THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

Environmental and Sustainable Technology Evaluation (ESTE)

ESTE Joint Verification Statement

TECHNOLOGY TYPE:	Biomass Co-firing
APPLICATION:	Industrial Boilers
TECHNOLOGY NAME:	Wood Waste Co-firing With Coal
COMPANY:	Minnesota Power, Rapids Energy Center
ADDRESS:	Grand Rapids, Minnesota

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies. This verification was conducted under the Environmental and Sustainable Technology Evaluation (ESTE) program, a component of ETV that was designed to address agency priorities for technology verification.

The goal of the ESTE program is to further environmental protection by substantially accelerating the acceptance and use of improved and innovative environmental technologies. The ESTE program was developed in in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. With performance data developed under this program, technology buyers, financiers, and permitters in the United States and abroad will be better equipped to make informed decisions regarding environmental technology purchase and use.

This ESTE project involved evaluation of co-firing common woody biomass in industrial, commercial or institutional coal-fired boilers. For this project ERG was the responsible contractor and Southern Research Institute (Southern) performed the work under subcontract. Client offices within the EPA, those with an explicit interest in this project and its results, include: Office of Air and Radiation (OAR), Combined Heat and Power (CHP) Partnership, Office of Air Quality Planning and Standards (OAQPS), Combustion Group, Office of Solid Waste (OSW), Municipal and Industrial Solid Waste Division, and ORD’s Sustainable Technology Division. Letters of support have been received from the U.S. Department of Agriculture Forest Service and the Council of Industrial Boiler Owners.

TECHNOLOGY DESCRIPTION

Minnesota Power's Rapids Energy Center (REC) hosted this testing. REC provides power and heat for the neighboring Blandin Paper Mill in Grand Rapids, Minnesota. The facility has two identical Foster Wheeler Spreader Stoker Boilers installed in 1980 (Boilers 5 and 6). This verification was conducted on Boiler 5. Each boiler has a steaming capacity of approximately 175,000 lb/hour. The boilers can be fired with western subbituminous coal supplied by Decker Coal Company, located in the northwest section of the Powder River Basin, wood waste, railroad ties, on-site generated waste oils and solvents, and other paper wastes. Particulate emissions from each boiler are controlled by a Zurn multiclone dust collector and cold side electrostatic precipitator (ESP).

Waste wood and bark from the neighboring Blandin Paper mill, as well as waste wood from other local facilities, was co-fired with coal during this verification. The fuels (woody biomass and coal) are conveyed to the boiler separately and mixed on the stoker. Proximate analyses of the woody biomass used for this testing is as follows (wet weight basis):

Component	% by Weight
Moisture	46.5
Ash	1.28
Fixed carbon	27.3

The average heating value of the woody biomass was 4,645 Btu/lb.

Under normal operations, each boiler generates approximately 175,000 lb/h steam which is used to power a 15 MW steam turbine and provide process steam to the Blandin mill. The boilers typically co-fire woody waste, primarily bark, at a nominal coal:biomass fuel ratio of 15:85 percent. The woody biomass waste is of sufficient supply nearly all year long with the exception of spring months. During periods of reduced wood waste supply the facility increases the amount of coal used to fuel the boilers.

VERIFICATION DESCRIPTION

This project was designed to evaluate changes in boiler performance due to co-firing woody biomass with coal. Boiler operational performance with regard to efficiency, emissions, and fly ash characteristics were evaluated while combusting 100 percent coal and then reevaluated while co-firing biomass with coal. The verification also addressed sustainability issues associated with biomass co-firing at this site.

The testing was limited to two operating points on Boiler 5:

- firing coal only at a typical nominal load
- firing a coal:biomass "co-firing" mixture of approximately 7:93 percent by weight at the same operating load

Under each condition, testing was conducted in triplicate with each test run approximately three hours in duration. In addition to the emissions evaluation, this verification addressed changes in fly ash composition. Fly ash can serve as a portland cement production component, structural fill, road materials, soil stabilization, and other beneficial uses. An important property that limits the use of fly ash is carbon content. Presence of metals in the ash, particularly mercury (Hg), can also limit fly ash use, such as in cement manufacturing. Biomass co-firing could impact fly ash composition and properties, so this verification included evaluation of changes in fly ash carbon burnout (loss on ignition), minerals, and metals content.

During testing, the verification parameters listed below were evaluated. This list was developed based on project objectives cited by the client organizations and input from the Biomass Co-firing Stakeholder Group (BCSG).

