RESULTS FROM THE CHARITON VALLEY BIOMASS PROJECT SWITCHGRASS CO-FIRE TESTING

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Introduction

From November 30, 2000, through January 25, 2001, the Chariton Valley Biomass Project co-fired 1,269 tons (1,151 tonnes) of switchgrass at rates up to 17 tons/hour (15 tonnes/hour) at Alliant Energy's Ottumwa Generating Station in Chillicothe, Iowa. Various improvements were made to the feed-handling system during testing and data was collected on boiler performance and power plant emissions. This paper presents a description of the feed-handling system used for the testing and some of the key results and lessons learned.

Background & Project Partners

The Chariton Valley RC&D in Centerville, Iowa, is leading a project to investigate the economic, environmental and agronomic effects of growing switchgrass (*Paniium vigatum*) for electricity production in Southeastern Iowa. The Chariton Valley Biomass Project is jointly sponsored by the U.S. Department of Energy and the U.S. Department of Agriculture. The co-fire testing at Ottumwa Generating Station (OGS) is only a part of the much larger project that includes studies of gasification, switchgrass harvesting, fertilizer requirements, seeding methods, runoff, and effects on native wildlife.

Alliant Energy hosted the co-fire testing at its Ottumwa Generating Station in Chillicothe, Iowa, just ten miles northwest of Ottumwa. The National Renewable Energy Laboratory (NREL) provided onsite test coordination for the entire two months of testing and conducted much of the data analysis, with the support of Sandia National Laboratories. Startup support was provided by the Danish consulting firm Tech-wise A/S (formerly Elsamprojekt), T.R. Miles Technical Consultants, Inc. of Portland, Oregon, and Delta Process Technologies of Mobile, Alabama. The switchgrass for the testing was harvested by Prairie Lands Bio-Products, Inc. The operating personnel during testing were provided by Prairie Lands and Kelderman Manufacturing, Inc. of Oskaloosa, Iowa.

There were three goals of this first of three planned co-fire test campaigns. The first goal was to confirm that there were no adverse effects on the boiler performance. The second goal was to determine the effect of co-firing on power plant emissions. The last goal was to gather a better understanding of the characteristics of ground switchgrass for the design of future feed-handling systems.

The Ottumwa Generating Station

Ottumwa Generating Station is a 725 MW_{gross}/675 MW_{net} pulverized coal, dual cyclone boiler with no dividing wall and one reheat pass. The plant burns low-sulfur (0.5%) sub-bituminous Wyoming Powder River Basin coal from the Cordero Mine near Gillette, Wyoming. Switchgrass was fired in one of the two fireballs using two Foster Wheeler designed nozzles in opposing corners of the east fireball. There are seven levels of burners at OGS and the switchgrass nozzles were located between the third and fourth coal burners from the bottom. The boiler is equipped with a hot-side electrostatic precipitator (ESP), but has no NO_x or SO_2 control.

Switchgrass Feed-Handling System

The switchgrass fuel for the co-fire testing was produced by Prairie Lands and delivered in 3'x3'x8' (0.9x0.9x2.4 m) bales and 3'x4'x8' (0.9x1.2x2.4 m) bales, weighing 700 lbs (318 kg) and 1,000 lbs (454 kg), respectively. An attempt was made at feeding round bales into the system, but because of density differences between the inner and the outer layers of the bales, it was difficult to feed them evenly. The as-received moisture was consistently below 15%, which is the approximate field-dried moisture. All bales were stored indoors after harvesting. The average bale moisture from samples collected during testing was 11%. A limited number of samples were collected for fuel analysis. In addition, the nodes in the switchgrass were analyzed separately from the total switchgrass sample. Table 1 compares the fuel compositions.

