FETC/EPRI BIOMASS COFIRING COOPERATIVE AGREEMENT

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ABSTRACT

The FETC/EPRI Biomass Cofiring Program has completed one year of activity, accelerating the pace of cofiring development. Cofiring tests were completed at the Seward Generating Station of GPU Genco and at the Michigan City Generating Station of NIPSCO. The NYSEG work at Greenidge Station resulted in a workable, low cost method for injecting biofuels into coal-fired PC boilers. Support studies and modeling continued to provide analytics for the cofiring program.

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

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EXECUTIVE SUMMARY

The FETC/EPRI Biomass Cofiring Program accelerated its activities with respect to cofiring testing and analytical procedures. The Seward cofiring tests were significant in documenting the impacts of cofiring using separate feeding in a wall-fired PC boiler. The Seward program is the only effort with moderate percentage cofiring. The results of this testing included quantification of the impact of biofuels on boiler efficiency, quantification of the impact of cofiring on unburned carbon in the bottom ash and in the flyash, and quantification of the maximum cofiring rate that could be achieved with old, partially decomposed sawdust. At the same time, the tests documented the reductions in NO_x that could be achieved by cofiring wood in a wall-fired boiler.

The NIPSCO test was equally significant in that it established several firsts:

1. It was the first supercritical boiler where cofiring was tested by the FETC/EPRI project team led by Foster Wheeler
2. It was the first cofiring test where the base coal was dominated by PRB coal, which has properties that are significantly different from bituminous coals
3. It involved the largest boiler (469 MW_e, net) where biofuels have been tested in cofiring applications
4. It was the first FETC/EPRI test where urban wood wastes were a significant portion of the biofuel feed

The NIPSCO tests demonstrated that cofiring could occur with PRB coals as the base, although the impact on feeder speeds is significant and can cause capacity limitations. At the same time, the difference between biofuel and PRB coal is not so great that major efficiency penalties are encountered. Finally, the tests demonstrated that cofiring could reduce NO_x emissions disproportionately, even when PRB coal is the base fuel.

The NYSEG program established the first commercial implementation of cofiring in a PC boiler, using separate feeding of the wood waste to a T-fired unit.

These dramatic improvements were then supported by fuel characterization, modeling, and related assessments. The overall program, then, achieved significant results during its fourth quarter, from July 1, 1997 through September 30, 1997.

INTRODUCTION

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

1. Mitigate fossil CO₂ emissions from coal-fired boilers
2. Reduce NO_x emissions from cyclone and PC boilers
3. Provide customer service to utility clients, maintaining loads
4. Increase fuel diversity for utilities

In recent months, increasing attention has been paid to using cofiring to meet portfolio standards as reflected in the Schaefer bill, the Jeffords bill, and the Bumpers bill. Cofiring has also been used as a potential method for meeting our obligations internationally; and the Kyoto meeting in Japan to be held in December, 1997, heightened the awareness of that use of biofuel.

For the period of 1994 through 1997, utilities encouraged EPRI to pursue full-scale demonstrations of cofiring to reduce the uncertainties associated with this practice. As a consequence, numerous demonstrations occurred through EPRI. Other utility demonstrations included cofiring railroad ties with western coal at La Cygne Unit #1 of Kansas City Power & Light, additional cofiring tests conducted by TVA, and selected cofiring tests conducted by Duke Power. In total, over 20 cofiring parametric tests have now been conducted. The 16 FETC/EPRI projects are at the forefront of the cofiring effort in terms of scope, percentage cofiring, boiler size, and the ability to quantify the results of cofiring. These projects provide a bridge from the current economic conditions to a future when

The 16 projects in the FETC/EPRI program contribute significantly to that bridge. They are summarized below.

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

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).

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

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 combustion in the 100 MWe boiler at NYSEG’s Greenidge plant. Mid-level, i.e., about 10% by heat, cofiring is planned.

3. Pre-commercial Test Runs at TVA (~200 MWe)

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.

4. Switchgrass Cofiring with Madison Gas & Electric (50 MWe)

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. High-level Cofiring with Southern Company (50 MWe)

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 CO₂ under the Climate Challenge program of the federal government. The next phase, assuming the expected favorable findings that cofiring is a low-cost CO₂ 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.

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. Toxic Emissions

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. Fuel/Powerplant Models, Analysis and Interpretation

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 assessments and tools for developing supply/cost curves will be applied as appropriate to address regional or local biomass resource issues important to PETC.

