Co-firing of Biomass and Opportunity Fuels in Low NOx Burners

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Abstract

Solutions for simultaneous firing of biomass and other opportunity fuels with coal have gained increasing interest in the recent past. Many utilities are taking advantage of co-firing cost-effective biomass fuels with pulverized coal for green house gas reduction, SO2 and NOx reduction, and to increase the production of environmentally advantageous, renewable green power. Co-firing of production wastes or fuels such as petroleum coke, coal-water slurry, and tire-derived fuel can increase plant competitiveness through reduced fuel costs.

Biomass or opportunity fuel co-firing can be retrofit to most pulverized coal units. Apart from secondary fuel storage and handling, integration of the co-firing equipment into the existing burner system is one of the major tasks of such a retrofit. Full load coal capability, NOx emissions, boiler performance and equipment integration and long term reliability are major considerations when modifying low NOx combustion equipment to include biomass or other co-firing fuels.

Foster Wheeler has long been a leader in developing cost effective biomass firing systems. The paper presents the design considerations when biomass or opportunity fuels are to be fired in wall-fired and tangential fired pulverized coal boilers. Installing a burner specifically designed for firing two or more dissimilar fuels can optimize co-firing. The paper outlines the design concepts applicable to this approach to biomass co-firing.

Introduction

Cofiring, the simultaneous combustion of dissimilar fuels in one boiler, is a highly promising technology for using biomass and other opportunity fuels in large-scale utility boilers. Historically, cofiring of biomass production wastes in stoker-fired boilers is not new. A variety of techniques are available for industrial boilers /1/. The combustion technology most commonly used in steam boilers of the pulp and paper industry is the travelling grate in spreader-stoker boilers. These systems readily lend themselves to cofiring. It is common for pulp mill power boilers to be fired with combinations of wood waste, coal, pulp mill sludge, and other fossil fuels and wastes as well. Such firing maximizes responsiveness to changing load conditions while minimizing fuel costs.

The application of biomass cofiring technology to utility boilers requires innovative adaptation of existing technologies in materials handling and combustion. The larger capacities of such boilers, the higher main steam pressures (typically 2,400 psig or 3,500 psig) and the incorporation of reheat steam into the boilers imposes significant demands on the design and operation of these units that does not exist in industrial boilers. Further, the capacities of these units require fuel flows which significantly exceed those of even the largest pulp mill power boilers. Utility coal-fired boilers are typically either pulverized coal (PC) units or cyclone units. Most PC units are typically fired either in wall-fired or tangentially fired configurations.

Cofiring has been shown to be an effective means for greenhouse gas mitigation. Carbon dioxide (CO_2) generated from the combustion of fossil fuels such as coal is often considered to be one of the critical greenhouse gases. Methane (CH_4), which can be generated in landfills from the decomposition of organic matter such as wood waste, is also considered to be a greenhouse gas. Cofiring is an effective means for greenhouse gas mitigation by using biomass to displace fossil fuel and, simultaneously, removing such biofuels as wood waste, agricultural materials, and non-recyclable paper from the waste stream being interred in landfills. Apart from mitigating greenhouse gases, biomass cofiring also provides a low cost approach to increasing generation capacity for “green power” without major changes to existing equipment.

Research on developing appropriate, broadly applicable techniques for cofiring biofuels in utility boilers began in 1992, with a research project of the Electric Power Research Institute (EPRI), the Tennessee Valley Authority (TVA), and the U.S. Department of Energy (USDOE). Simultaneously, Southern Company conducted engineering studies and test programs. Since the initial engineering studies, significant cofiring testing has occurred at numerous plants as listed in /1/. They led to extensive cofiring demonstrations and full-scale deployments. Recent full-scale demonstrations include cofiring at Bailly Generating Station and Seward Generating Station /3/. These tests were performed with the support of EPRI, US DOE EERE, US DOE FETC, NIPSCO and GPU Generation.

Fuel Characteristics of Coal and Biomass

If biomass cofiring is planned for a coal fired boiler, several fuel related impacts have to be considered. Table 1 compares analyses of sawdust and switchgrass to those of two typical coals, a high volatile eastern bituminous coal and a western sub-bituminous PRB coal.