Table 1. Switchgrass and Coal Fuel Analyses

Property	Unit	PRB Coal	Switchgrass	Nodes
Moisture (as received)	%	33.52	6.34	7.22
Ash (dry basis)	%	8.24	5.70	2.75
Volatiles (dry basis)	%	43.60	78.84	81.75
Fixed Carbon (dry basis)	%	48.16	15.46	15.50
HHV (as received)	Btu/lb	7,774	7,458	7,631
HHV (as received)	kJ/kg	18,082	17,347	17,749
HHV (dry basis)	Btu/lb	11,696	7,965	8,225
HHV (dry basis)	kJ/kg	27,204	18,527	19,131
C (dry basis)	%	67.98	48.41	49.49
H (dry basis)	%	4.48	5.06	5.35
N (dry basis)	%	1.16	0.56	0.37
S (dry basis)	%	0.55	0.12	0.05
Cl (dry basis)	%	0.02	0.14	0.06
Na2O (dry basis)	%	0.067	0.003	0.003
K2O (dry basis)	%	0.004	0.809	0.438

Several changes were made to the feed-handling system over the test period. Figure 1 shows the final design of the feed handling system. Bales were retrieved from storage using a telescoping fork truck with a special fork attachment for pushing off the bales. Bales could be handled three at a time and were lowered onto a 10' wide (3 m) platform with a drag chain conveyor feeding a Bale Chopper C5000 de-baler. The twine from the bales was removed manually to prevent it from wrapping around shafts in the downstream processing equipment.

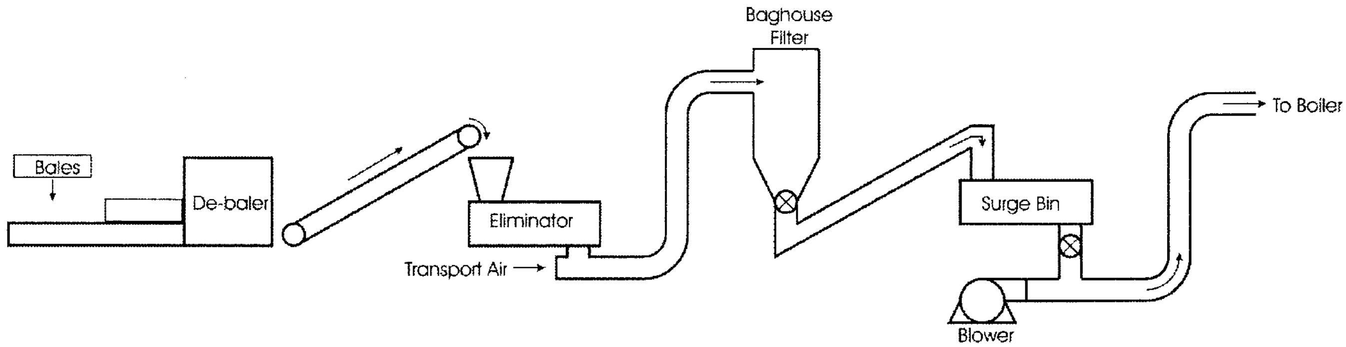


Figure 1. OGS Feed-Handling System

The Bale Chopper was driven by the Power Take Off (PTO) of a tractor, but the unit is also available with a 75 hp (56 kW) electric drive. The speed of the bale conveyor could be adjusted and was the primary means for controlling the switchgrass flow to the boiler—the downstream equipment was normally operated in starve-fed mode. The switchgrass material leaving the de-baler was still long and stingy, up to several feet (0.5 m) in length and had a density of only 1-4 lb/ft^3 (16-64 kg/m^3). The material was pushed out of the de-baler with a high-speed screw conveyor then the material was blown across a gap using an air knife. At low flow rates the air knife was very effective at removing rocks and other debris, but at higher flow rates, the mat of switchgrass was too thick to allow rocks to drop out.