13. CO₂ 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 CO₂ 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 CO₂ emissions: the use of CO₂ 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 CO₂ mitigation. Two forms of fossil CO₂ reduction are involved: (1) capture of CO₂ 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 CO₂-enhanced stream like powerplant fluegas; and (2) replacement of a fossil fuel by a biomass fuel, as the algae grown with the enhanced CO₂ stream replace fossil fuel, i.e., a process similar to the CO₂ 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. CO₂ 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.

Significant progress has been made on many of these projects, as shown in previous quarterly reports. Substantial progress continues to be made on these projects, as is shown below.

TECHNICAL PROGRESS

Project 1. Combustion Testing at the Seward Generating Station

Two sets of tests were performed: the first during nine days in December 1996 and the second during six days in July 1997. The first set demonstrated 10% by heat cofiring capability in this 32-MW wall-fired boiler using separate feed of wood through a central pipe and diffuser system that discharges along the center axis of each of the three top burners in a two-row six-burner array on the front wall of the boiler. This 10% cofiring level was reached with both supplies of green sawdust fired during the test runs: (1) coarse sawdust produced by a circular-saw headrig, and (2) a less coarse (“fine”) sawdust produced by a band-saw type of headrig. The coarse sawdust was 52% moisture and the fine sawdust was 47% moisture (weight percent, on a “wet basis,” i.e., percent of the total weight, including the moisture, not “dry basis” which would be percent of the dry, not total, weight). Flame stability, boiler stability, and ability to gain back lost capacity caused by wet coal were demonstrated, as well as the 10% by heat in a wall-fired boiler without loss of capacity and without supplemental gas firing. Concerns about unburned biomass particles observed in some tests led to a decision to do a second set of tests. These were done in July and showed no problem. In fact, the July tests showed a 15-20% NO_x decrease at 10% cofiring, and showed better stability and efficiency results than the December tests. (The July 1997 data are to be reported in October 1997.) The favorable results have led the plant manager to ask for a 3-year commercial cofiring operation, if some research funds can be found to pay for the up-front costs and the added data-taking, engineering analysis and report writing.

The cofiring tests conducted in July 1997 addressed the following issues:

- The impact of cofiring on boiler efficiency
- The impact of cofiring on unburned carbon in the flyash and bottom ash
- The impact of cofiring on the formation of burning embers or “fireflies” in the gaseous combustion products
- The impact of cofiring on NO_x emissions

Three types of wood waste were used: fresh green sawdust from a band saw mill, dry sawdust and planer shavings, and old sawdust from a circular saw mill. All of the wood was screened to <1/4” and pneumatically transported to the boiler separately from the coal. The wood waste was injected through the centerpipe of the power plant burners, and diffused into the coal flame.

The results of the test were significant. Cofiring was practiced at up to 20 percent on a mass basis, or >10 percent on a heat input basis. Cofiring did reduce boiler efficiency slightly (typically about 0.5 percent, always <1 percent). Cofiring did not significantly

increase unburned carbon in the bottom ash or flyash. The formation of “fireflies” was not problematical. The practice of cofiring did reduce NO_x formation substantially. Table 1 documents the impacts of cofiring at the Seward Generating Station.

The test program was limited to parametric testing. The results were sufficiently favorable on a technical basis that a long-term demonstration program is being planned to evaluate the fuel supply and the economic practicality of cofiring at this generating station.

Table 1. Summary of Results at the Seward Generating Station Tests, July 1997						
Test No	Wood Type	Cofiring Percentage		Boiler Efficiency (%)	Unburned Carbon in Flyash (%)	NO _x Emissions (lb/10 ⁶ Btu)
		Mass	Heat			
1	None	0	0	85.62	6.92	0.95
2	FGS (*)	3.4	1.47	85.79	4.61	0.85
3	FGS (*)	6.4	2.83	85.71	5.86	0.85
4	FGS (*)	9.5	4.31	85.47	6.02	0.83
5	FGS (*)	13	6.04	85.03	7.84	0.83
6	FGS (*)	16.1	7.60	84.21	8.68	0.80
7	DSS (*)	13.8	8.11	85.74	5.09	0.82
8	DSS (*)	17.2	10.3	84.09	10.16	0.78
9	FGS (*)	17.9	8.53	84.65	5.89	0.80
10	OS (*)	4.4	1.61	86.13	5.50	0.87
11	OS (*)	8.2	3.05	85.26	6.70	0.85
12	OS (*)	11.9	4.31	85.62	3.12	0.84
13	None	0	0	86.07	6.65	0.87
(*) FGS is fresh green sawdust at 38.8% moisture, DSS is dry shavings and sawdust at 13.5% moisture, and OS is old sawdust at 48.5% moisture.						

