

URBAN WOOD/COAL CO-FIRING IN THE BELLEFIELD BOILERPLANT

FINAL REPORT

MAY 15, 2000 — MAY 15, 2001

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April 8, 2004

Award No. DE-FG26-00NT40808

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ABSTRACT

An Environmental Questionnaire for the demonstration at the Bellefield Boiler Plant (BBP) was submitted to the national Energy Technology Laboratory.

An R&D variance for the air permit at the BBP was sought from the Allegheny County Health Department (ACHD). R&D variances for the solid waste permits at the J. A. Rutter Company (JARC), and Emery Tree Service (ETS) were sought from the Pennsylvania Department of Environmental Protection (PADEP). Construction wood was acquired from Thompson Properties and Seven D Corporation. Verbal authorizations were received in all cases.

Memoranda of understanding were executed by the University of Pittsburgh with BBP, JARC and ETS.

Construction wood was collected from Thompson Properties and from Seven D Corporation. Forty tons of pallet and construction wood were ground to produce BioGrind Wood Chips at JARC and delivered to Mon Valley Transportation Company (MVTC). Five tons of construction wood were hammermilled at ETS and half of the product delivered to MVTC. Blends of wood and coal, produced at MVTC by staff of JARC and MVTC, were shipped by rail to BBP.

The experimental portion of the project was carried out at BBP in late March and early April 2001. Several preliminary tests were successfully conducted using blends of 20% and 33% wood by volume. Four one-day tests using a blend of 40% wood by volume were then carried out. Problems of feeding and slagging were experienced with the 40% blend. Light-colored fly ash was observed coming from the stack during all four tests.

Emissions of SO₂, NO_x and total particulates, measured by Energy Systems Associates, decreased when compared with combusting coal alone.

A procedure for calculating material and energy balances on BBP's Boiler #1 was developed, using the results of an earlier compliance test at the plant. Material and energy balances were then calculated for the four test periods. Boiler efficiency was found to decrease slightly when the fuel was shifted from coal to the 40% blend.

Neither commercial production of sized urban waste wood for the energy market in Pittsburgh nor commercial cofiring of wood/coal blends at BBP are anticipated in the near future.

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INTRODUCTION

This final report describes work done during the one-year contract period of the University of Pittsburgh's project on "Urban Wood/Coal Co-firing in the Bellefield Boiler Plant."

The core of this work was a field test that occurred during a brief period in late March and early April 2001. The section of this report, entitled "Experimentation", describes the field test in detail.

However, the preparation for the field test, and its aftermath, was an extensive process of great variety. Three of the four subsections of the section on "Results and Discussion" focus upon this process: "Environmental Aspects", "Wood Supply", and "Plant Operations".

The final subsection, "Analysis", of the section on "Results and Discussion" of the report provides a set of material and energy balances for each of the four test periods. Because of the limited availability of sensors on the boiler, no attempt was made to perform a parametric study of the data collected in the field test.

EXECUTIVE SUMMARY

During this one-year project, work was pursued on experimentation, environmental issues, wood supply, plant operations, analysis, and evaluation of commercialization.

EXPERIMENTAL

In late March and early April four railcars of wood/coal blends were delivered to the Bellefield Boiler Plant (BBP) – one railcar each of a 20% wood by volume/80% coal blend and a 30% wood by volume/70% coal blend, and two railcars of a 40% wood by volume/60% coal blend. The load from each railcar was fed to the bunker of Boiler #1 and thence to the boiler itself. The 20% and 30% blends flowed and combusted well. However, the 40% blend behaved marginally; occasional modest assistance was required for its flow; two negative observations were made – (1) some maldistribution on the grate and (2) an increase in slagging. On all four days of testing, light colored fly ash was carried from the stack.

RESULTS AND DISCUSSION

Environmental Issues

The Environmental Questionnaire was submitted to the National Energy Technology Laboratory.

In June 2000 letters announcing the project were sent to the Allegheny County Health Department (ACHD) and the Southwest Regional Office of the Pennsylvania Department of Environmental Protection (PADEP).

In November 2000 the project team provided a letter to PADEP describing the provenance of the construction wood to be processed at JARC and ETS and seeking an extension of the “permit by rule” at both companies for this project. Early in 2001 both wood processors reported to the project team that oral extensions of the “permit by rule” at both companies had been granted for this project.

In December 2000 a letter was submitted to the ACHD seeking an R&D variance for the air permit at the BBP. A verbal authorization was received shortly before the experimental work commenced.

Emissions monitoring by Energy Systems Associates (ESA) during the field test showed decreases in SO₂, NO_x and total particulates when compared with combusting coal alone.

JARC and ETS considered establishing urban waste recycling facilities that would provide properly sized wood for producing a commercial wood/coal blend for the

stoker boiler market in Pittsburgh. For this blend to be used at the BBP, installation of a baghouse would be required.

Wood Supply

Construction wood was collected from Thompson Properties and Seven D Corporation.

