DESIGNING AN OPPORTUNITY FUEL WITH BIOMASS AND TIRE-DERIVED FUEL FOR COFIRING AT WILLOW ISLAND GENERATING STATION

Quarterly Technical Report

Reporting Period: 1/1/2001 – 3/31/2001

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Report Issue Date: April 2001

DE-FC26-00NT40894

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ABSTRACT`

During the period January 1, 2001 – March 31, 2001, Allegheny Energy Supply Co., LLC (Allegheny) finalized the engineering of the Willow Island cofiring project, completed the fuel characterizations for both the Willow Island and Albright Generating Station projects, and initiated construction of both projects. Allegheny and its contractor, Foster Wheeler, selected appropriate fuel blends and issued purchase orders for all processing and mechanical equipment to be installed at both sites.

This report summarizes the activities associated with the Designer Opportunity Fuel program, and demonstrations at Willow Island and Albright Generating Stations. The third quarter of the project involved completing the detailed designs for the Willow Island Designer Fuel project. It also included complete characterization of the coal and biomass fuels being burned, focusing upon the following characteristics: proximate and ultimate analysis; higher heating value; carbon 13 nuclear magnetic resonance testing for aromaticity, number of aromatic carbons per cluster, and the structural characteristics of oxygen in the fuel; drop tube reactor testing for high temperature devolatilization kinetics and generation of fuel chars; thermogravimetric analyses (TGA) for char oxidation kinetics; and related testing. The construction at both sites commenced during this quarter, and was largely completed at the Albright Generating Station site.

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EXECUTIVE SUMMARY

The Third Quarter of the USDOE-Allegheny Energy Supply Co., LLC (Allegheny) Cooperative Agreement, January 1, 2001 through March 31, 2001, was characterized by project initiation, engineering, and initial construction activities at both the Willow Island and Albright sites. Technical work that proceeded during the second quarter of the cooperative agreement included the following:

- At Willow Island Generating Station, fuel samples were obtained and characterized completely by Pennsylvania State University (PSU). The resulting data were then analyzed by PSU and Foster Wheeler personnel. Characterizations included proximate and ultimate analyses, higher heating value determinations, Carbon 13 Nuclear Magnetic Resonance (13 C NMR) testing to evaluate fuel structure, drop tube reactor (DTR) testing to determine devolatilization kinetics and produce chars for analysis, and Thermogravimetric analysis (TGA) to determine char oxidation kinetics.

- At Willow Island Generating Station, detailed engineering by Foster Wheeler, supported by plant engineering staff proceeded and a final design was completed. Purchase orders were issued for all process and mechanical equipment, plus all electrical equipment.

- The demolition of two small buildings at the Willow Island Generating Station site was completed, including removal of old foundations.

- Fuel characterizations proceeded for the Albright Generating Station site, consistent with the fuel characterizations for the Willow Island site.

- Construction commenced at the Albright Generating Station site. All of the equipment located at the Seward Generating Station was dismantled and relocated to the Albright site. The new disc screen was received and installed, along with associated conveyors. The steel building housing the cofiring facilities at Albright was erected.

- Biomass injector nozzles were delivered and installed at the Albright Generating Station site. Two nozzles were installed at Albright Boiler #3 for firing sawdust in that tangentially fired boiler. The injection materials handling design was approved for the Albright station.

- Fuel procurement strategies were pursued and an initial bid solicitation was established based upon the Albright test.

Progress anticipated for the third quarter of this cooperative agreement—January 1, 2001 through March 31, 2001—includes significant activities pursuant to completing the construction of the Albright sawdust handling facility, and initiation of the baseline testing at the Albright site. It also includes ordering all equipment for the Willow Island site, demolition of the two small buildings on the Willow Island site, and progress on the construction of the Willow Island

facility. Progress anticipated also includes initiation of sawdust acquisition for the Albright and Willow Island sites, and completion of test planning for both sites.

1.0. INTRODUCTION

Cofiring—the firing of two dissimilar fuels at the same time in the same boiler—has been proposed for using biomass in coal-fired utility boilers. In practice, this cofiring introduces a family of technologies rather than a single technology. The family of technologies includes blending the fuels on the coal pile or coal belt, and feeding them simultaneously to any processing (e.g., crushing and/or milling) systems on their way to the boiler; preparing the biofuels separately from the coal and introducing them into the boiler in a manner that does not impact fossil fuel delivery; or converting the solid biofuels to some other fuel form (e.g., producer gas) for firing in a coal-fired or natural gas-fired installation. The Allegheny project is designed to demonstrate both direct combustion approaches to cofiring.

1.1. THE WILLOW ISLAND DEMONSTRATION

Allegheny Energy Supply, LLC will demonstrate blending wood waste and tire-derived fuel to create a new opportunity fuel for cofiring in cyclone boilers, and integrating this fuel combination with a separated overfire air system for maximum NO_x management. This project also will demonstrate the use of biomass-TDF blends to reduce SO_2 and fossil CO_2 emissions along with trace metal emissions. The demonstration will occur at Willow Island Generating Station Boiler #2. It is a 188-MW_e cyclone boiler operated in a pressurized mode and equipped with a "hot side" electrostatic precipitator (ESP). This demonstration, located in Willow Island, WV, has numerous unique features to significantly advance cofiring technology. Allegheny Energy, using Foster Wheeler Development Corporation, has completed a feasibility study for the project and plans to move directly into Phase II—construction and operation of the demonstration system.

Cofiring of wood wastes with coal has been demonstrated as an effective means for using biomass in cyclone boilers; demonstrations have occurred at the Allen Fossil Plant of TVA, the Michigan City Generating Station of NIPSCO, and the Bailly Generating Station (BGS) of NIPSCO. In these demonstrations, NO_x, SO_2, and fossil-based CO_2 emissions reductions occurred. In each case, the volatility of the wood waste created the mechanism for NO_x reduction, while the use of a sulfur-free fuel reduced SO_2 emissions. Testing at BGS opened a new area of investigation: designing blends of opportunity fuels to optimize the impacts of cofiring. At BGS, urban wood waste is mixed with petroleum coke at a specified blend to optimize NO_x emissions management while accomplishing the goals of fossil CO_2 emissions reductions. The NO_x emissions reductions at BGS are ~30 percent when firing the designed opportunity fuel blend.

The Willow Island demonstration will blend sawdust with TDF to create a new opportunity fuel for cofiring in a cyclone boiler equipped with a separated overfire air system. This demonstration will create a second opportunity fuel blend that maximizes NO_x emissions reductions from the combustion process and that can be integrated into the overall NO_x emissions management strategy using overfire air. At the same time, SO_2 emissions will be reduced along with fossil CO_2 emissions and heavy metal emissions. The Willow Island plant "hot-side" ESP requires the use of a sodium additive to enhance the resistivity of the flyash particles. This demonstration will examine the potential of biofuel cofiring to obviate the need for such additives in the control of particulates and opacity—capitalizing upon the potassium and sodium content of the biomass ash.