The impact of cofiring on unburned carbon can be seen from Table 1. It can also be considered through the analysis of glowing carbon embers at the entrance to the air heater. Figures 1 through 3 illustrate the impact of cofiring on glowing embers or “fireflies”. Cofiring, by itself, does not necessarily cause a problem with unburned carbon in the flyash or glowing fireflies in the gaseous combustion products.

Figure 1. Fireflies in the Gaseous Combustion Products as a Function of Cofiring Percentage for Fresh Green Sawdust.

Figure 2. Fireflies in the Gaseous Combustion Products as a Function of Cofiring Percentage for Kiln Dried Sawdust.

Figure 3. Fireflies in the Gaseous Combustion Products as a Function of Cofiring Percentage for Old, Coarse Sawdust

The NO_x reduction achieved by the cofiring tests at Seward Generating Station are highly significant, as shown in Figure 4. This figure includes data from both the December test and the July test.

Figure 4. NO_x Emissions as a Function of Wood Waste Cofiring at the Seward Generating Station.

These results provided the impetus to seek a 3-year demonstration program.

Project 2. Fuel Preparation Tests at Greenidge Generating Station

The first energy crop fuel was prepared and cofired at NYSEG's Greenidge Generating Station, a large sample of this fuel was shipped to FETC for test burns at the CERF, and the wood fuel preparation and handling system was improved at Greenidge. The final report is being written and will be delivered to EPRI in October 1997, i.e., in Year 2 rather than Year 1. The key technical results are known and are as follows: (1) In routine operations, the plant frequently cofires wood fuels at the 5% level, on a heat basis. (2) Frequent test runs at 8% by heat are performed. (3) The limiting factor on the heat fraction cofired is the wood-fuel handling system, not the capacity of the fuel injection system and furnace to burn out the wood particles. (4) The energy crop fuel (shrub willow from the State University of New York's experimental station at Tully, near Syracuse, NY) was not easy to handle and could not be fed alone at the rate required to get to 8%, or even 5%, by heat cofiring levels. (5) Clogging in feed lines enroute to the airlock hopper that puts the fuel into the air stream blowing fuel to the boiler, prevented the energy crop willow from being fed, despite the fact that the willow fuel particles were in small sizes (e.g., 6 mm x 1 mm x 1 mm) and because these particles had "fingers" to a greater extent than other wood fuels being fed at Greenidge (i.e., the particles grab hold of each other and bundle in bunches that clog the feed pipes and other passages). (6) The willow fuel was finally burned, but only by mixing it into a blend with the other wood fuels, at only 30%, or less, fractions of the wood feed. (7) Typical performance numbers are 108-MW gross power at full load, 104 MW net power, net heat rate on coal 10,000 Btu/kWh, fuel flow of coal for full power is 1040×10^6 Btu/h, fuel flow of wood to hit 8% of power from wood is 87×10^6 Btu/h since wood converts at about 5% worse heat rate than coal when the wood is about 25% moisture, and this requires, therefore, 6.9 tons/hour of 25% moisture wood to get 8% (or 8 MWe net) from wood. The wood-fuel preparation system that will be documented in the report routinely supplies 5 tons/hour, often runs at 7 tons/hour when desired, and is being upgraded by system improvements (also to be documented for EPRI and FETC) to at least 10 tons/hour.

Project 3. Precommercial Testing at TVA Fossil Plants

Particle size effects were tested at Allen, the 275-MW cyclone-fired boiler, in June 1996, and NO_x measurements were made there in a set of special test runs in November 1996. A draft report on these tests was delivered to FETC in July 1997 and a revised final report will be delivered to FETC in October 1997. The tests showed that 1-inch (25 mm) particles of 40% moisture wood are marginal as cofiring fuel for cyclones, 3/4-inch (19 mm) are acceptable fuel, 1/2-inch (13 mm) is a good size, and the by-now-standard 1/4-inch (6 mm) size is also good. The limiting factor at 1-inch (25 mm) size is unburned wood particles. At 3/4-inch (19 mm) size the limiting factor is the loss of NO_x-control that could otherwise be achieved by keeping the wood flames back inside the cyclone barrels where the wood flames' consumption of combustion air helps reduce NO formation by essentially "staging" the coal combustion through use of oxygen to consume wood fuel rather than helping to drive some of the reactions that form NO from N or N₂.