JARC modified its grinder. The resulting product, BioGrind Wood Chips, appeared much chunkier than previous materials. JARC then ground 40 tons of urban wood waste, including pallets and construction wood from Thompson Properties. The resulting BioGrind Wood Chips were delivered to the Mon Valley Transportation Company (MVTC).

ETS milled 5 tons of urban wood waste, the construction wood from Seven D Corporation, and delivered half of the resulting products to MVTC.

Three wood/coal blends, prepared by JARC and MVTC, were delivered by rail to BBP.

The project team discussed with JARC and ETS the establishment of an urban solid waste recycling center to provide properly sized ground or hammermilled wood for sale to the stoker boiler market in Pittsburgh. Both companies declined to implement such a project.

Plant Operations

A memorandum of understanding (MOU) was executed with BBP. A kick-off meeting was held with the BBP in June 2000, followed by a project review meeting in September, at which the draft test plan was discussed. Discussions were held with BBP throughout the fall and winter on the timing of the tests.

Occasional discussions were held throughout the fall and winter with ESA about air monitoring at BBP.

Regular group meetings of the project team were held to coordinate activities across the project. One of the focuses of the team was on measuring and estimating the solid fuel flow rate (SFFR) during the experimental tests. Estimates of SFFR using gate height, grate speed and fuel bulk density were high by 30%. The SFFR was measured during the tests of the 20% and 30% blends, but could not be measured during the tests of the 40% blend.

In late April the project team met with BBP's superintendent to discuss technical issues related to the possibility of commercializing wood/coal cofiring there. Because of operational problems encountered during the field test, BBP will not pursue this.

Analysis

Well before the field test, the procedure to calculate material and energy balances on Boiler #1 was prepared, and a plan for data collection was developed.

Shortly before the field test, material and energy balances were prepared on two compliance tests in early March. Material and energy balances were then prepared on the coal-only baseline test, run at the BBP between the two tests using the 40% blend.

Following the field test, material and energy balances were prepared for the four key test periods. They showed that, when switching from coal to a 40% (by volume) blend of wood and coal:

- The mass flow rate of solid fuel increased by about 14% and the mass flow rate of coal decreased by about 6%
- The mass flow rate of natural gas increased by an average of 28%
- The mass flow rate of combustion air decreased by an average of 35%
- The boiler efficiency decreased by an average of 2.8%.

EXPERIMENTAL

Wood/coal co-firing in this project was conducted in Boiler #1 of the Bellefield Boiler Plant (BBP) during the period of March 27 through April 4, 2001.

BBP supplies steam for the district heating system that serves the University of Pittsburgh, Carnegie-Mellon University, several major hospitals and three other institutional customers in the Oakland District of Pittsburgh. The plant produces steam with two underfeed multiple-retort stoker boilers, three chain-grate coal-fired stoker boilers and two gas-fired boilers. The plant produces saturated steam at approximately 175 psig and 375°F. It operates 24 hours per day, 365 days per year.

Coal is delivered to the plant in 70-ton railcars. It is bottom dumped directly from the cars into a receiving hopper. From the receiving hopper it passes through a crusher (used to break up frozen coal) to a 40-ton/hour bucket conveyor/elevator. The conveyor transport the coal across the top of the plant to a series of five bunkers. Each bunker holds about 500 tons of coal.

The cofiring demonstration was conducted in Boiler #1, one of the chain-grate boilers. It has a capacity of 80,000 pounds of steam per hour using Eastern Kentucky near-compliance $\frac{3}{4}$ " x $\frac{1}{4}$ " junior pea stoker coal. It is configured to burn over-fired natural gas, up to 25% of capacity, for particulate emission control. Coal for this boiler is fed by gravity from the bottom of its bunker through a chute into a non-functioning Stock coal scale. From the scale the coal passes through a Stock conical non-segregation distributor that spreads the coal evenly across the entrance to the air-cooled chain grate. Ambient air is used for combustion. Dampers are manually adjusted to distribute the flow of under-grate air. Bed depth and grate speed are adjusted to match the load. Pneumatic-electronic controls are used to manage the boiler. Flue gas from the boiler passes directly to the stack.

Urban wood wastes used were (1) pallets collected from numerous sources by J. A. Rutter Company (JARC) of Monroeville, PA, (2) trim-ends of framing lumber, mixed with about 30% plywood and particleboard, collected at a condominium construction site being developed by Thompson Properties in a northern suburb of Pittsburgh and delivered to JARC, and (3) trim-ends up to several feet long from Seven D Corporation, a wood truss manufacturer in Tyrone, PA, delivered to Emery Tree Service (ETS) of Indianola, PA. JARC tub-ground the wood passing through its processing plant, while ETS hammer-milled the trim-ends it received. All of the wood for use at BBP was delivered to the Mon Valley Transportation Company (MVTC) in Glassport, PA, where it was blended with coal and loaded into railcars for delivery to the boiler-plant, as described in the subsection on "Wood Supply".