Proximate Analysis		**Sawdust**	**Switch-grass**	**Black Thunder (PRB)**	**Illinois #6**
Fixed Carbon (FC)	%	9.34	12.19	34.94	44.98
Volatile Matter (VM)	%	55.03	65.19	30.72	35.32
Ash	%	0.69	7.63	5.19	7.43
Moisture	%	34.93	15.00	29.15	12.27
Ultimate Analysis					
Carbon	%	32.06	39.68	51.30	66.04
Hydrogen	%	3.86	4.95	2.87	4.38
Oxygen	%	28.17	31.77	10.46	5.66
Nitrogen	%	0.26	0.65	0.68	1.40
Sulfur	%	0.01	0.16	0.35	2.79
Higher Heating Value	Btu/lb	5431	6601	8888	11731
Higher Heating Value	MJ/kg	12.62	15.34	20.66	27.26
FC/VM Ratio		0.17	0.19	1.14	1.27
lb Fuel N/10^6 Btu		0.48	0.98	0.77	1.19
lb Fuel S/10^6 Btu (as SO_2)		0.04	0.48	0.79	4.76

Table 1: Differences of Fuel Analyses, Biomass and Coal

The data in Table 1 highlight some of the critical differences between the biofuels and coals. Note the low sulfur content, increased moisture content, and the reduced heat content of the biofuels when compared to typical US coals. Biofuels have significantly higher volatile matter contents than coals and their Fixed Carbon/Volatile Matter Ratio is much below unity. High volatile matter coals such as Powder River Basin coals typically have values close to unity. PRB coals are known for low NOx emissions in low NOx combustion systems. Coals with lower volatile matter content show increased NOx emission.

In addition, many biofuels have low nitrogen contents which also leads to low NOx emissions, due to decreased fuel nitrogen conversion to NOx. This characteristic is not universal, however. Biofuels such as alfalfa stalks, rice hulls, and clean urban wood waste can contain concentrations of fuel nitrogen that are higher than most coals when measured in lb N/10^6 Btu. Biomass typically contains less sulfur, which favorably influences the sulfur emissions when cofiring. The data in Table 1 also demonstrates the possible variability among biofuels in nitrogen content, ash content, and moisture content. However, the two biofuels shown compare favorably to coals with respect to combustion parameters. Thus, biofuels are low NOx fuels and cofiring of biomass can reduce the NOx emissions from coal fired boilers.

The differences discussed here influence the combustion of and emissions from biomass cofiring. However, other fuel properties such as HHV, bulk density and moisture have significant impact on the fuel handling and storage. Since the ash composition of biofuels is different from that of coals, the implications on furnace heat transfer and fouling need to be considered. Lastly, high moisture biomass reduces boiler efficiency due to the additional fuel drying energy required.

Thermogravimetric Analyses (TGA) demonstrate that the biofuels begin releasing volatiles at a lower temperature, and much more rapidly compared to coals. The increased volatility of the biofuels is among the most critical considerations in cofiring. The biofuel particles volatilize earlier and independently of the fossil fuel particles. This does cause some key changes in fuel particle-particle interactions, including reducing the ignition temperature of the mass of the fuel. These changes need to be considered when designing a burner for cofiring of biomass.

Cofiring Biofuels in Pulverized Coal Boilers

Utilities seeking to cofire biomass in their boilers can use two distinct approaches or techniques:

- biomass and/or other opportunity fuels can be blended with coal in the coal yard, and the blend can be transported to the bunkers and then the firing system; or

- biofuel is transported separately from the coal, and it can be injected into the boiler without impacting the coal supply or delivery process.

The first approach has been used with less than 5 percent biomass (mass basis) in PC boilers and at moderate percentages (e.g., <20 percent cofiring on a mass basis) for cyclone boilers. Blending dissimilar fuels in the coal yard is particularly useful for cyclone boilers as demonstrated at Bailly Generating Station of NIPSCO and at the Allen Fossil Plant of TVA /3,4/. Both urban wood waste and petroleum coke were being blended with coal. Foster Wheeler is the prime contractor for the USDOE-EPRI cofiring program.

On PC fired boilers, results show that blending biofuels with coal in the fuel pile had significant impacts on pulverizer performance /3/. Blending small quantities of sawdust into coal reduced pulverizer capacity due to changes in fuel moisture and Hardgrove Index. Unless there is significant excess mill and drying capacity or a spare mill, blending biofuels into the coal before the pulverizer may lead to significant capacity derating of the boilers.