Tests of drier wood fuel -- say at 20% moisture instead of 40%+ moisture -- indicated that the drier fuel is better for NO_x control than the wetter. This again, suggests that the “staging” effect is the more important one, the slight cooling effect of the moisture being of less help in avoiding NO formation than the faster (i.e., earlier in the flow of fuel and gas) consumption of oxygen due to earlier ignition of the wood fuel.

At Colbert, in a 190-MW wall-fired pulverized coal boiler, TVA began “precommercial” operations. “Precommercial” means that the program is an ongoing, long-term test in a continuing mode that resembles commercial operations and where no special data gathering effort is normally made. Special test sets were run on two occasions when EPRI’s contractor, Foster Wheeler Environmental, came to the site and joined TVA in making special measurements during representative cofired operation of the boiler. At about the 1-1/2% (heat basis) cofiring level, some 4-5% by mass, sawdust fuel of some 40% (or more) moisture content is being routinely cofired at Colbert. The particle size is the “standard” 1/4 -inch (6 mm), which means that the sawdust fuel is virtually all less than 3/8-inch (9 mm) long (passing a 3/8-inch (9 mm) screen, the great majority less than 1/4-inch (6 mm) long and about 60% is even less than 1/16-inch (1.5 mm) long. Here the sizes refer to length, because the screening is done by accepting as fuel the product that passes a particular screen size and, in practice, a 3/8-inch (9 mm) hole size in a commercial screen on a large hammermill, or on a large trommel screen, lets through product that is overwhelmingly no longer than 1/4-inch (6 mm). The thickness of these sawdust particles, i.e., the narrowest dimensions, is usually about 25% of the length, meaning that the critical dimension for achieving burnout is about 1/16-inch (1.5 mm) for nominal 1/4-inch (6 mm) sawdust. For reasons of dust control, both at the wood pile itself and as a help in reducing the dust from coal to less than its normal levels, “green” sawdust at about 40%+ moisture is to be preferred over “dry” sawdust, dry meaning, in this case, less than about 20% moisture.

To extend TVA’s ability to decide on when and whether to proceed to yet more precommercial or commercial operations, EPRI’s subcontractor Foster Wheeler Environmental (FWE) is developing a model to predict burnout, slag formation and NO_x in cofiring in cyclone-fired boilers. FWE is also analyzing the potential for enhanced cofiring operations in TVA cyclone-fired boilers, and in wall- or tangentially-fired also, via gasification of the biomass (a tire-derived) fuel. Finally, FWE is also extending the EPRI Alternate Fuel Database via a module to predict where coal-fired boilers may have locations along the gas or ash flow paths that are hot enough to cause problems due to slagging or fouling during cofiring operations.

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

The test program was completed by the final two sets of test runs, which were performed in October 1996 and April 1997. The first cofiring of grass (“switchgrass”) and the first cofiring of an energy crop at levels above 1% of the heat input was accomplished through this subtask. Results are favorable in that the plant manager at Madison Gas & Electric’s host site, Blount Street Station in Madison, Wisconsin, is satisfied that he can and would

cofire switchgrass, if the fuel price were right. A final report, prepared by EPRI's subcontractor, the U. Wisconsin-Madison, was sent to FETC in August 1997. However, technical questions remain to be addressed as a result of review and comments by EPRI, Foster Wheeler and the Nebraska Public Power District (NPPD). Therefore, EPRI plans to extend the end date to do some additional analysis/interpretation of the data. Nevertheless, the result stands: 10% by heat cofiring has been achieved with grass fuel in a 50-MW wall-fired pulverized coal boiler, making this the first test in the U.S. that has come anywhere close to this level of cofiring when grass is the cofired fuel; this was done in a pulverized-coal boiler; and the test was favorable enough to prove technical feasibility for purposes of plant operation.

Specific results are: (1) achieved a peak of 10% by heat at 40 MW and several times achieved 6.5% by heat at full-load conditions of 49 MW. (2) Measured significant NO_x reductions when cofiring, about 25%. (3) No measurable SO₂ reduction, but expected only 6% reduction and there was about that much scatter in the data. (4) Measured a large i.e., 60%, reduction in particulate emissions as measured by opacity, a reduction that has also been observed when the plant cofires its usual alternate fuel, which is pre-consumer waste paper and plastic. (5) Unburned carbon in the ash was measured at acceptable levels and does not appear significantly different from coal-only firing. (6) Heat rate and boiler efficiency aspects need to be analyzed in more detail than done so far. (7) Additional analysis and interpretation will be useful for the opacity, NO_x and carbon results, as well as for the primary unresolved issue regarding heat rate and boiler efficiency effects.