For Test #1 at BBP, a railcar containing the blend of 20% by volume of hammer-milled construction wood and 80% coal, was brought to the BBP from the marshalling yard on Friday, March 23. On the morning of Monday, March 26 it was unloaded and

the blend was fed to the bunker above the #1 Boiler. The project team took a number of pictures during the unloading of the railcar and transfer of the blend to the bunker. This feed was introduced to the boiler later in the morning and continued as the boiler fuel for approximately 24 hours. The BBP operators reported no difference between the fire in the boiler feeding the blend and that feeding coal. The observed opacity was unchanged. During the afternoon, the project team weighed one hour's fuel through the feed system. On the next afternoon (Tuesday, March 27) the project team received all the data that the computers had collected during Test #1 to use for the material and energy balance workups. (This general practice continued throughout the testing program.)

During the afternoon of Monday, March 26 the day shift foreman called for the railcar, containing the blend of 33% by volume of tub-ground construction wood and pallets, to be delivered that evening from the marshalling yard. On the morning of Tuesday, March 27 this car was unloaded and the new blend transferred to the bunker. It fed well from the rail car to the bunker. It began to enter the boiler in the early afternoon, starting Test #2. Shortly thereafter another one-hour mass flow measurement was performed. With this blend the project team had to rap the six-inch bypass line (installed specially for sampling) occasionally to keep the flow going. (The two main 15-inch lines feeding directly from the bunker to Boiler #1 worked fine.) Opacity was observed to have dropped from about 9 (on coal) to about 7 (on the 33% blend). During Test #2 the BBP operators found that they needed to increase the grate speed to try to maintain load, but even an increase of about 5% was not enough; the steam make still dropped over 5% from the previous day.

During the afternoon of Tuesday, March 27 the day shift foreman called for the first railcar with a 40% by volume blend of tub-ground construction wood and pallets with coal to be sent from the marshalling yard that evening. On the morning of Wednesday, March 28 this car was brought into the unloading area. The plant operators had considerable difficulty starting its removal from the bottom of the rail car, and occasionally they had to encourage it to slump from the sides of the feed pit to the 30-inch pipe at the bottom of the pit. These difficulties were manageable for a brief test, but were too much for commercial operation. A commercial operation would need to be kept below at least a 33% blend, using this tub-ground material. A 40% blend might be acceptable if either (1) the blending operation was gentler and fewer fines were included in the tub-ground wood or (2) hammer-milled wood was used. Once into the conveying system, the blend moved well to the bunker above Boiler #1. It began to enter the boiler in the early afternoon, starting Test #3.

During most of Test #3 the blend flowed through the boiler feed system without incident, but intermittently the "no flow" alarm would sound. Often the alarm would stop after a minute or so without intervention by the operators, but on some occasions the operators would have to strike the feed pipe to move the blend along. The Pitt project team attempted another one-hour mass flow measurement, but could not establish a good enough flow through the bypass line to make the measurement.

As the test got underway, the load dropped as a result of the lower heating value of the fuel. At the suggestion of the engineer from Energy Systems Associates (ESA), who was present to advise the plant on boiler operations, the gate was raised to allow more fuel to enter. The gate had not been moved since the unit was cleaned the previous summer. There was little effect on the load, suggesting that the upper part of the feed slot was blocked.

In the boiler four observations were made that showed differences from normal operation: (1) Just after the gate was raised, there appeared a thin tongue of apparently unburned material extending along the sides of the grate, which could be allowing hot, unburned material to drop into the ash pit; (2) there was a lot of fine ash floating around - one of the operators reported that there had been some light, white ash on his car outside since Monday, March 26, the first day of testing – however opacity continued to be lower than normal; (3) evidence of increased slagging appeared on the front wall; and (4) some larger-than-usual masses of clinkers (some fist sized) were discharged into the ash pit.

Following Test #3, Boiler #1 reverted to pure coal on Thursday morning, March 29.

On Thursday and Friday, the plant superintendent reviewed the observations and experiences of the 24-hour period on the 40% blend with members of the plant's operating committee and governing board. It was concluded that during the following week the BBP would conduct a fourth day of testing with the 40% blend that was sitting in the fourth railcar in the marshalling yard. During that day – and the day following, when the unit was back on pure coal – ESA would monitor the flue gas composition.

So, the plant's staff called for the second railcar with the 40% blend to come on Monday evening, April 2. ESA brought in its flue gas monitoring group and equipment on Monday. When the set of railcars, including the one with the blend, arrived at the siding, the operators found that the car with the blend was embedded after five cars with coal only. The car with the blend therefore could not be brought into the unloading area until Tuesday evening April 3, so Boiler #1 continued to operate with pure coal on Tuesday. ESA took the opportunity to conduct its baseline monitoring on that day. Test #4 at 55 KPPH steam and Test #5 at 37 KPPH steam were made.

On Wednesday, April 4, the fourth railcar with the 40% wood/coal blend was unloaded, starting at 7:00 a.m. The blend flowed out of the railcar in much the same manner as it did on Wednesday, March 28. However, it did not hang up at all in the chute from the bunker to the boiler, perhaps because it seemed a bit drier than the one last week. The mixture began entering the boiler at 9:00 a.m. and continued well into the following morning. Inside the boiler there were no signs of additional slagging or fingering along the sides of the grate.