The demonstration program involves optimizing the sawdust-TDF-coal blend for maximum impact in the cyclone combustion process. Further, it involves optimizing this blend to capitalize upon the overfire air system for NO_x management. It is estimated that the project will fire at least 10 percent wood waste, along with about 10 percent TDF in the project.

While this demonstration involves integrating past successful programs, it provides a significant enhancement of cofiring and the use of biomass. If successful, it will be the first demonstration where cofiring has been explicitly integrated into an overall NO_x control strategy as a significant contributor. Further, if successful, it provides a means for cyclone boiler owners and operators to consider NO_x management strategies other than end-of-pipe solutions or expensive fossil-based combustion strategies to achieve compliance with current and proposed regulations.

Further, this will be the first cofiring demonstration where the boiler is equipped with a "hot side" electrostatic precipitator—an ESP installed between the economizer and the air heater rather than after the air heater. Such "hot side" ESP's conventionally use sodium additives to improve the resistivity of the flyash and enhance its capture. Biomass, with its concentrations of potassium and sodium, may reduce or eliminate the need for such additives. This demonstration will address that condition and, as a consequence, advance the use of cofiring in coal-fired boilers.

1.2. THE ALBRIGHT DEMONSTRATION

The Albright Generating Station demonstration provides a means for comparing the NO_x reduction results obtained at Willow Island Generating Station—in a cyclone boiler—to those that can be obtained in a pulverized coal boiler. The Albright Generating Station Boiler #3 is a 150 MW_e boiler, comparable in capacity to the Willow Island boiler. It burns a similar eastern bituminous coal. Of critical importance, the Albright boiler is equipped with a low-NO_x firing system including a separated overfire air system.

The Electric Power Research Institute (EPRI) has developed a demonstration of sawdust cofiring in a PC boiler at the Seward Generating Station. This demonstration must be moved in order for it to be completed. Boiler #12, where sawdust has been fired, is now only maintained for capacity purposes and is not regularly fired. Boiler #15, which was intended as a site for cofiring, has an operating selective catalytic reduction (SCR) system essential to the operation of both Seward and Titus Generating Stations. Recent research by Elsamprojekt and Midkraft, supported by research of Sandia National Laboratories, has shown that biomass cofiring has the potential to be detrimental to SCR catalysts. Consequently the demonstration can no longer be operated at that site.

A favorable biomass fuel supply potential and the favorable technology potential has led Allegheny to consider relocating the cofiring demonstration to Albright. The relocation of the separate injection demonstration from Seward Generating Station to Albright Generating Station provides opportunities to extend the knowledge base concerning cofiring—capitalizing upon the configuration of Albright Boiler #3. Specifically cofiring has not been applied to a generating station equipped with low NO_x firing separated overfire air system. In relocating the demonstration from Seward to Albright, it is prudent to capitalize upon such an opportunity.

Given this opportunity, Allegheny and Foster Wheeler will accomplish the following:

- Disassemble and remove the existing demonstration from the Seward site,
- Supply and install two biomass injectors in Albright Boiler #3
- Install piping sufficient to transport sawdust to the biomass injectors at Albright Boiler #3
- Install the process equipment removed from Seward Generating Station to the Albright Generating Station
- Construct a steel building to house the process equipment associated with the demonstration of separate injection cofiring
- Demonstrate cofiring at Albright, providing emissions data for comparison to the Willow Island demonstration.

1.3. THE COMBINED RESULTS

The combination of the Willow Island demonstration at the cyclone boiler and the comparative data developed at the Albright demonstration in a tangentially-fired pulverized coal boiler will provide definitive data concerning the emissions reduction potential of biomass cofiring in units already equipped with low NO_x firing systems. As such, these data will help define the potential, and limits, of biomass cofiring as an emissions reduction strategy. At the same time these demonstrations will provide a means for evaluating biomass cofiring as a cost-effective strategy for voluntary fossil CO_2 emissions reductions. Finally these projects will demonstrate additional environmental benefits of cofiring.

2.0. TECHNICAL PROGRESS

Overall progress has included concluding contract negotiations with Foster Wheeler and, consequently, with the specialty subcontractors. With these contracts in place, progress has been significant on both projects.

2.1. TECHNICAL PROGRESS ON THE FUELS ISSUES

The fuels issues are dominated by fuel characterization. Pennsylvania State University performed extensive laboratory testing on samples of West Virginia sawdust, bituminous coal delivered to the Willow Island Generating Station, and bituminous coal delivered to Albright Generating Station.

Table 1 presents the proximate and ultimate analyses of the three fuels, on a dry basis. It also presents the typical moistures for these fuels. Note that the compositions of the sawdust and coals are very similar to those previously reported for the biomass and fossil fuels to be burned at the Allegheny Energy Supply generating stations (see Tillman, Payette, and Battista. 2000).

Table 1. Composition of the Sawdust and Coals to be Burned by Allegheny Energy Supply Co., LLC

Parameter	Fuel		
	Sawdust	Willow Island Coal(*)	Albright Coal
Typical Moisture %	42.4	7.11	11.02
Proximate Analysis (wt %, dry basis)			
Ash	1.0	10.5	13.7
Volatile Matter	80.0	34.0	30.6
Fixed Carbon	19.0	35.5	55.7
Ultimate Analysis (wt %, dry basis)			
Carbon	49.2	76.7	73.6
Hydrogen	6.0	4.9	4.7
Oxygen	43.0	4.9	5.0
Nitrogen	0.8	1.4	1.4
Sulfur	<0.1	1.6	1.6
Ash	1.0	10.5	13.7
Chlorine (ppmw)	750	2200	850
Higher Heating Value (Btu/lb)	8400	13600	13000

Note: (*): Includes addition of sodium chloride for "hot side" ESP performance support.

Using Carbon 13 Nuclear Magnetic Resonance (^{13}C NMR) and Nitrogen 15 Nuclear Magnetic Resonance (^{15}N NMR), The Energy Institute of Pennsylvania State University was able to determine certain structural characteristics of the fuels to be burned at the Allegheny Energy Supply generating stations. Table 2 presents the results of the ^{13}C NMR studies. The ^{15}N NMR studies were performed only for the coals, and indicated that the nitrogen exists in pyrollic structures; the nitrogen in the Albright coal exists in substituted pyrollic structures.