Verification Parameters:

- Changes in emissions due to biomass co-firing including:
  - Nitrogen oxides (NO_X)
  - Sulfur dioxide (SO_2)
  - Carbon monoxide (CO)
  - Carbon dioxide (CO_2)
  - Total particulates (TPM) (including condensable particulates)
  - Primary metals: arsenic (As), selenium (Se), zinc (Zn), and Hg
  - Secondary metals: barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), and silver (Ag)
  - Hydrogen chloride (HCl) and hydrogen fluoride (HF)
- Boiler efficiency
- Changes in fly ash characteristics including:
  - Carbon, hydrogen, and nitrogen (CHN), and SiO_2, Al_2O_3, and Fe_2O_3 content
  - Primary metals: As, Se, Zn, and Hg
  - Secondary metals: Ba, Be, Cd, Cr, Cu, Mn, Ni, and Ag
  - fly ash fusion temperature
  - Resource Conservation Recovery Act (RCRA) metals and Toxic Characteristic Leaching Procedure (TCLP).
- Sustainability indicators including CO_2 emissions associated with sourcing and transportation of biomass and ash disposal under baseline (no biomass co-firing) and test case (with biomass co-firing) conditions.

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and QA/QC procedures can be found in Test and Quality Assurance Plan titled *Test and Quality Assurance Plan – Environmental and Sustainable Technology Evaluation Biomass Co-firing in Industrial Boilers.*

Quality Assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). Southern's QA Manager conducted a technical systems audit and an audit of data quality on a representative portion of the data generated during this verification and a review of this report. Data review and validation was conducted at three levels including the field team leader (for data generated by subcontractors), the project manager, and the QA manager. Through these activities, the QA manager has concluded that the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan.

VERIFICATION OF PERFORMANCE

Boiler Efficiency

Table S-1. Boiler Efficiency

Test ID	Fuel	Heat Input (MMBtu/hr)	Heat Output (MMBtu/hr)	Efficiency (%)
Baseline 1	100 % Coal	296.6	220.4	74.3
Baseline 2		304.1	225.8	74.2
Baseline 3		295.7	221.3	74.9
Cofire 1	Blended Fuel (8 Coal; 92 Woody biomass)	368.4	227.9	61.8
Cofire 2		363.7	219.9	60.5
Cofire 3		357.8	220.1	61.5
Baseline Average		298.8	222.5	74.5 ± 0.3
Cofire Average		363.3	222.6	61.3 ± 0.7
Absolute Difference		64.5	0.1	-13.2
% Difference		21.8%	0.00%	-17.7%
Statistically Significant Change?		na	na	Yes

The average efficiencies during baseline (coal only) and co-firing tests were 74.5 ± 0.3 and 61.3 ± 0.7 percent respectively. This results in a statistically significant decrease of 17.7 percent efficiency when firing the blended fuel. The mass of woody fuel needed to provide an equal amount of heat is much greater. During baseline testing, an average 31,600 lb/h coal was consumed. During co-firing, fuel feed rates for coal and woody biomass averaged approximately 6,470 and 75,200 lb/h, respectively.

Emissions Performance

Table S-2. Gaseous Pollutants (lb/MMBtu)

Test ID	Fuel	SO_2	CO_2	NO_x	CO
Baseline 1	100 % Coal	0.489	167	0.533	0.229
Baseline 2		0.485	160	0.540	0.210
Baseline 3		0.448	153	0.509	0.251
Cofire 1	Blended Fuel	0.0013	131	0.188	0.680
Cofire 2		0.0014	127	0.193	0.337
Cofire 3		0.0012	134	0.201	0.649
Baseline Averages		0.474 ± 0.02	160 ± 7	0.527 ± 0.01	0.230 ± 0.02
Cofire Averages		0.0013 ± 0.0001	131 ± 4	0.194 ± 0.007	0.555 ± 0.2
% Difference		-99.7%	-18.3	-63.2%	142%
Statistically Significant Change?		Yes	Yes	Yes	Yes

As expected SO_2 emissions were essentially eliminated using this high blend of woody biomass. NO_X emissions were also greatly reduced when co-firing (less fuel-bound nitrogen and lower thermal NO_X formation due to higher fuel moisture content, both shown in Table 3-1), and there was a statistically significant change in CO_2 emissions and a large increase in CO emissions. In similar testing at a different facility, wood pellets were co-fired with coal at a much lower rate (about 15 percent) and at a much lower moisture content (about 7 percent). During that testing NO_X emissions were slightly increased and CO and CO_2 emissions were not significantly impacted. The two tests serve as a useful comparison between relatively dry and very moist woody fuels, and how this can impact emissions.

A large reduction in condensable particulates was evident while co-firing the woody fuel. Although there was not a significant change in emissions of filterable particulates, the total particulate emission rate was reduced by 81 percent due to the large decrease in condensable particulates.

Table S-3. Particulate Emissions (lb/MMBtu)

Test ID	Fuel	Total Particulate	Filterable PM	Condensable PM
Baseline 1	100 % Coal	0.0295	0.0044	0.0251
Baseline 2		0.0277	0.0042	0.0236
Baseline 3		0.0379	0.0049	0.0262
Cofire 1	Blended Fuel	0.0088	0.0055	0.0050
Cofire 2		0.0029	0.0031	0.0030
Cofire 3		0.0062	0.0026	0.0021
Baseline Averages		0.0317 ± 0.005	0.0045 ± 0.0004	0.0249 ± 0.0013
Cofire Averages		0.0060 ± 0.003	0.0037 ± 0.002	0.0034 ± 0.0015
Absolute Difference		-0.0257	-0.0008	-0.0216
% Difference		-81.2%	-17.1%	-86.5%
Statistically Significant Change?		Yes	No	Yes

Metals emissions were extremely low during all test periods. Changes in metals emissions on a percentage basis were large and quite variable across the elements analyzed, including the list of eight secondary metals. For the four primary metals shown, the reductions in mercury and selenium were statistically significant.