Tests # 6 and #7 were conducted during the operations on April 4. The following table shows key operating parameters during Tests #4-7. The method of computation to obtain the values shown in the table is provided in the subsection on “Analysis”.

Table 1. Operating Parameters during Tests #4-7

TEST	4	5	6	7
Coal (lb/hr)	5075	3615	4784	3432
Wood (lb/hr)			971	708
Natural Gas (lb/hr)	844	563	892	844
Air (lb/hr)	71033	85000	63257	52255
Flue Gas (lb/hr)	79006	90144	70295	57055
Steam (lb/hr)	53850	36500	54000	36900
Boiler Efficiency (%)	62.13	60.04	60.32	59.55

On April 4 ESA monitored the flue gas from 9:00 a.m. to after 5:00 p.m. They reported preliminarily that the SO₂ dropped as expected from Tuesday (on pure coal) to Wednesday. The amount of particulates remained about the same, but some of them changed to white ash on Wednesday. Surprisingly, the NO_x rose 20%.

Sean Plasynski of NETL and Dave Delmastro of CTC visited the boiler-plant on the afternoon of April 4 to observe the testing and discuss the overall program.

The operational phase of the project concluded on Thursday morning, April 5, when the last of the 40% blend cleared the boiler.

RESULTS AND DISCUSSION

ENVIRONMENTAL ASPECTS

Environmental Questionnaire

Early in the project period, the Environmental Questionnaire was prepared by the project team and approved by the Bellefield Boiler Plant (BBP) and the Environmental Health and Safety Department of the University of Pittsburgh (University). It was submitted on August 21, 2000 to Lloyd Lorenzi, Environmental Officer, U.S.DOE National Energy Technology Laboratory (NETL).

Variances to Permits

In late June 2000, letters were sent to:

Sandra T. Etzel
Chief, Engineering Section
Air Quality Program
Allegheny County Health Department (ACHD)

David Emmert
Pennsylvania Department of Environmental Protection (PADEP)
Southwest Regional Office

The air permit of the BBP is administered by the ACHD, and the solid waste permit of J. A. Rutter Company (JARC) is administered by the Southwest Regional Office of the PADEP. Both letters informed the permitting agencies of the grant from NETL, and provided additional information.

The letter to the ACHD reported that the project team would be working with the boilerplant to seek a research and development (R&D) variance to the boilerplant's operating permit to conduct experiments utilizing a fuel blend composed of tub-ground urban wood residues mixed with the boilerplant's standard coal.

The letter to the PADEP reported that the project team was planning to use source-segregated construction-site wood residues to replace some or all of the pallet wood residues used in earlier projects at the Pittsburgh Brewing Company and the boilerplant at the Bruce Research Laboratory of NIOSH. It noted that it would be working with JARC to provide information to PADEP to receive its approval for the demonstration.

In early November 2000 the project team drafted a letter for submission by the University, on behalf of the BBP, to the ACHD, requesting the R&D variance to the boilerplant's operating permit for the project. After BBP approval, it was submitted to

ACHD in December 2000. Shortly before the start of operations at the BBP in March 2001, the ACHD provided verbal approval to proceed with the demonstration.

The BBP requested that testing results for air emissions be reported only as percentage differences found with and without co-firing. Doing so avoided any possibility that the results at BBP during co-firing testing could be found to contradict the results that BBP had obtained during past compliance testing.

The PADEP regulates the operations of JARC and Emery Tree Service (ETS) through a procedure known as “permit by rule.” In November 2000 the project team also provided a letter to PADEP describing the provenance of the construction wood to be processed at JARC and ETS, which had come aboard the project since June, and seeking an extension of the “permit by rule” at both companies for this project. Early in the following year (2001) both wood processors reported to the project team that oral extensions of the “permit by rule” at both companies had been granted for this project.

On May 4 the project team attended a meeting at the PADEP’s Pittsburgh Office with members of PADEP’s and ACHD’s air and solid waste staffs. Following a review of the demonstrations at both the BBP and the NIOSH boilerplants, the attendees discussed how approximately 30,000 tons/year of construction/demolition (C/D) wood could be provided to the energy market in Pittsburgh. The principal concern expressed by the regulators was the quality control of the composition of the wood delivered to the boiler-plants. If JARC and ETS wish to satisfy a market for fuel from C/D wood, they will each need a Municipal Waste Processing Permit. JARC has already received the application form for this permit and ETS will have to obtain one also. ACHD can provide assistance in filling them out. Six to nine months are required to obtain the permit, once the application is filed. It was also noted that any boiler-plant wishing to switch to a fuel containing C/D wood must receive a construction air permit, a temporary operating air permit and a permanent air permit. During the period covered by the temporary operating air permit, compliance testing is required.