Table 2. Results of ^{13}C NMR Studies of Fuels for the Allegheny Energy Supply Cofiring Program

Parameter	Fuel		
	Sawdust	Willow Island Coal	Albright Coal
Aromaticity (aromatic carbon atoms divided by total carbon atoms)	0.08	0.70	0.73
Aromatic Carbons per Aromatic Cluster	6(*)	15(**)	13(***)

Notes:

(*) Not measured, based upon literature showing single aromatic rings in lignin

(**) Indicates >3 aromatic rings/cluster on average

(***) Indicates ~3 aromatic rings/cluster on average

Drop Tube Reactor (DTR) studies were then conducted with fuels of consistent particle sizes to develop kinetic parameters for devolatilization, trace the fate of nitrogen relative to carbon, and to develop chars for subsequent char oxidation kinetics. DTR tests were conducted at low temperatures (e.g., 400 – 800°C or 752 – 1472°F) for the sawdust, and at high temperatures (up to 1700°C or 3092°F) for all fuels. Chars used for char oxidation kinetics were generated at 1700°C (3092°F). The chars were generated at temperatures representative of commercial boilers. Because the experiments were used to evaluate the partitioning of nitrogen between volatile matter and char, the DTR was operated using an argon atmosphere.

Initial tests for devolatilization kinetics determination were performed by the Energy Institute of PSU to determine the ultimate volatile yield of the three fuels. Results of these tests are summarized in Figure 1. Note that the devolatilization of sawdust commences at low temperatures, and that the ultimate volatile yield, V_∞, is achieved for biomass at about 1000°C (1832°F). Note, also that the V_∞ for sawdust is 91 percent. It is important to compare these values to the coals being burned. The V_∞ for the Willow Island coal is 68 percent and the V_∞ for Albright coal is 52 percent. Further note that the ultimate volatile yield for the Willow Island coal is achieved at 1500°C (2732°F) while the ultimate volatile yield for Albright coal is achieved at 1700°C (3092°F). The sawdust almost completely volatilizes before burning.

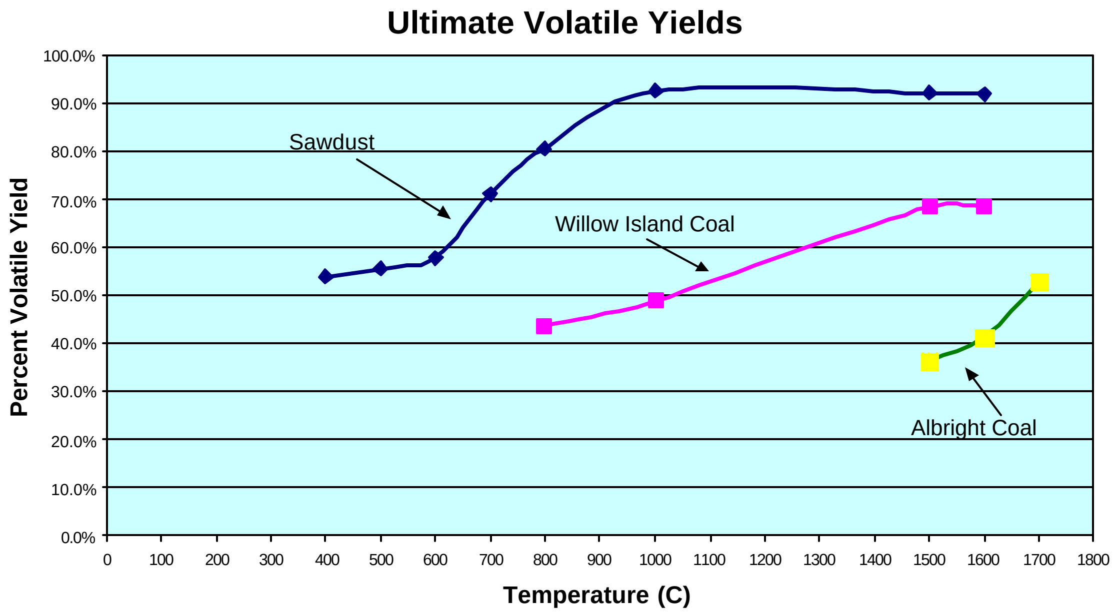

Figure 1. Ultimate Volatile Yields for Sawdust, Willow Island Coal, and Albright Coal

Kinetics were calculated according to the traditional Arrhenius equation shown in equation [1]:

$$k = Ae^{-(E/RT)} \qquad [1]$$

Where A represents the pre-exponential factor, E represents the activation energy, and T is measured in absolute temperature (K). Calculating k for any temperature is performed using equation [2]

$$k = (V/V_{\infty})/t_r \qquad [2]$$

Where V is volatile yield at that temperature and t_r is residence time. Kinetics for sawdust devolatilization involved two distinct mechanisms, as is apparent from Figure 1. There is clearly a low temperature mechanism, where extractives, hemicelluloses, and cellulose apparently devolatilize. There is a higher temperature mechanism when the lignin is devolatilized. After ~1000°C (1832°F), the remaining material is char. The kinetics for coal devolatilization are not broken into the distinct mechanism pathways that exist for biomass. Table 3 presents the devolatilization kinetic parameters for both low temperature and higher temperature sawdust devolatilization, and for coal devolatilization.

Table 3. Devolatilization Kinetic Parameters for Sawdust, Willow Island Coal, and Albright Coal

Fuel	A (pre-exponential factor; 1/sec)	E (activation energy; kcal/mol)
Sawdust (400 – 600°C)	1.17	0.681
Sawdust (600 – 1000°C)	5.74	3.42
Willow Island Coal	89.50	10.7
Albright Coal	72.62	10.6

The data in Table 3 clearly demonstrate that the sawdust is more reactive than either coal, particularly at lower temperatures.

Figures 2 – 5 are the Arrhenius plots for sawdust and the coals at Willow Island and Albright Generating Stations. These plots show the increased reactivity of the sawdust, particularly at the low temperatures. Note that, below 600°C (1110°F), there is virtually no activation energy required for the devolatilization of the biomass.