The material that passed over the air knife was blown onto a belt conveyor that dropped the material into the inlet of an Eliminator grinder. The Eliminator could be described as an attrition mill, consisting of two shafts with 1"x2"x8" (2.5x5x20 cm) bars, running at 1300 rpm. Early tests using the Eliminator provided promising results grinding switchgrass, but because the unit was originally designed for granular or aggregate material, several modifications were required for it to work effectively on switchgrass. Unlike an hammer mill or tub grinder, the Eliminator did not have an outlet screen, so particle size was determined based upon the residence time in the grinder and the amount of material being processed. While this requires changing the physical layout of the equipment and adjusting the suction at the outlet of the grinder, there is no screen to blind or plug. Because of the attrition effect, the particle size actually *decreased* with higher switchgrass flow rates.

As the individual switchgrass stems passed through the Eliminator, the stem would be split lengthwise and be broken up into flat pieces about 1/8" (3 mm) in width and less than one inch (2.5 cm) in length. Because the pieces of stem were less than 1/16" (1 mm) in thickness, they quickly burned in suspension with the pulverized coal. A significant amount of dust was created during grinding, but the nodes—where the individual sections of stem come together—were not reduced in size. These nodes would simply drop to the bottom of the boiler without burning and be sluiced out to the ash pond with the bottom ash.

The entire stream of material leaving the Eliminator was directed through a baghouse, with some additional air being added to aid in the transport of the switchgrass. The baghouse was a Farr Big Round Filter, where the material would enter the baghouse tangentially, like in a cyclone. The larger pieces of switchgrass would simply fall to the bottom of the baghouse and the smaller material would form a cake on the bags, which were continuously cleaned using high-pressure air jets from a rotating cleaning arm on the clean side of the baghouse. By keeping all equipment downstream of the Eliminator enclosed and under a negative pressure, dust in the processing building was kept to a minimum. An enclosed tube conveyor (consisting of a belt laid into a curved trough) transferred the material from rotary valve in the bottom of the baghouse to a surge bin feeding material to the pneumatic transport system going to the boiler. A slight negative pressure was pulled on this conveyor and on the surge bin to prevent dust from entering the processing area, but the airflow for this portion of the dust collection system was relatively low.

The surge bin had been designed with two pairs of variable speed screws in the bottom to allow material to be metered to the boiler. However, switchgrass bridges very easily and would sometimes cause binding of the feed screws or rat-holing with large switchgrass inventories in the bin. It was therefore decided that the bale feed rate would be used to control the switchgrass flow to the boiler, so most of the time the surge bin was run empty with the screws at maximum speed. With some design improvements, it would have been possible to run the surge bin as a metering bin.

Each pair of screws fed a 20"x25" (51x64 cm) diameter Western Pneumatics rotary airlock, which, in turn, fed a dilute-phase pneumatic transport line. Each of the two transport lines was 10" (25 cm) in diameter and 550 feet (168 m) long and had a 100 hp (75 kW) Gardner Denver positive-displacement, rotary-lobe blower. The total pressure drop through the lines was less than 2 psi (14 kPa). During the two months of testing, these lines never plugged. The rotary airlocks, however, had some problems with the dusty material and probably should have been larger. Each blower operated at about 3,000 scfm (1.4 m^3/s) for a transport velocity of 100 ft/s (28 m/s). Lower transport velocities have been used in other installations; the minimum velocity for transporting the switchgrass is about 30 ft/s (9 m/s).

Minimal controls were used for this round of testing. The OGS control room had indicators showing when the blowers and feed system were operating and there was an emergency stop and a boiler trip indicator tied into the switchgrass system's Programmable Logic Controller (PLC). Switchgrass operators had manual controls for most equipment and Motor Control Center (MCC) controls for the baghouse equipment and surge bin screws.

Boiler Performance

During this round of testing, only qualitative observations were made of boiler performance. Sandia National Laboratories installed a data acquisition system to collect boiler pressure and temperature data, but this was primarily used for confirming stable operation and to troubleshoot operational problems, if they occurred.