Emissions Monitoring

Energy Systems Associates (ESA) installed a gas analyzer at a sample port in the duct leading from Boiler #1 to the stack. The analyzer obtained measurements of the composition of the flue gas (NO_x, SO₂, CO, CO₂ and O₂) from Boiler #1 during the one-day period (Tuesday, April 3, 2001) prior to Test #4 when the boiler operated on coal alone, and during Test #4 (Wednesday, April 4). ESA also installed equipment to measure moisture, particulate, gas velocity and oxygen concentration at the sample port in the stack. The boiler was operated at two loads on each day. ESA also collected samples of particulates on Tuesday and Wednesday, April 3 and 4. It was noted that the BBP had requested that testing results for air emissions be reported only as percentage differences found with and without co-firing.

Several weeks after concluding the demonstration testing, ESA provided results of the testing. Table 2 summarizes the change in emissions on a volumetric basis after

correcting for excess oxygen (to 3% oxygen), effectively stating the results on the basis of lbs/MMBtu. Table 3 summarizes the change in emissions on a mass per time basis.

Table 2. Percentage Change from Baseline on a Volumetric Basis (ESA)

Load	NO _x	SO ₂	Particulate	CO
54 KPPH	+15.6%	-16.1%	+5.9%	+17.6%
37 KPPH	+8.4%	-19.0%	+19.1%	-21.4%

Table 3. Percentage Change from Baseline on a Mass per Time Basis (ESA)

Load	NO _x	SO ₂	Particulate
54 KPPH	-3.5%	-30.0%	-17.1%
37 KPPH	-36.7%	-53.0%	-20.8%

Public Interactions

Public notification was planned for the demonstration. It had been agreed in the fall of 2000 that the superintendent of the BBP would arrange for a presentation about the project at a forthcoming regular community meeting. Unfortunately, that individual retired in late 2000 and the presentation failed to be scheduled. On the first day of the demonstration a message was sent to the Chancellor of the University telling of its initiation. By the fourth day of the demonstration several vocal community members became aware of it and asked the plant manager about it. They reported the fallout of white ash on their vehicles. This observation led to the conclusion (discussed below) that a bag-house would have to be installed at the plant before commercialization of co-firing could be contemplated.

Vocal neighborhood concerns about particulate emissions from BBP are longstanding. The boiler-plant began gas over-firing many years ago as one measure to control particulates. They also recently improved their soot removal system, replacing blowers with sonic horns to release smaller amounts of fly ash from the boiler tubes more frequently.

The owners of the BBP have seriously considered installing one or more bag-houses, even though the capacity for additional equipment at the plant is severely limited. They recently commissioned a study of this by a major engineering firm, which concluded that funds in excess of \$5 million would be required to install fabric filters at the BBP.

The capacity of the BBP currently is at the maximum allowed by its physical dimensions. In addition, its owners are expanding their facilities and demand is increasing. They are actively discussing a variety of options for increasing capacity, switching fuel (especially to gas), satellite operations, and entire plant replacement. As a

result, the topics of wood/coal co-firing and bag-house installation are embedded in a much larger conversation, which will require considerable time to conclude.

WOOD SUPPLY

Collection, Grinding and Blending

Thomson Properties, a building of single-family homes and residential structures, began a new condominium project in the north hills of Pittsburgh in mid-summer 2000. In mid-July the company agreed to place clean construction wood into roll-offs on its building site. The waste placed in the roll-offs would contain plywood (including plywood treated with fire retardants), glulams, and trim ends of framing wood.

In late July, JARC modified its grinder to produce more chunk-like material. When operated, the product was much better than before – fewer spears and fines, as determined by Mr. Rutter and Mr. Elder, the project's Research Associate.

On September 22 a signed memorandum of understanding (MOU) was received from JARC. On September 25 a signed MOU was received from ETS.

JARC began receiving construction wood waste from Thompson Properties in mid-October. The wood was collected in roll-off containers at a condominium construction site being developed by Thompson Properties. The wood consisted of trim-ends of framing lumber, mixed with about 30% plywood and particleboard.

On December 1 JARC ground 35 tons of broken pallets and 5 tons of urban construction wood waste, using a modified method of operation. Upon inspection, the product from the modified method of operation contains more fines than anticipated, principally from the particleboard that had been commingled with the trim-ends, but the larger pieces are comprised of far fewer lengthy spears than previous grinds. JARC denotes this new material as "BioGrind Wood Chips." The entire 40 tons of BioGrind Wood Chips were delivered to MVTC in Glassport, PA in mid-December.

During the fall of 2000, the project team received information from CQ Inc. about Seven D Corporation, a wood truss manufacturer in Tyrone, PA, which had expressed interest in providing construction wood waste to the University's wood/coal cofiring program. In early November, two truck loads of construction wood were delivered to ETS by Seven D Corporation. This wood consisted of trim-ends up to several feet long. On January 23, 2001 ETS milled this wood and placed the milled product in rolloffs. One of the rolloffs was delivered to MVTC for use in this project.