Thus, the second approach is most applicable to PC boilers firing more than 10 percent biomass (mass basis). Separate injection permits careful management of fuels with very low bulk densities - fuels that are not readily blended with coals. Apart from secondary fuel storage and handling, integration of the co-firing equipment into the existing burner system is one of the major tasks of such a retrofit. NOx emissions, boiler performance and equipment reliability are major considerations when modifying low NOx combustion equipment to include biomass or other co-firing fuels. The following sections of this paper will focus on the firing equipment for the separate biomass cofiring on tangentially and wall fired furnaces.

Separate Biofuel Cofiring in Tangentially Fired Boilers

In tangentially fired furnaces fuel and air nozzles can be mounted in the corners or in the walls of the furnace. The nozzles are arranged in alternating sequence as displayed in Figure 1. The fuel and air jets are directed towards a common firing circle in the center of the furnace, which results in a swirling flow pattern in the entire furnace. This principle is well known in the power generation industry as tangentially or corner fired furnace. Figure 1 shows a Foster Wheeler Low NOx Tangential Firing System TLN2 with separate Secondary Air Staging /5/.

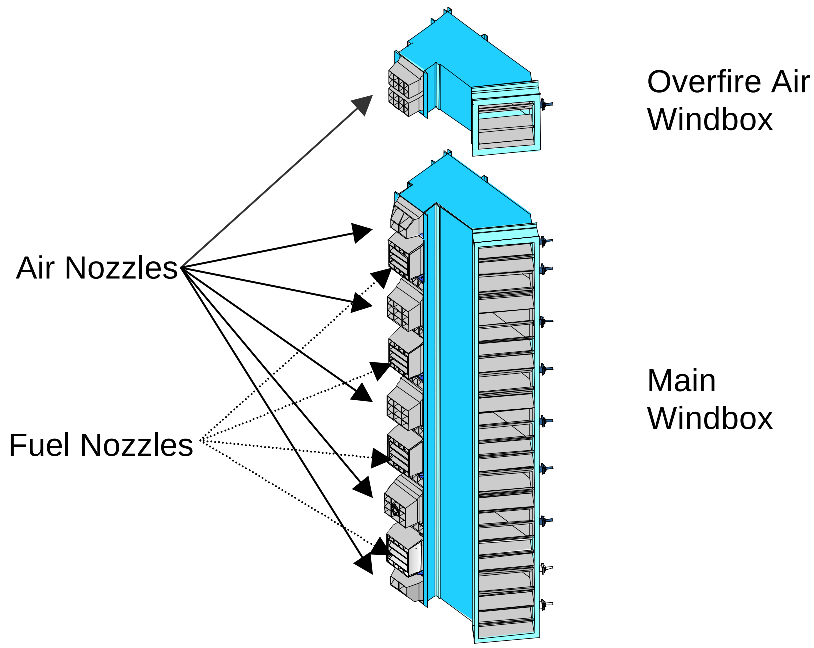

Figure 1: FW TLN2 Tangentially Fired Low NOx System

There are four possible methods of retrofitting biofuel injectors to tangentially fired boilers. To avoid separation of the biofuel from the main firing cycle and assure sufficient furnace mixing the biofuel injectors should be directed towards the common firing cycle.

- Injection through the air compartments in the main windbox
- Injection coaxial with the coal nozzles
- Injection with biofuel nozzles replacing coal nozzles
- Injection through separate furnace wall penetrations

Of these possibilities the first two require redesign of the air and fuel nozzles, respectively. A custom fuel injector needs to be designed to fit into the windbox between the fuel nozzles or to be integrated into the coal fuel nozzles. Cofiring demonstrations at Alliant Power’s 700 MWe Ottumwa Generating Station and Alabama Power’s Gadsden Station will use separate biofuel nozzles for switchgrass integrated in the auxiliary air compartments. The Federal Government is sponsoring this project. Solutions for replacing unused oil compartments for smaller biofuel quantities are available. Since biofuels have very high reactivity and volatility, care must be taken to protect the biofuel nozzle and adjacent air nozzles from overheating.

If the current firing system has sufficient milling capacity, the third approach might be advantageous. Either an entire mill is taken out of service and the respective coal nozzles are replaced with biofuel nozzles, or a few pipes of the mills are disabled to allow integration of the biofuel nozzles.