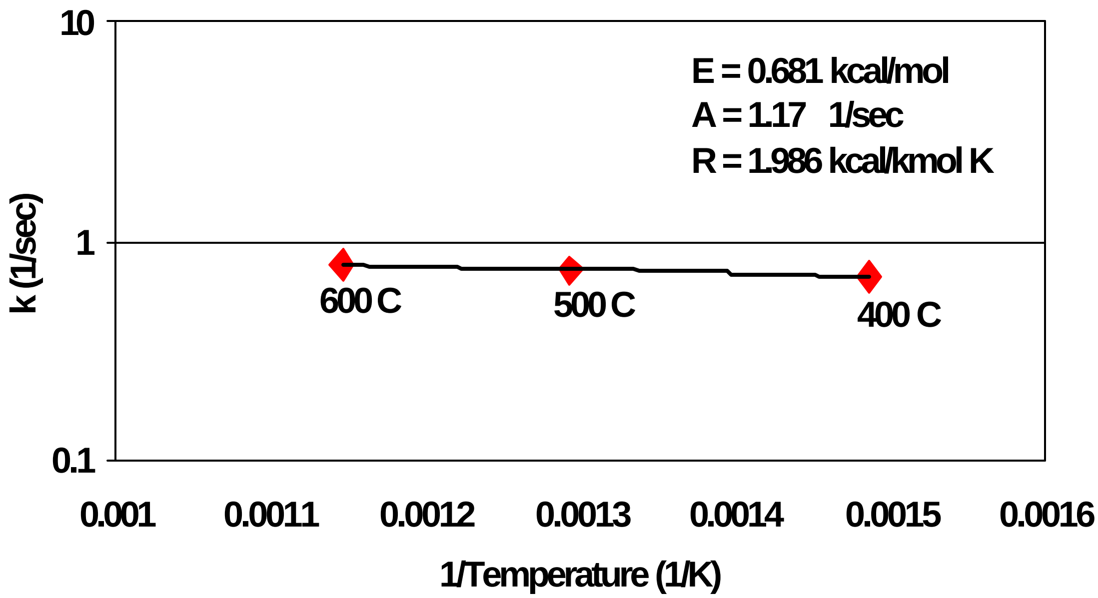

Figure 2. Low Temperature Sawdust Devolatilization Kinetics.
Source: The Energy Institute, Pennsylvania State University

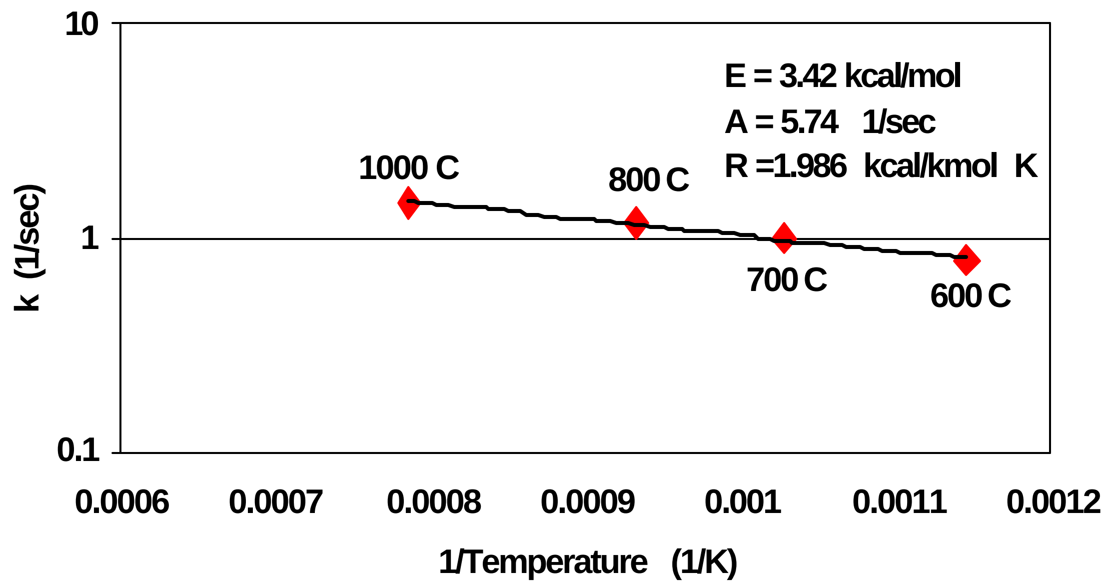

Figure 3. Higher Temperature Sawdust Devolatilization Kinetics

Source: The Energy Institute, Pennsylvania State University

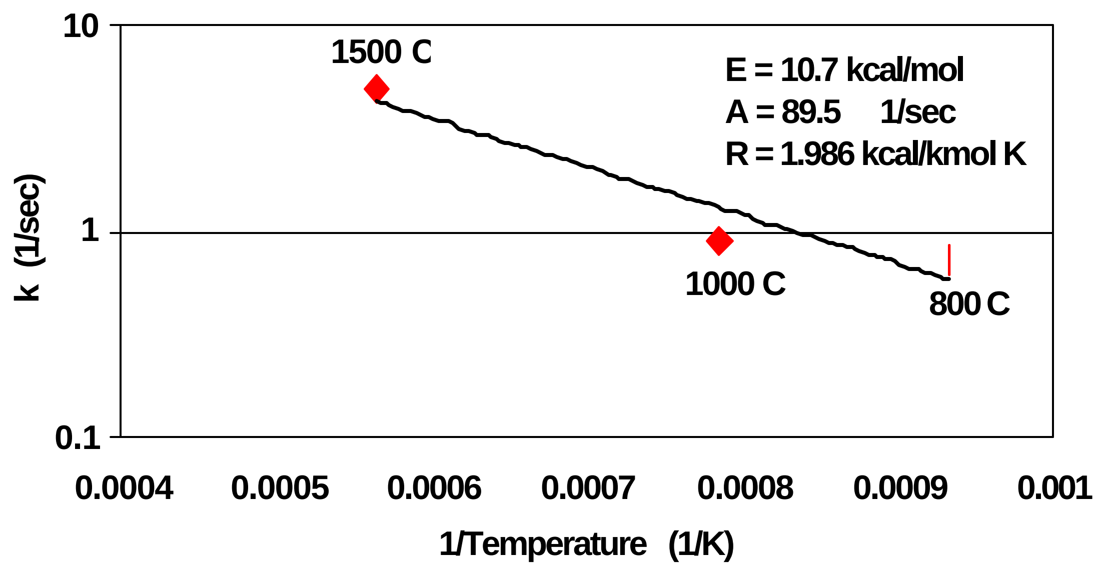

Figure 4. Devolatilization Kinetics for Willow Island Generating Station Coal

Source: The Energy Institute, Pennsylvania State University

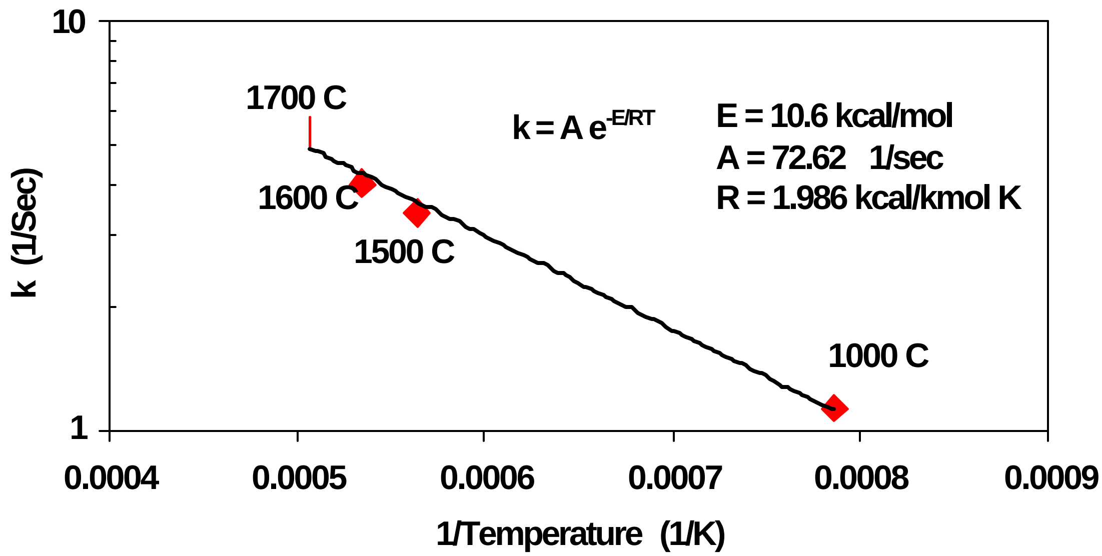

Figure 5. Devolatilization Kinetics of Albright Generating Station Coal
Source: The Energy Institute, Pennsylvania State University