On February 21 JARC relocated a mulch blender from its plant in Monroeville, PA to MVTC. Blending was accomplished on February 22 by a team from JARC and

MVTC. JARC provided the blender operator and MTVC provided union workers for all other aspects of materials handling. Three blends were produced: (1) 20% by volume hammer-milled wood from ETS, 80% by volume coal; (2) 30% by volume tub-ground wood from JARC, 70% by volume coal; (3) 40% by volume tub-ground wood from JARC, 60% by volume coal. The coal used was drawn from the coal pile regularly supplying BBP. Both the coal and the wood were partially frozen. To assure complete blending and smooth operation of the blender, appropriate aliquots of wood and coal were placed in piles on the ground and blended with a front loader, creating extra fines. The mixture was transferred from those piles to the blender.

On March 16 the finished blends were loaded onto 70-ton railcars – one car each for the 20% and 30% blends and two cars for the 40% blend. The cars were moved to the siding at the Glenwood rail-yard from which coal deliveries are regularly made to BBP.

Samples were collected:

- #1 and #2: hammer-milled construction wood supplied by ETS;
- #3 tub-ground construction/pallet wood supplied by JARC;
- #4 the feed coal;
- #5 the 40% wood/60% coal by volume blend.

These five samples were submitted to Geochemical Testing, of Somerset, PA. The following analyses were provided: proximate, ultimate, heating value (Btu/lb), ash elemental, and ash fusion temperatures. Table 4 presents the results.

Commercial Supply

The project team has determined the direction in which ETS and JARC are going in providing an urban waste wood product meeting specifications for the stoker boiler co-firing market and the solid waste regulations of the Commonwealth of Pennsylvania.

ETS does not plan to enter into this business in Pittsburgh, although it is involved to a certain extent in it in another community.

JARC gave serious consideration to establishing an urban waste recycling operation at its plant in Monroeville, but, like ETS, has decided not to enter into this business. If it had decided to do so, it would have accept construction and demolition debris at its plant where the debris would have been separated into a number of product streams, such as aggregate, brick, metal, gypsum and wood. Remnant material not fitting into these products would have been disposed to landfill. Major issues that JARC addressed in deciding not to proceed were (1) product specifications, (2) processing to meet those specifications, (3) procedures to meet regulations, (4) permitting, (5) bonding and (6) economics.

Table 4. Wood Analyses

Analysis	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5
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Proximate Analysis (%) as received					
Moisture	9.20	51.91	49.09	3.76	8.85
Ash	0.16	1.01	0.45	6.94	6.79
VM	74.99	39.97	42.64	37.98	37.54
FC	15.65	7.11	7.82	51.32	46.82
Ultimate Analysis (%) as received					
H	6.59	8.69	8.56	5.40	5.76
C	46.03	24.02	25.14	74.16	67.37
N	0.14	0.07	0.14	1.35	1.10
S	0.19	0.12	0.18	0.96	0.80
O	46.89	66.09	65.53	11.19	18.18
Ash	0.16	1.01	0.45	6.94	6.79
Ht. Value	7,796	4,061	4,272	13,202	11,938
Ash Elemental (%)					
SiO ₂	10.90	48.13	30.15	49.02	56.27
Al ₂ O ₃	3.12	9.32	8.84	27.95	28.15
Fe ₂ O ₃	2.71	5.92	8.10	8.25	6.64
TiO ₂	0.27	0.62	0.66	0.93	1.18
P ₂ O ₅	0.45	0.55	0.90	0.20	0.13
CaO	42.43	16.43	20.48	4.34	1.83
MgO	6.88	3.17	4.88	0.77	0.86
Na ₂ O	1.01	1.42	1.81	0.15	0.26
K ₂ O	6.02	3.79	6.54	0.20	1.85
SO ₃	8.63	3.03	7.91	2.86	1.22
MnO ₃	1.44	0.34	0.35	0.01	0.02
Ash Fusion Temperature (°F)					
Initial	2,500	2,130	2,180	2,600	2,760
Softening	2,510	2,150	2,220	2,640	>2,800
Hemi	2,520	2,160	2,230	2,680	>2,800
Fluid	2,530	2,170	2,240	2,740	>2,800

PLANT OPERATIONS

Memorandum of Understanding (MOU)

A MOU was executed with BBP.

Discussions with BBP and Others about the Demonstration

During the one-year period covered by this report the project team held a number of discussions with BBP and others about the demonstration.

On September 21, a meeting was held with BBP to discuss the following topics:

- decision-making concerning boiler operating parameters during test periods;
- schedule for loading wood/coal blends on railcars and transferring each blend from its railcar to the bunker of Boiler #1 and then on to Boiler #1 for each test;
- stack testing;
- data collection;
- calculation of weight of wood/coal blend fed, using the volume of the dump bucket at the front of the grate, its frequency of filling and the density of the blend;
- approach to informing the neighborhood about the demonstration.

On November 8 a meeting was held with personnel from ESA to discuss the test plan and the role of ESA in the conduct of the test program and the analysis of its results (including modeling).