Low NOx tangential firing systems divert part of the secondary air at the burner nozzles to an overfire air system. Thus, the lower furnace is at or below stoichiometric conditions. As a consequence, NOx is reduced but complete burnout is delayed until full excess air level is attained at the elevation of the overfire air nozzles. The high volatility of the biomass is generally beneficial for the NOx emissions of the furnace. However, any fuel and air imbalance on such a system likely increases the generation of CO and unburned carbon due to locally very high fuel concentrations. This has to be kept in mind when cofiring biofuels on low NOx tangentially fired boilers. The high volatile biomass competes with the coal for oxygen. If the air supply is not sufficient to maintain combustion progress for both fuels, coal burnout will be significantly delayed and high unburned carbon levels and increased CO emissions are to be expected.

Separate Biofuel Cofiring in Wall Fired Boilers

Integration of biofuel firing system into a wall fired boiler can be far more challenging than for a tangentially fired boiler due to the many different burner designs on the market. Wall firing systems are generally designed as single wall fired furnaces or opposed fired furnaces. The burners have one or two concentric annuli around a central fuel nozzle that supply combustion air. The air is swirled to control flame stability and local flame mixing. In Low NOx burners the flame core is kept substoichiometric to reduce the tendency of nitrogen compounds to form nitrous oxides. As an example, Figure 2 shows the Foster Wheeler Vortex Series/Split Flame Low NOx Burner. In addition to the dual air zone described above, this burner has a specially designed coal nozzle to provide local fuel staging and enhanced ignition /6/.

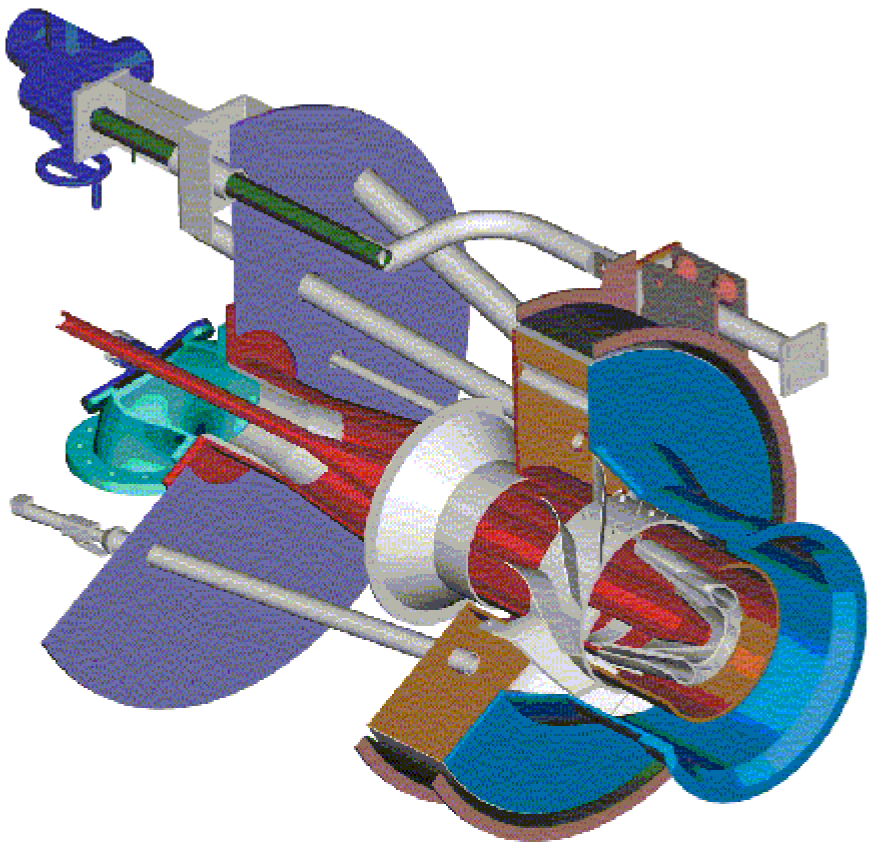

Figure 2: FW Vortex Series/Split Flame Low NOx Burner

Biofuel can be introduced into a wall fired burner by

- Injection coaxial with the coal nozzles
- Injection with biofuel nozzles replacing coal nozzles
- Injection through separate furnace wall penetrations

Of these, only the coaxial injection of the biofuel into the coal flame has been tried successfully at this point. The conversion of entire burners to biofuel burners creates the challenge that the burner air control needs to be truly independent for the biomass burners, because the air requirement of both fuels are quite different. Since furnace mixing in wall fired boilers is more limited compared to tangentially fired boilers, the injection of biomass through separate furnace wall penetrations might create the additional challenge of achieving sufficient furnace mixing. However, if sufficient injection ports are provided, biofuel injection between main firing zone and overfire air might be an effective approach for NOx reduction with reburn technology.