Char oxidation kinetics also were developed, using Thermogravimetric analysis (TGA). These analyses were based upon chars generated at 1700°C (3092°F) in the DTR. Char oxidation kinetics are developed at low temperatures and then extrapolated to higher temperatures. Figures 6 – 7 present the char oxidation kinetics for sawdust, Willow Island Generating Station coal. Coal from Albright Generating Station has properties similar to that of coal from Willow Island.

The data in Figures 6 – 7 clearly document the fact that the sawdust char is significantly more reactive than the coal chars. This is illustrated in Figure 8, a comparison of rate constants for char oxidation of the sawdust and Willow Island coals. Note that the rate constant for sawdust char oxidation is about twice the rate constant for coal char oxidation at any given temperature. The chart is developed using °F as the basis, rather than absolute temperatures, in order to provide a rapid relationship between the values in the chart and conventional combustion conditions.

The kinetics data, then, clearly document the fact that the biomass will devolatilize at lower temperatures and more rapidly than the coals, and that the biomass char will oxidize more rapidly than the coal chars. These factors are increasingly important when considering the potential impacts of biomass cofiring on both NO_x emissions and unburned carbon losses. These data provide a basis for subsequent detailed computational fluid dynamics (CFD) modeling of the Willow Island cyclones to establish the potential operating characteristics of the cofiring system.

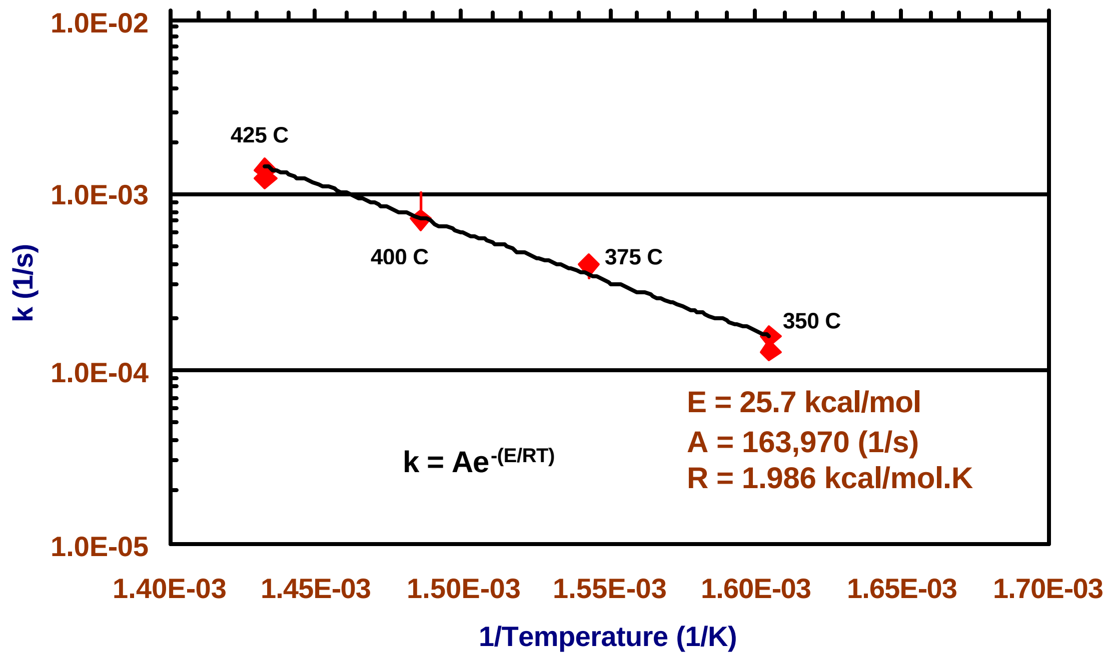

Figure 6. Sawdust Char Oxidation Kinetics for Chars Generated at 1700°C (3092°F)
Source: The Energy Institute, Pennsylvania State University

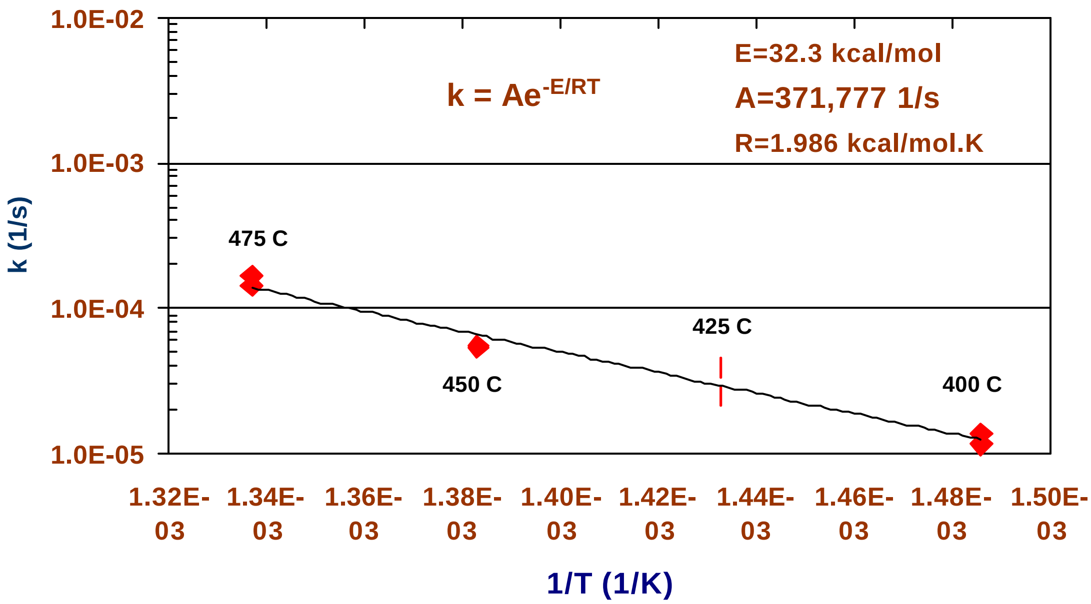

Figure 7. Willow Island Coal Char Oxidation Kinetics for Chars Generated at 1700°C (3092oF)
Source: The Energy Institute, Pennsylvania State University