During the three months prior to the demonstration, the project team continued discussions with ESA about ESA's flue gas analysis during the tests at BBP. It was decided that the five gases, NO, SO₂, CO, O₂ and CO₂, would be analyzed by EPA Methods 10, 3A, 6C and 7E. Particulate sampling will be conducted by EPA Method 17. The sampling would follow the Compliance Test Protocol for BBP that ESA submitted to ACHD in 1996, but with several variations. First, ESA would obtain only two particulate samples per condition. Second, ESA would not obtain coal samples, but would use only estimated fuel factors in emissions calculations. Third, this protocol listed five ESA engineers and technicians for the testing, but there would only be two involved in the co-fire testing. Fourth, the particulate would likely be collected at the stack since boiler outlet ducts would be used for continuous gaseous sampling. Fifth, SO₂ emissions would be determined through instrument analysis rather than chemical analysis (Method 6C rather than Methods 6 and 8). Sixth, the gaseous sampling would likely be conducted through the four sample ports utilizing three probes per port (with probe lengths based on equal area). Lastly, there would be no assembly of calibration sheets for testing equipment, instrumentation and calibration gases.

Throughout this same period, the project team has had an ongoing discussion with BBP as to the timing of the demonstration. A special compliance test was being conducted at BBP in early March. The BBP expected that test to be completed by mid-March and had scheduled the co-firing demonstration for the period from March 19 through March 31. Also throughout this period, Mr. Li visited the BBP on numerous occasions and engaged in several wide-ranging discussions with ESA to obtain background information for collecting data during the tests and analyzing the system for his masters thesis and the final report of the project.

Measurement of Solid Fuel Flow Rate

Mr. Li continued to give special attention to the methods for measuring the flow of solid fuel to the #1 Boiler, which was used in the test. Two methods were developed:

1. Because the fuel flow rate is determined by the speed and the height of the gate leading onto the traveling grate, the speed of the chain grate, the height of the gate opening to the grate, and the boiler loading were collected and recorded during each test.
2. At the same time, the project team weighed one hour's fuel through the feed system by opening a six-inch bypass line (installed specially for sampling), collecting the fuel in buckets, weighing the buckets, and returning the fuel to the distributor.

After comparing the results of these two methods, the project team found the figure calculated from the grate speed and gate height didn't exactly indicate the real flow rate of blend fuel, probably because the chain grate looks like a curve, not a straight line, when it moves if observed from the side, calculating the volume of fuel simply by multiplying the height of the gate with the speed of the grate is not accurate enough. Therefore in the calculation of the mass and energy balances, the values calculated from flue gas emissions were still used.

In early March Mr. Li collected information during a compliance testing program that was being conducted at BBP during that period. During two compliance tests, one on Boiler #3 and one on Boiler #5, ESA measured the coal flow rate by Method #1. At the same time Mr. Li, using Method #2, measured the speed of the chain grate and the height of the gate, calculated the volumetric flow rate of the coal (knowing the width of the gate), and then computed the mass flow rate of the coal (knowing its bulk density). The results of his analysis are:

	Pounds per Hour		Error (%)
	Method 1	Method 2	
Boiler #3	6,164	8,606	28
Boiler #5	5,704	8,592	34

Discussions with BBP Following the Experimentation

Three weeks after the final test at BBP the project team met with the BBP superintendent, Robert Miller. Five concerns were identified, coming out of the experimental campaign of March 27 through April 5.

1. The volumetric heating value of the wood/coal blend is significantly lower than that of coal. At peak load during extremely cold periods of the winter heating season, this fuel cannot provide enough energy. The strategy of fuel supply would bring the wood/coal blend to the plant during the months of April through October and coal to the plant from November through March.

2. At certain times the fire on the grate was not “straight-line” across the boiler. In particular, several “fingers” of slow-burning fuel appeared at some of those times along the grate in the direction of travel, extending toward the ash pit. High fines and moisture content, coupled with irregularities in the height of the grate (caused by long-term slag buildup) may have contributed to this problem.
3. An increase in slag was observed on the front wall. Again, high amounts of fines in the wood/coal blend could well have been the cause of this. Both coal and wood fines burn very quickly and very hot just inside the combustion chamber below the front wall. Reducing the amount of fines should correct this problem.
4. Larger and harder particles, caused by slagging, were observed in the bottom ash falling from the grate. Again, reducing the amount of fines should reduce the slag draining from the front wall and should extend the combustion time of the larger particles in the bed, thus reducing their peak temperature and tendency to slag.
5. A white ash was observed on cars in the parking lot and in the immediately surrounding neighborhood downwind of the plant. Installing a bag-house on the boiler-plant would eliminate this problem. An earlier evaluation of bag-house installation on Boilers #3, 4 and 5 suggests that such an addition would cost in excess of \$7 million.

If solutions to these five problems were provided by the addition of a bag-house, better quality control of the blend, and deliveries scheduled in consideration of the plant load, the BBP would likely entertain a second test period using a wood/coal blend.