Separate injection of sawdust in a wall fired burner has been demonstrated at GPU Generation's (now Sithe) Seward Station. Cofiring up to 20 percent by mass (10 percent by heat) had been successfully tested in this unit /2,7/. Seward Unit 12 is a 32 MWe wall fired pulverized coal boiler. It has two rows of burners, with each row having three burners. The burners are B&W single air zone coal burners, similar to the one shown in Figure 3. Coal is injected trough a center pipe and distributed by a spreader at the fuel nozzle. The conical spreader diverts the coal into the swirled air, which generates a highly turbulent flame with good mixing and burnout. However, since the burners are uncontrolled, NOx emissions of this boiler are quite high.

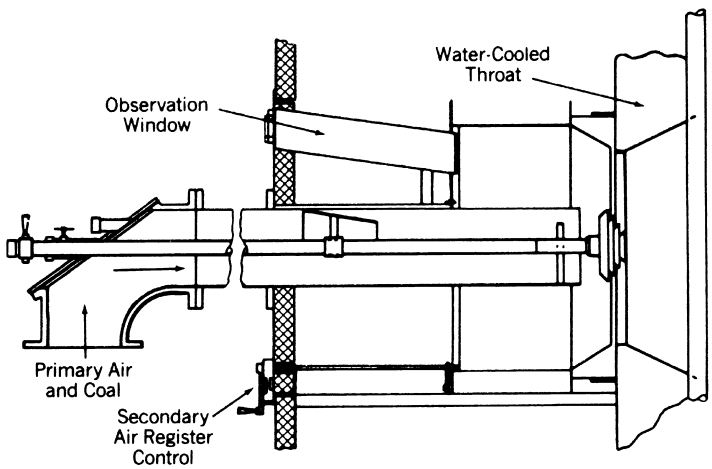

Figure 3: B&W uncontrolled coal burner (pre-NSPS)

The center burners of each row were fired with coal and biomass during the demonstration. The separate injection technique used at Seward Boiler # 12 involved a minor modification to the burner, firing the sawdust down the center pipe and diffusing it into the coal flame in the furnace. A special central biomass injector was designed to deliver the sawdust on the burner axis to the exit point at the coal nozzle. A new spreader was developed to divert the sawdust outwards in order to prevent the biofuel from penetrating the internal recirculation zone.

The sawdust fired had an analysis similar to that in listed in Table 1. The coal burned at Seward Generating Station is a low volatile bituminous coal with a volatile matter content of typically 22 percent and an ash content of 15 percent (both as received). The testing was conducted cofiring up to 15 percent by mass (7 percent by heat). Load was varied between 65 percent and 100 percent and excess oxygen was varied between 3 and 4.5 percent.

Figure 4 shows the trend of the NOx emissions with increasing mass percentage of sawdust. The data was normalized for a common load and excess air to account for the variations during the testing. It can be seen that more than 10 percent NOx reduction was achieved during the demonstration tests with a maximum of 15 percent cofiring. Earlier parametric tests in 1997 showed that more than 15 percent NOx reduction can be achieved with less than 20% cofiring.