Project 5. High Percentage Cofiring with Southern Company

This subtask has not started, so there are no results of research or testing to report. This is in accord with the Management Plan, which put the Southern Company project as a Year 3 activity. However, EPRI has discussed two possible projects with Southern Company during the past year. One is the high-level cofiring of wood in a PC boiler. Here "high-level" means pushing the limit by a great deal, if possible. Cofiring levels of up to 40% by heat were tested briefly at Plant Kraft in Savannah about 4 years ago. This subtask was to expand the potential for biomass cofiring, by returning to Plant Kraft to test the high-level cofiring in more detail and to find an operating point that would be economic. Recent conversations with Southern Company suggest that expansion to an energy crop fuel, namely switchgrass, in the less-costly blended feed mode (i.e., through the pulverizer, blended with the coal) is more promising as the next step in Southern's biomass energy R&D effort. The switchgrass project will include demonstration of lower-cost harvesting/processing as well as co-pulverization and cofiring.

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

All preparations have been made and the combustion test took place in late September. The wood fuel was procured, delivered, screened and blended with coal in April and May 1997. The wood fuel was screened to 1/2-inch (13 mm) top size and includes urban

woodwaste (ground-up pallets) as well as sawdust. The wood fuel was stored for over four months as a coal/wood blend at the plant with no problems. This coal/wood blend, blended here with a low-bituminous (10,000 Btu/lb) Shoshone coal, was in turn blended with a sub-bituminous Powder River Basin coal enroute to the boiler for the actual cofiring test runs which occurred 22-26 September 1997. The final blend was 50/40/10 by mass PRB/Shoshone/wood, which gives a blend that is 6.0% by heat for the wood fraction.

The salient results of this test are shown in Figures 5 through 10. Figure 5 illustrates how cofiring increased feeder speeds relative to baseline tests. Figures 6 and 7 demonstrate the impact of cofiring on boiler efficiency. There was a modest decrease in efficiency relative to what could have occurred with 100 percent coal. Unfortunately the Union Pacific difficulties with rail deliveries of coal resulted in baseline tests on a blend of Shoshone and Caballo Rojo coal; and the cofiring tests were conducted with Shoshone and Black Thunder coal. Figure 8 depicts the influence of cofiring on Furnace Exit Gas Temperature, showing a significant reduction in this parameter as a consequence of cofiring. Figure 9 illustrates that cofiring has very little impact on unburned carbon in the flyash. Figure 10 illustrates the NO_x reduction achieved, and the influence of FEGT on that outcome.

Figure 5 Impact of Cofiring on Feeder Speeds at Michigan City Generating Station.

Figure 6 Impact of Cofiring on Boiler Efficiency at Michigan City Generating Station

Figure 7 Efficiency Comparison for Tests at the Michigan City Generating Station.

Figure 8 Impact of Cofiring on Furnace Exit Gas Temperatures at Michigan City Generating Station

Cofiring Test: Tests 1-3 are Baseline While Tests 4-7 are Cofiring Tests

Figure 9 Impact of Cofiring on Unburned Carbon in the Flyash at Michigan City Generating Station

Figure 10. Impact of Furnace Exit Gas Temperatures on NO_x Emissions at Michigan City Generating Station.

The unburned carbon results are particularly significant; there has been considerable attention on this parameter as a consequence of ash sales issues. With respect to NO_x, these data are consistent with the results at the Allen Fossil Plant. The presence of biofuel in the mix entering the cyclone increases the completeness of combustion thereby reducing temperatures in the primary furnace and reducing thermal NO_x formed there.

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

No direct activity on this investigation of switchgrass cofiring took place. Instead, the Nebraska Public Power District (NPPD) took part in the switchgrass test at Madison (per No. 4, above), and Sandia National Lab met informally with EPRI to discuss potential lab tests, modeling or field test support that could be done to support cofiring field tests.

Project 8. Waste Plastics Cofiring at Duke Power

The activity planned for Year 1 on plastics cofiring in a pulverized coal boiler did not take place, because the utility (Duke Energy) was not ready to proceed to full-scale testing.