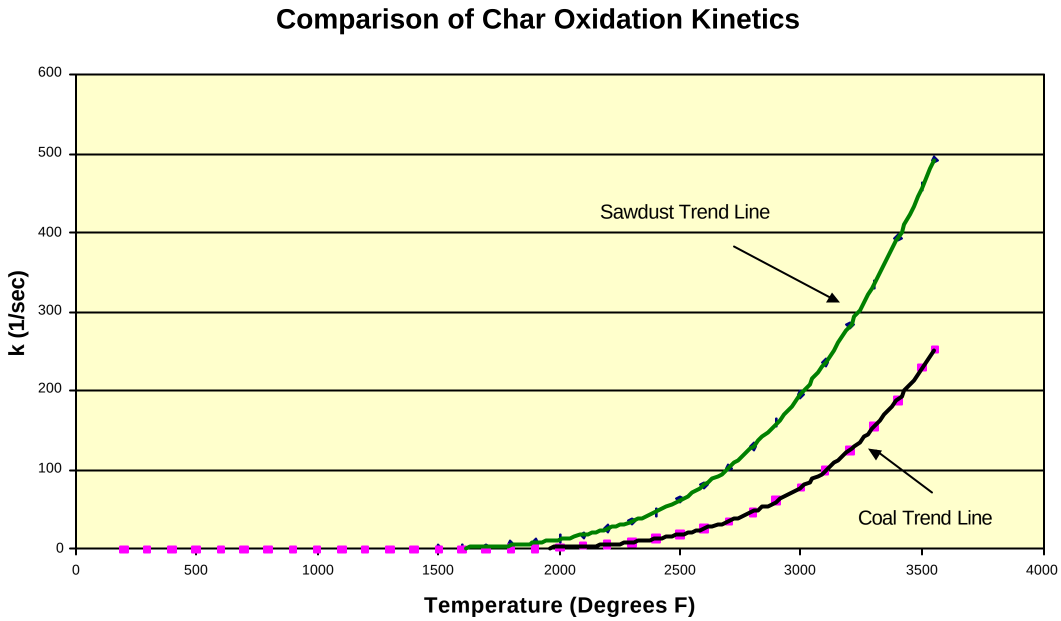

Figure 8. Comparison of Rate Constants for Sawdust and Willow Island Coal

Of final interest in the area of fuel characterization, all chars were analyzed in terms of proximate and ultimate analysis. The data were then compiled to evaluate the partitioning of fuel nitrogen atoms into volatile matter and in char, relative to the partitioning of carbon atoms into volatile matter and in char. Baxter et. al. (1996) published data indicating that, for a wide range of coals, the nitrogen volatiles evolve more slowly than the carbon volatiles. The data published generally indicate that nitrogen volatile evolution lags behind carbon volatile evolution—particularly in the early stages of the combustion process.

The data developed by The Energy Institute of Pennsylvania State University are temperature dependent, rather than time dependent. However, given the temperature history of a given fuel particle, the data developed provide comparable insights to the Baxter et. al. data.

Figure 9 presents the nitrogen volatile evolution relative to carbon volatile evolution for sawdust while Figure 10 presents the same data for Willow Island coal.

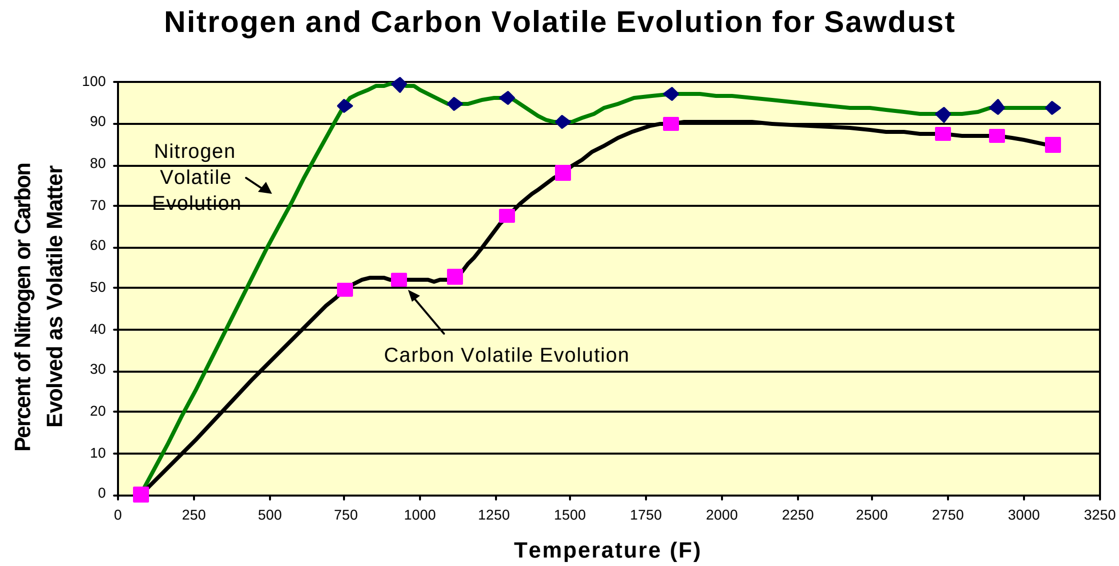

Figure 9. Nitrogen and Carbon Volatile Evolution from Sawdust as a Function of Temperature

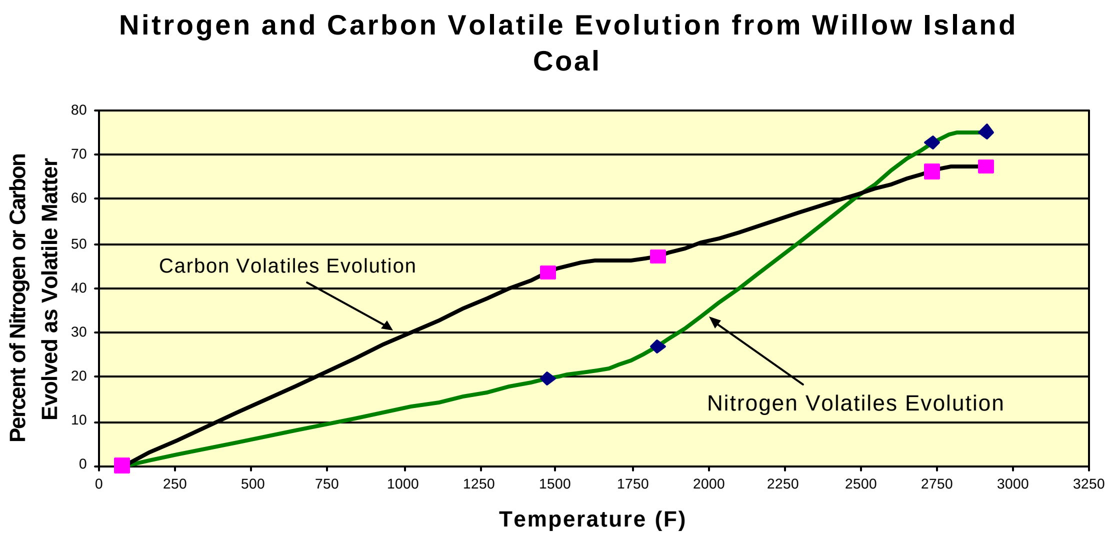

Figure 10. Nitrogen and Carbon Volatile Evolution from Willow Island Coal as a Function of Temperature

