility of wood accentuated the ability to reduce the stoichiometric ratio at the center of the flame.

The cofiring test then demonstrated that sawdust could be fired with coal in a wall-fired boiler. Economic advantages occurred in terms of increasing the boiler capacity when cofiring with wet coal, and reducing SO₂ and NO_x emissions. Economic penalties associated with boiler efficiency were modest. The primary concern, unburned carbon in the bottom ash and flyash, merits additional investigation because this issue must be resolved if moderate percentage cofiring is to be practiced commercially in older wall-fired pulverized coal boilers.

Project 2. Fuel Preparation Tests at Greenidge Generating Station

The NYSEG project focuses on the preparation of wood-based fuels for cofiring with coal in the 104 MWe (net) boiler at NYSEG's Greenidge generating station. During this period, NYSEG continued the cofiring of wood wastes at Greenidge, using the fuel preparation system built during earlier (pre-FETC) phases of the project, and also continued modifications of the fuel processing and delivery system (i.e., delivery to the boiler), as needed to improve fuel delivery in the light of operating experience. Special performance measurements were made. Using wood of moisture contents ranging from 19% to 46% (wet basis) and particle size to the boiler less than 1/4-inch nominal top size, NYSEG achieved good results using two wood burners at opposite corners of the tangentially-fired boiler. Tests were done with each burner singly and also with both burners. Cofiring levels of 6% by heat were achieved with two burners, even when the wood fuel moisture was approximately 35% (wet basis).

Project 3. Precommercial Testing at TVA Fossil Plants

Computer modeling of the Allen Fossil Plant boilers, performed by Reaction Engineering International under subcontract to Foster Wheeler, was completed during this quarter. This modeling was performed assuming a base case of 100 percent Utah Bituminous Coal, and assuming 15 percent wood waste/85 percent western coal. It was performed assuming excess O₂ levels of 2.6 percent and 2.2 percent.

The modeling calculated that the NO_x concentrations in the cyclone would not be impacted significantly by cofiring. Further, the temperature profile in the cyclone would not be impacted significantly by cofiring (see Figures 5 and 6). The modeling demonstrated that combustion would be more complete in the cyclone when cofiring than when firing 100 percent coal. As such, the modeling provided additional insights into the proposed mechanism for NO_x reduction by cofiring in cyclones: the combustion is more complete in the cyclone, leading to reduced temperatures in the primary furnace. This would be reflected by lower furnace exit gas temperatures and reduced thermal NO_x formation in the primary furnace.

Figure 5. Temperature Profile of an Allen Fossil Plant Cyclone Barrel, as Modeled, When Firing 100 Percent Utah Bituminous Coal

Figure 6. Temperature Profile of an Allen Fossil Plant Cyclone Barrel, as Modeled, When Firing 15 Percent Wood/85 Percent Utah Bituminous Coal

These data provided additional insights into the overall impact of cofiring at the Allen Fossil Plant. They completed the data set necessary for report preparation.

Initial baseline tests were conducted for the precommercial testing of low percentage cofiring at the Colbert Fossil Plant. A larger trommel screen was brought to the site and installed at the pole building. Wood procurement activities continued.

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

Work continued on the material handling system, including the new building for waste paper and plastics handling, at the Blount St. Station.

Project 5. High Percentage Cofiring with Southern Company

No progress was made on this project.

Project 6. Cofiring Testing at Michigan City Generating Station of NIPSCO

Meetings were held planning this cofiring test at Michigan City. A test plan was constructed and approved by NIPSCO corporate and plant personnel. Fuel vendors were identified for both urban wood waste (Ealy Forest Products) and kiln dried sawdust (Koetter & Smith). Contracts for the test were finalized.

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

No progress was made on this project.

Project 8. Waste Plastics Cofiring at Duke Power

No progress was made on this project.

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

No progress was made on this project.

Project 10. Urban Wood Waste Cofiring in Pittsburgh, PA

Dr. J. Cobb and the University of Pittsburgh team initiated the cofiring program at Iron City Brewing. EPRI and Foster Wheeler performed a site visit to one of the fuel suppliers to evaluate the fuel production process. EPRI and Foster Wheeler also performed a site visit at the brewery to consider methods for evaluating the results of the cofiring program.

Cofiring runs were begun at 5 percent by volume wood waste in the stoker boilers. Cofiring percentages were increased as experience was gained.

Project 11. Toxic Emissions from Cofiring Evaluation

No progress was made on this project.

Project 12. Fuel/Powerplant Model Development

No progress was made on this project.

Project 13. CO₂ Utilization in Algal Systems

EPRI executed contracts with the Institute for Environmental Management (IEM) in Palo Alto, CA, and with John R. Benemann of Walnut Creek, CA. Those two consultants will provide the evaluations of these systems.

Project 14. Combustion Tests and Combustor Development

No progress was made on this project.

Project 15. Support for Ash Sales from Cofiring Plants

No progress was made on this project.

Project 16. CO₂ Capture and Disposal Options

EPRI initiated contractual discussions with Battelle Columbus Laboratories concerning this project.