While the switchgrass only contributed 2-3% to the total heat input to the boiler, there was the possibility that the additional fuel and air entering through the pneumatic transport system might affect the automatic fuel and oxygen controls at OGS. Pre-startup checks confirmed that the small amount of air entering through the pneumatic transport system did not effect the boiler oxygen controls and at high switchgrass flows over 12 tons/hour (11 tonnes/hour), it was possible to see the coal mill controls automatically back-off on the coal flow in response to the switchgrass fuel input to the boiler. No cycling was observed and the coal flow would completely level off at the new rate within ten minutes.

Inspections immediately after shutdown showed no unusual slag or buildup in the boiler. Based upon the limited number of samples collected, there was no noticeable difference in the fly ash composition or unburned carbon. As mentioned previously, the nodes from the switchgrass were too heavy to remain suspended in the boiler and would drop to the bottom of the boiler and get sluiced out to the bottom ash pond. The nodes showed little or no charring, but did not cause any operational problems. The bottom ash is primarily used in landscaping applications, so the presence of nodes is acceptable.

One benefit of using an independent injection system for the switchgrass was that there was no de-rating of the boiler capacity—if the boiler output began to drop on switchgrass, 100% of the coal system capability was still available, unlike in co-firing configurations where the biomass is mixed with the coal in the bunker. The OGS boiler is induced-draft fan limited, so as the normally scheduled maintenance shutdown and cleaning approached, the pressure drop through the reheat and superheater sections of the boiler increased from 1.0 inches of water to 2.9 inches of water, limiting power production. This, however, is typical for the OGS boiler, but was made worse by the failure of one bank of soot blowers before switchgrass testing began.

Power Plant Emissions

There were three sources of emissions data for the co-fire testing. First, the OGS boiler is equipped with a continuous emissions monitoring (CEM) system to measure stack opacity, NO_x, SO_2, CO_2 and O_2. These readings were recorded every four minutes, although hourly averages were used for analyzing co-fire emissions. Second, a portable Orsat gas analyzer was used to measure NO_x, CO and O_2 levels leaving the economizer, leaving the ESP and leaving the air heater. Finally, two stack tests were conducted to determine CO and particulate matter (PM) emissions: one when burning coal and one when firing switchgrass at rates of 4-6 tons/hour (3.6-5.4 tonnes/hour).

While the switchgrass only represented 2-3% of the total heat input to the boiler, soda ash is currently added to the coal feed to control the fly ash resistivity, so there was some concern that the high alkali content of the switchgrass could affect ESP performance. This was apparently not the case because there was no change in opacity based upon the CEM data and although there's some question about the reliability of the PM results from the stack test, there was no evidence of any increase in particulate emissions.

Previous co-fire tests indicated that biomass might help reduce NO_x emissions from coal-fired boilers. During this test campaign the NO_x emissions did not change significantly and may have gone up slightly when co-firing, but were well within the normal range. The average NO_x level during baseline coal-only testing was 0.352 lb/MM Btu. An early attempt was made to compare daily NO_x emissions when co-firing with those days when no co-firing occurred, but it was discovered that there was a strong correlation between the power plant load and both the NO_x and SO_2 emissions: as the power plant load increases, so do the emissions. Since all of the co-firing was done during the day on weekdays, the OGS boiler was typically at full output and had correspondingly higher emissions compared to the non-cofire days, which were typically holidays and weekends. For a correct comparison, the emissions were plotted as a function of power plant load and then the co-fire data was superimposed on the base-line emissions.

Because of the difference in sulfur content between the switchgrass and the coal (0.12% vs. 0.55%, respectively), some reduction in SO_2 emissions was expected. However, a comparison of the SO_2 during co-firing with the baseline emissions of 0.654 lb/MM Btu indicated a reduction greater than that just from the fuel substitution. More data must be collected, but it is believed that the potassium in the switchgrass may tie-up a portion of the SO_2 and is subsequently captured in the fly ash.