Note that both sets of experiments were performed in an argon atmosphere. Both sets of experiments are devolatilization experiments, with no data concerning oxidation. What is apparent from the data, however, is the fact that nitrogen volatile formation leads carbon volatile formation in the case of sawdust while nitrogen volatile formation lags behind carbon volatile formation—until temperatures exceed 2500°F (1370°C) in the case of the Willow Island coal. Note, also, that some 25 percent of the nitrogen in the original fuel remains in the char formed from the coal while only about 5 percent of the nitrogen in the original biomass remains in the char formed from the sawdust.

The data can be recast, comparing the volatilization of carbon and nitrogen to the total volatile production from the fuel. This is presented in Figures 11 and 12. Note that the sawdust shows the rapid volatilization of nitrogen, and it also shows that the carbon volatilization slightly lags behind the rate of total volatile production. This phenomenon associated with carbon relates to the high hydrogen and oxygen contents of the biomass. The sawdust has a hydrogen/carbon atomic ratio of 1.46 and an oxygen/carbon atomic ratio of 0.66. These contrast to the H/C atomic ratio of the coal, 0.77, and the O/C atomic ratio of the coal, 0.05. In the case of the coal, the carbon volatilization is virtually identical to total volatile production until over 50 percent of the dry matter has evolved as volatile matter. The nitrogen volatile production clearly lags behind the carbon volatile production until most of the volatile matter has evolved.

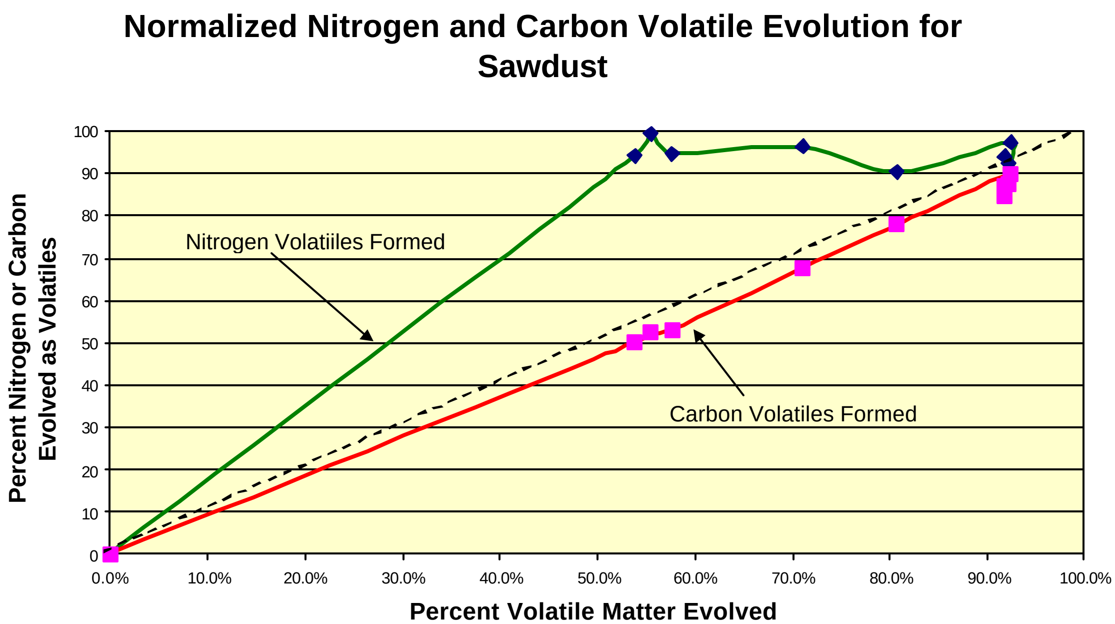

Figure 11. Comparison of Nitrogen and Carbon Volatile Matter Evolution to Total Volatile Matter Evolution from Sawdust

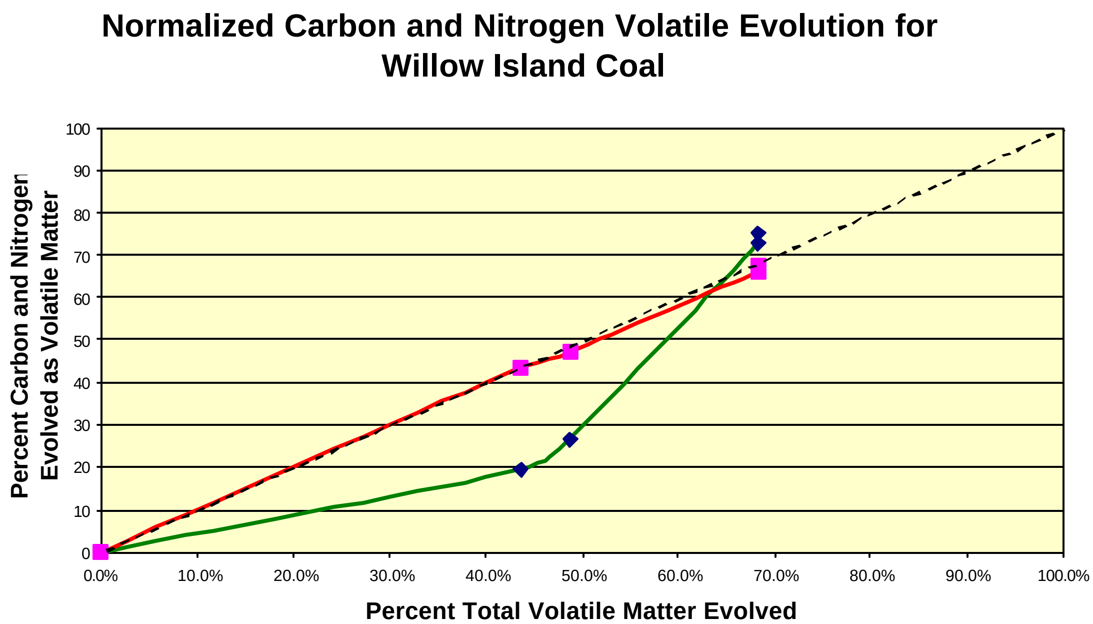

Figure 12. Comparison of Nitrogen and Carbon Volatile Matter Evolution to Total Volatile Matter Evolution from Willow Island Coal

The detailed coal characterizations, then, have shown that the biomass has the potential to significantly improve combustion in both the Willow Island cyclone boiler and the Albright tangentially-fired boiler. It can rapidly release its volatile matter sufficiently to promote early ignition and internal fuel staging. It will release nitrogen early, in a fuel-rich environment, to promote NO_x reduction.