ANALYSIS

Mr. Li conducted the analysis of the data acquired during testing at the BBP. Prior to the cofiring tests, he developed detailed generic material and energy balances for coal firing in Boiler #1 using data from the unit

He tested his analytical approach on the two compliance tests, mentioned above. For each test, he calculated a flue gas composition and the flow rate from data that he obtained from the boiler. Key values of this data are shown in Table 5 in the following box. Mr. Li then performed a heat balance. The results of the heat balances are shown in Table 6, following the box.

In mid-June Mr. Li prepared material and energy balances for Runs #4 - #7. The calculations were based upon the analyses for coal and wood shown in Table 7.

Table 5. Operating Data during Compliance Tests

		<u>Boiler #3</u>	<u>Boiler #5</u>
Steam flow (lb/hr)		80,000	73,700
Coal flow (lb/hr)		6,164	5,704
Gas flow (ft ³ /hr)		27,000	18,900
Percent excess air		7.1	7.2
<u>Coal Analysis (%)</u>		<u>Natural Gas Analysis (%)</u>	
C	74	CH ₄	74
H	5	C ₂ H ₆	11
O	8	CO ₂	2
N	2	<u>Steam Properties</u>	
S	2	P	175 psi
Ash	6	T	370 F
H ₂ O	3		

Table 6. Energy Balances during Compliance Tests

	<u>Boiler #3*</u>	<u>Boiler #5*</u>
Input	1.13	1.00
Steam	0.81	0.74
Loss to Stack	0.13	0.14
Unaccounted	0.19	0.12

* All values in 10⁸ Btu/hr

Table 7. Estimated Wood and Coal Analyses during Tests at BBP

	<u>Coal (%)</u>	<u>Wood (%)</u>
C	75	43
H	5	5
O	8	38
N	2	
S	1	
Ash	6	4
H ₂ O	3	10

The following values in the material balance were estimated from the plant data:

Table 8. Operating Data during Tests at BBP

	<u>Run #4</u>	<u>Run #5</u>	<u>Run #6</u>	<u>Run #7</u>
Steam flow (lb/hr)	53,850	36,500	54,000	36,900
Estimated coal flow (lb/hr)	5,075	3,615	4,784	3,432
Estimated gas flow (lb/hr)	844	563	892	844
Estimated wood flow (lb/hr)			971	708
Percent excess air	128	279	109	239
Percent material balance error		3.1	1.4	1.1
0.2				

The percent error in the material balance is quite small. However, it may be observed that the calculated values for excess air in Table 8 range from 109% to 239%. This appears to be quite a high set of values and likely would not be found in the composition of the flue gas. There may well be significant discrepancies in the values inserted into the material balances, relating to the oxygen balance, and the results flowing from them.

The energy balances (in 10^8 Btu/hr) were calculated to be:

Table 9. Energy Balances during Tests at BBP

	<u>Run #4</u>	<u>Run #5</u>	<u>Run #6</u>	<u>Run #7</u>
Input	0.868	0.609	0.896	0.620
Steam	0.539	0.365	0.541	0.369
Loss to stack	0.227	0.153	0.256	0.176
Unaccounted	0.102	0.091	0.099	0.075

The calculation procedures for the material and energy balances may be found in Mr. Li's masters thesis. [1]

CONCLUSIONS

The field work has been successfully completed.

Construction wood was acquired from Thompson Properties and Seven D Corporation. Forty tons of wood were ground by JARC to produce BioGrind Wood Chips and delivered to MVTC. Five tons of wood were milled by ETS and delivered to MVTC. Three blends of wood and coal were prepared at MVTC and delivered to the BBP.

Four one-day tests were made in Boiler #1 at the BBP. Feeding and firing of 20% (by volume) and 30% blends were successful, but four operational problems occurred when using a 40% blend. Particulate emissions from all four tests were unacceptable. A baghouse must be installed to eliminate the particulate emissions problem.

The quantity of emissions of SO_2 , NO_x and particulates were all reduced, as expected, by the use of wood/coal blends.

The material and energy balances showed that, when switching from coal to a 40% blend:

- the mass flow rate of solid fuel increased by about 14% and the mass flow rate of coal decreased by about 6%;
- the mass flow rate of natural gas increased by an average of 28%;
- the mass flow rate of combustion air decreased by an average of 35%;
- the boiler efficiency decreased by an average of 2.8%.

REFERENCES

1. Li, Hongming, "Commercialization of Biomass Cofiring with Coal in Stoker Boilers," M. S. Thesis, University of Pittsburgh, Department of Chemical and Petroleum Engineering, 2002.

LIST OF ACRONYMS AND ABBREVIATIONS

ACHD	Allegheny County Health Department
BBP	Bellefield Boiler Plant
ESA	Energy Systems Associates
ETS	Emery Tree Service
JARC	J. A. Rutter Company
MVTC	Mon Valley Transportation Company
NETL	National Energy Technology Laboratory
NIOSH	National Institute of Occupational Safety and Health
PADEP	Pennsylvania Department of Environmental Protection
USDOE	U.S. Department of Energy