Emissions of HCl and HF were considerably lower during co-firing due the reduced levels of chlorine and fluorine in the fuel, showing decreases of approximately 62 and 77 percent, respectively. The reductions for both are statistically significant using the t-test.

Fly Ash Characteristics

Changes in ash characteristics were significant. Minerals content was much lower in the cofired fuel ash. Loss on ignition was significantly higher, indicating that the woody biomass is more difficult to fully combust. Changes in carbon content or fusion temperatures of the ash were not statistically significant. Quantitative flyash results are voluminous and not presented here, but can be viewed in the main body of the report in Tables 3-7 through 3-9.

Biomass co-firing during this verification did not impact the quality of the ash with regard to fly ash TCLP metals (40 CFR 261.24). Metals content was well below the TCLP requirements for all tests as shown in Table 3-8. Ash results did not meet the Class F Requirements (C 618-05) for use in concrete for either the baseline or co-fired fuels.

Sustainability Issues

- The REC receives woody biomass based fuel from the neighboring Blandin Mill and a wide variety of commercial suppliers throughout the northern plains region. During the first 6 months of 2007, the facility received a total of approximately 173,000 tons of woody biomass based fuel. Of that, approximately 83,000 tons came from the Blandin Mill, and the remaining 90,000 tons were purchased from commercial providers.

- Fuel and emissions associated with transportation of woody biomass to the Blandin Mill are not considered in this analysis since the woody biomass is transported to the facility whether used as fuel or not. Collected data show that approximately 33,000 gallons of diesel fuel was used to transport woody biomass based fuels from commercial suppliers to the REC (equating to an estimated 0.37 gallons per ton of woody biomass delivered). Based on an Energy Information Administration emission factor of 19.564 lbs CO_2/gallon, CO_2 emissions per ton of woody biomass based fuel transported to the facility are:

  7.2 lbs CO_2 / ton woody biomass (0.37 gal fuel /ton pellets * 19.564 lbs CO_2/gal).
  648 tons CO_2 annually (7.2 lb/ton * 180,000 tons woody biomass delivered annually).

- Based on data generated during this testing, the CO_2 emission rates while firing straight coal and blended fuel (at a blending rate of approximately 92 percent woody biomass by mass) were 160 and 165 lb/MMBtu, respectively. However, combustion of wood-based fuel, which is composed of biogenic carbon, emits no appreciable CO_2 emissions under international greenhouse gas accounting methods developed by the IPCC and adopted by the ICFPA [6]. By analyzing the heat content of the coal and the woody biomass, the total boiler heat input for the test periods, and boiler efficiency, it was determined that approximately 90 percent of the heat generated during co-firing test periods is attributable to the wood-based fuel. It is therefore estimated that the CO_2 emissions offset during this testing is approximately 90 percent, or 148 lb/MMBtu at this co-firing blend. REC Boiler 5 typically operates around 220 MMBtu/hr heat generating rate. Assuming an availability and utilization rate of 75 percent for Boiler 5 at this heat rate, this would equate to estimated annual CO_2 emission reductions of approximately 107,000 tons per year.

- The mass of woody fuel needed to provide an equal amount of heat is much greater. During baseline testing, an average 31,600 lb/h coal was consumed. During co-firing, fuel feed rates for coal and woody biomass averaged approximately 6,470 and 75,200 lb/h, respectively.

- Biomass co-firing during this verification did not impact the quality of the ash with regard to fly ash TCLP metals (40 CFR 261.24). Metals content was well below the TCLP requirements for all tests. Ash results did not meet the Class F Requirements (C 618-05) for use in concrete for either the baseline or co-fired fuels. As such, biomass co-firing did not impact either sustainability issue since the quality of the ash with regard to fly ash TCLP metals and Class F Requirements was unchanged.

Details on the verification test design, measurement test procedures, and Quality Assurance/Quality Control (QA/QC) procedures can be found in the Test Plan titled *Test and Quality Assurance Plan – Environmental and Sustainable Technology Evaluation Biomass Co-firing in Industrial Boilers.* (Southern 2006). Detailed results of the verification are presented in the Final Report titled *Environmental and Sustainable Technology Evaluation Biomass Co-firing in Industrial Boilers – Minnesota Power's Rapids Energy Center* (Southern 2007). Both can be downloaded from Southern's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

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Notice: This verification was based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The EPA and Southern Research Institute make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and Local requirements. Mention of commercial product names does not imply endorsement or recommendation.

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