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

No activity, in accord with the Management Plan.

Project 10. Urban Wood Waste Cofiring in Pittsburgh, PA

EPRI's subcontractor, Dr. David Tillman of Foster Wheeler Environmental, supported the urban woodwaste cofiring project through advice to Dr. James Cobb of the University of Pittsburgh and his graduate student, Wiles Elder. This subtask was expanded through a supplemental urban woodwaste resource assessment for the Pittsburgh area done for EPRI and Duquesne Light by Foster Wheeler. This new assessment found sufficient potential wood supply for a 40,000 ton/year reburn cofiring operation at Duquesne's down-fired pulverized coal boiler at Elrama, just south of Pittsburgh.

Both projects were essentially completed by the third quarter of this project. Advice and information was supplied to Dr. Cobb during the fourth quarter.

Project 11. Toxic Emissions from Cofiring Evaluation

A preliminary, informal assessment of the cost, benefit, and opportunity for a measurement of toxics in air emissions was performed by EPRI and FETC staff members as they discussed tests that could have been performed during Year 1 at NYSEG's Kintigh or Greenidge plants or at GPU's Seward plant. None of these was found to be the right opportunity for a meaningful test, due to considerations of (1) importance of the information to be gained, (2) cost versus scope, and (3) timing and equipment issues at each specific site.

Project 12. Fuel/Powerplant Model Development

EPRI developed a national "supply curve" (or "mitigation curve") model that takes into account five major groups of powerplant categories, costs of cofiring for each category, and biomass fuel supply vs. cost. The model shows how some 50 million metric tons of fossil CO₂ can be displaced by biomass cofiring at a total national cost of \$250 to \$350 million, assuming that the coal displaced has a cost of \$1.40 to \$1.15/MBtu, respectively, and that biomass fuel can be found for \$0.50/MBtu delivered cost (first 10 million metric tons) and \$1.00/MBtu (next 20 million metric tons). Foster Wheeler has improved the EPRI Alternate Fuels Database, another subcontractor (University of California at Davis) has developed a database containing more than 400 biomass fuel data sets, and Foster Wheeler has developed approaches to model (1) ash fouling/agglomeration in biomass-fired fluidized-bed boilers, and (2) ash slagging/fouling, plus cofired combustion and NO_x, in cofired cyclone boilers.

During this quarter, the EPRI Biomass Cofiring Guidelines Report (TR-108592) was published. This report provides guidance on fuel procurement, processing, combustion, and emissions management. It also provides some cost and economics data. This provides additional information with which to evaluate cofiring projects.

Project 13. CO₂ Utilization in Algal Systems

EPRI's subcontractor I.E.M. and EPRI's consultant Dr. John Benemann have started the assessment of a potential low-cost entry point for utilities to arrange for CO₂ capture via

algae production at wastewater treatment plants. Comparisons to the better-known and already-in-use landfill gas energy recovery projects are being developed, and the national potential for CO₂ reductions (including CH₄ and N₂O on a CO₂-equivalent basis) is being estimated. Wastewater treatment technologies are being described and characterized for their greenhouse gas emissions, and two specific wastewater treatment plants are being described and evaluated as case studies.

Project 14. Combustion Tests and Combustor Development

No activity, in accord with the Management Plan.

Project 15. Support for Ash Sales from Cofiring Plants

EPRI and EPRI subcontractor Foster Wheeler have begun assessment of the ash sales issue that confronts biomass cofiring: the practical fact that plant managers will most probably decide not to cofire if they perceive that they will lose existing or likely sales of flyash into the cement industry. Work to date consists of attendance, presentation and discussions at appropriate technical meetings.

Project 16. CO₂ Capture and Disposal Options

EPRI's consultant, John Benemann, has prepared and assisted on papers and presentations regarding biomass cofiring and other direct biological processes for fossil CO₂ control. He has put the cofiring and biological processes into the context of the more-usually-considered CO₂ capture and disposal options (more aptly, "sequestration" options). EPRI's Richard Rhudy has put into place the subcontract with Battelle-Columbus to evaluate aquifer sequestration, and has joined with FETC in planning future work through his attendance at meetings, participation in technical discussions, and taking steps to define the next subcontract (after Battelle), which is to cover sequestration via existing wells that were drilled for oil or natural gas production.

REFERENCES

Foster Wheeler Environmental Corporation. 1997. Biomass Cofiring Guidelines. Electric Power Research Institute, Palo Alto, CA. (TR-108952).