Although carbon monoxide emissions were recorded during the stack testing, the results could not be used because operational problems caused carry-over of unburned material out of the boiler, causing abnormally high CO emissions. This was observed *when burning only coal* but resulted in high emissions during the co-fire stack testing. The Orsat gas analyzer readings detected the change in CO during stack testing, but showed no increase in CO emissions under normal operation. The baseline CO emissions were 0.0004 lb/MM Btu.

Switchgrass Feed-Handling Properties

The final goal of the co-fire testing was to gather information on the feed-handling characteristics of the switchgrass. The first discovery regarding the switchgrass was that round bales caused difficulties feeding because of the difference in density between the outer layers of the bale and the inner core. With the round bales, if the drag-chain conveyor feeding the de-baler was run at a constant speed, there were wide variations in flow rate leaving the de-baler. Surges in flow would plug the inlet to the Eliminator grinder. A similar problem was experienced with the rectangular bales when the end of a bale was reached, but did not create as many problems.

The switchgrass leaving the de-baler has an extremely low density of 1.3-4.0 lb/ft^3 (21-64 kg/m^3) and side pieces had to be added to the belt conveyor from the de-baler to the Eliminator because the mat of material might be a foot (30 cm) or more in height when running at peak feed rates. The switchgrass pieces leaving the de-baler were still 1-2 feet (0.5 m) in length and therefore were prone to bridging. If these long pieces of material entered the dust collection system and made their way to the baghouse, a plug would most certainly result in the converging bottom of the baghouse.

Leaving the Eliminator, the average switchgrass size was less than 1" (2.5 cm). The switchgrass at this point can be described as having three fractions: The largest fraction represents the main part of the stem, which is flat and about 1/8" (3 mm) in width. The plant stem ends up being split lengthwise then breaks into short pieces, as if you took a plastic drinking straw and cut it lengthwise, then cut it into pieces. The second fraction is a dust fraction that is less typically smaller than 200 microns in size. This faction, if kept separate, acts as a fluid and cannot be transported with a screw conveyor; instead it just flows out the bottom of the conveyor. If the dust is mixed with some larger material, it can be conveyed with the bigger pieces trapping the dust and pulling it along.

The last fraction of the material is the nodes. They are not reduced in size by the Eliminator and look like popcorn kernels and have a high density. It is extremely important to take the nodes into account when designing the pneumatic transport sections of the system. While the split stem and dusty material is easily transported at velocities as low as 10 ft/s (3m/s), the nodes required a velocity of about 30 ft/s (9 m/s). Although the nodes are a small fraction of the flow, if the transport velocity drops, they will quickly build up in the system when processing flows of switchgrass on the order of 15 tons/hour (14 tonnes/hour).

Even the shorter chopped pieces of switchgrass had a tendency to bridge to some degree. Although no major problems were observed moving the material through the converging cone section of the baghouse, some problems were experienced trying to move the material out of the surge bin. If the inventory in the surge bin became to great, the screws in the bottom would attempt to move the whole pile of material toward the front wall instead of just moving the material near the bottom of the pile. This would result in too much load on the feed screws and cause the drive motors to trip out. Under normal conditions, the surge bin was kept empty with the screws running at high speed.

The switchgrass after grinding would not only settle quickly to approximately 90% of its initial volume leaving the Eliminator, but it actually had a higher density than the original switchgrass bales. This is because the dust-like fraction of the switchgrass would fill in empty spaces between the larger stem pieces. The density of the material after the grinder was 9 to 18 lb/ft^3 (144-288 kg/m^3).

The most notable feature of switchgrass is the dust. Even the de-baler operation created high dust levels in the building. The initial installation of the Eliminator resulted in a positive pressure at the Eliminator outlet, which added to dust problems in the building. Eventually modifications were made so that the entire equipment train downstream of the Eliminator operated under a slight negative pressure (1-2 inches of water). It is important to note that if the system doesn't have many air leaks, this dust collection flow is relatively low—the important thing is keeping the equipment under a negative pressure so no dust leaves through the cracks between equipment.