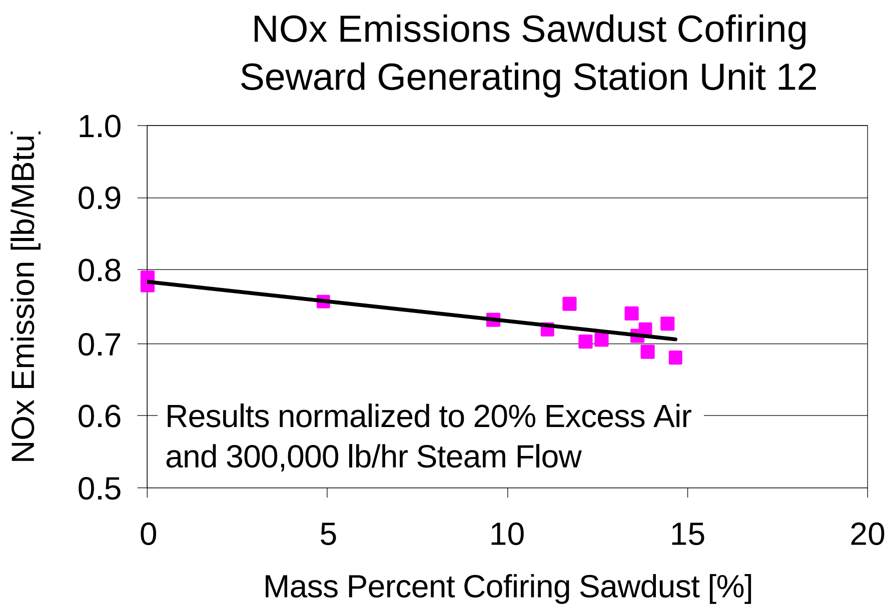

Figure 4: Normalized NOx Emissions as a Function of Biomass Cofiring Percentage at Seward Generating Station

The reductions show the impact of the reduced nitrogen content of the sawdust and the impact of the injection method. The high volatile sawdust essentially creates a zone of low oxygen in the flame core producing combustion conditions that are more similar to Low NOx burner flames. This is supported by the finding that very low percentages of sawdust cofiring increase NOx slightly, because sawdust transport air introduces additional oxygen to the flame root that is not immediately consumed by the high volatile biomass.

The Seward tests provide valuable experience when cofiring biomass in wall fired burners. The differences in volatile matter contents and fuel reactivity between coals and biomass create a challenge to integrate a biomass injector into a Low NOx burner. The large number of different Low NOx burner designs adds to the complexity of the biomass injector design. The low nitrogen and high volatile matter content of the biomass can significantly enhance low NOx combustion, because volatile matter is the key factor in creating Low NOx combustion conditions in flames. Biomass can enhance burner stability due to the early release of volatiles, especially when cofired with low volatile coals.

Therefore, biomass can offset the negative impacts of low volatile petcoke when tri-firing these opportunity fuels with coal. This has been successfully demonstrated at Bailly Generating Station.

Biofuels can be introduced to a low NOx burner flame with a separate injection lance on the burner axis as demonstrated at Seward Station. The high volatile biofuel in the center of the flame rapidly consumes the oxygen and results in very low excess air levels that promote NOx reduction. However, Low NOx burners have already primary flame conditions with low oxygen levels and care must be taken to provide sufficient oxygen to both biofuel and coal in order not to delay combustion which might have a negative impact on flame length and burnout. It is essential that the biofuels is properly dispersed into the flame.

As an alternative, biofuel can be injected in such a manner that it surrounds the coal stream fully or partially. While basically the same considerations on the local availability of oxygen are valid, this approach can be beneficial to support the coal flame root. For biofuels with significantly lower nitrogen loading than the coal to be fired it can result in sizable additional NOx reduction, because reaction kinetics at the border to the main air stream are different.

The best design depends mostly on the fuels to be fired and their volatility and NOx generation tendency. As mentioned in the fuel comparison section above, TGA analysis shows that the biomass reactivity is very high compared to even the most reactive coals such as lignites and PRB type coals. The differences between the fuels can be an advantage or a liability when designing a Low NOx burner for cofiring.

Aside from fuel characteristics, the transport system conditions and biomass moisture are additional impacts on a burner design. The Low NOx coal burner's reliability and performance must be maintained, if the biofuel should not be available. Since most cofiring applications in the US will be retrofits, the final design depends also on the type of the existing Low NOx burner to be retrofitted with a biofuel firing system.

Conclusions and Prospectus

Recent demonstrations of biomass cofiring have shown that biofuels are a viable option for cost effective reduction of greenhouse gases and other emissions on coal fired utility boilers. Solutions for tangentially and wall fired boilers are available. Biofuels show significant differences in volatility, reactivity and ash characteristics when compared to coals. These differences need to be considered when a biofuel firing system is to be integrated into the existing Low NOx firing system.

Ongoing and planned demonstration projects will further broaden the experience with Low NOx cofiring of very dissimilar solid fuels. In view of proposed tax incentives for cofiring biomass it is also expected that new projects will grow in size to demonstrate the economic advantages of the approach.

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