Another problem created by the dust affected the rotary airlocks that transferred material from the surge bin into the pneumatic transport lines. The airlocks were designed with pockets having end walls, sitting inside a closely fitting housing. It is believed that dust was getting between the end of the rotating pocket and the housing wall, causing the airlock to bind up and trip out. The airlock also may have been undersized for this application.

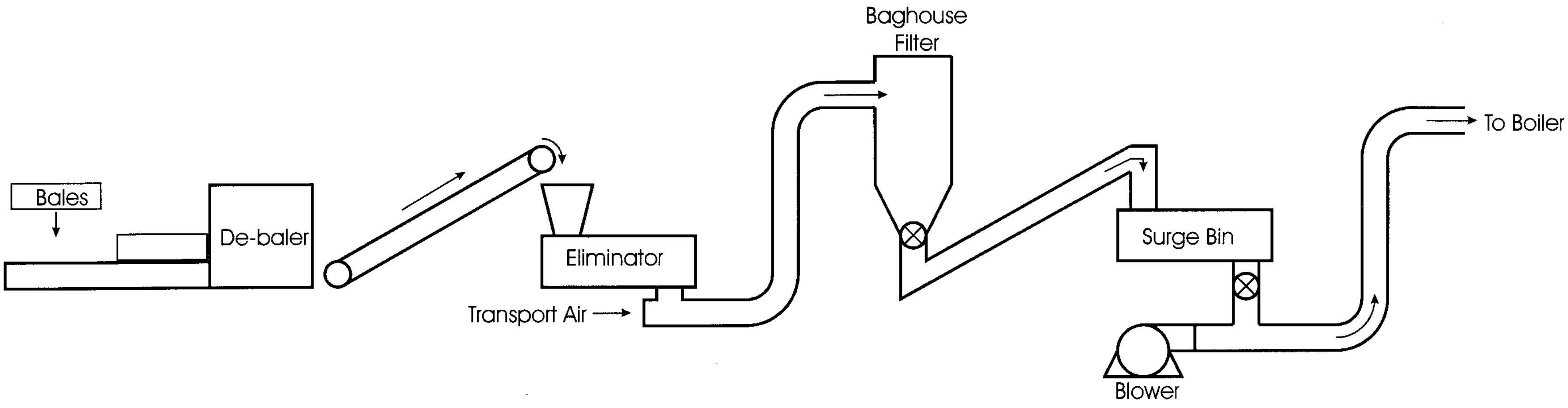
We had no problems transporting the switchgrass through the pneumatic transport lines, although there were some design issues with the compressors that were easily rectified. The boiler nozzles were designed by Foster Wheeler and appeared to work well. No increases in unburned carbon resulted from co-firing, although that it is believed that most of the nodes in the switchgrass dropped into the bottom ash without being burned. After shutdown, the OGS staff noticed no buildup around the burners from firing switchgrass.

Future Work

Chariton Valley has proposed three test campaigns to demonstrate the feasibility of co-firing switchgrass commercially. This test was used mainly to prove that there were no adverse effects from co-firing and to collect data on feed properties to help design the feed handling equipment. The second round of testing will demonstrate the ability to design and operate a switchgrass feed system that can operate continuously with little or no operator attention. Once the functionality of the equipment has been demonstrated, the third and final test campaign will be used to examine the effects of corrosion and/or erosion in the boiler. This will require a longer duration test of 2,000 hours at a design flow rate of 12.5 tons/hour. The final commercial system will be designed to co-fire at 25 tons/hour.

References

1. Amos, Wade A. (2002), *Summary of Chariton Valley Switchgrass Co-Fire Testing at the Ottumwa Generating Station in Chillicothe, Iowa*, NREL/TP-510-32424, Golden, CO, National Renewable Energy Laboratory.


Bales
De-baler
Eliminator
Transport Air
Baghouse
Filter
Surge Bin
Blower
To Boiler