2.2. TECHNICAL PROGRESS ON THE WILLOW ISLAND DEMONSTRATION

Activities at the Willow Island demonstration include both engineering and the beginnings of construction. These are discussed below.

2.2.1. Engineering and Design Activities

Detailed Design has been completed for the Willow Island site. The general arrangement plan and elevation views for the project are shown in Figures 13 and 14.

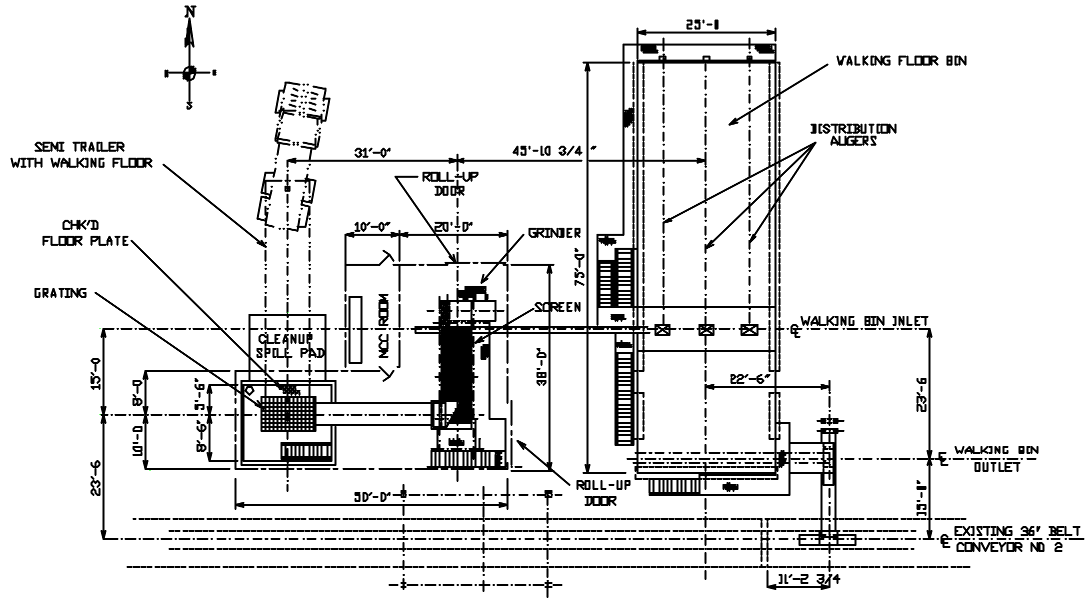

Figure 13. Plan View of Willow Island Cofiring Project

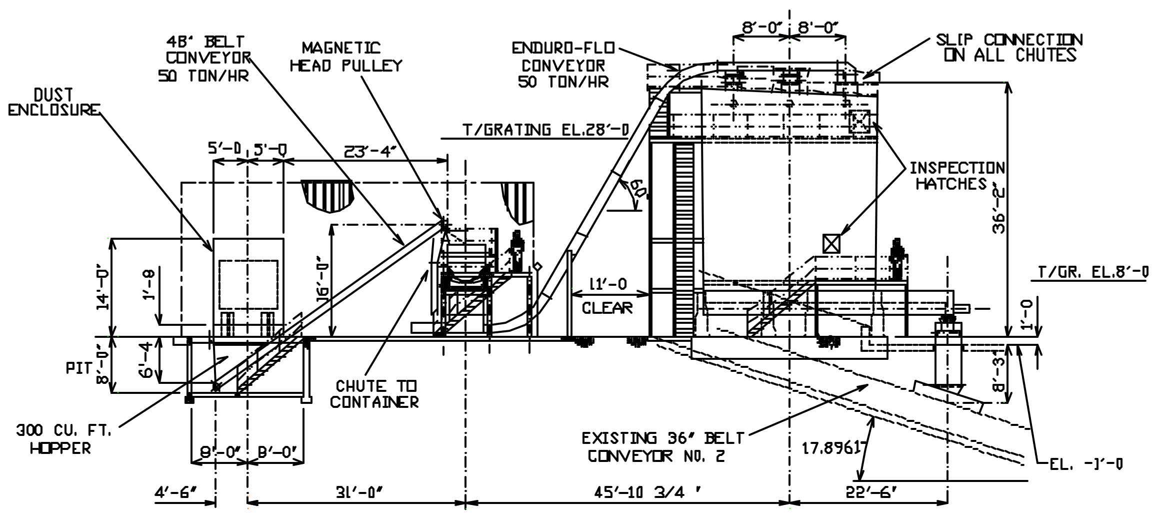

Figure 14. Elevation view of Willow Island Cofiring Project

Note that the project is designed for simplicity, and for ease of maintenance. Note, also, that it has been successfully integrated into the overall coal handling system of the plant.

Given the success of final design, all of the process and mechanical equipment has been procured. This includes the truck unloading pit and associated conveyors, the disc screen, the grinder for oversized particles, the conveyor feeding the fuel storage bin, and the walking floor bin with outfeed conveyor.

2.2.2. Initial Construction Activities

Construction activities have been initiated at the Willow Island Site. Initially two small buildings on the site have been demolished as shown in Figure 15. Further, the site has been completely surveyed for development of construction drawings and for erection of the biomass facilities.

Figure 15. Demolition of Existing Structures and Associated Foundations at Willow Island.

2.3. TECHNICAL PROGRESS ON THE ALBRIGHT DEMONSTRATION

Technical progress on the Albright Demonstration focused upon construction activities. All equipment required from the Seward Generating Station was relocated to the Albright Generating Station. This included the following:

- Walking floor truck unloader
- Harvistore storage silo with Laidig unloader
- Metering chute
- Distribution bin
- Rotary air locks
- Blowers
- “Overs” grinder

A new disc screen was purchased for the facility, and a new steel building was constructed for the project. Figures 16 – 19 illustrate construction on the site.

Figure 16. Overview of Building Construction at the Albright Generating Station.

Figure 17. Construction of the Structure at Albright, Including the Walking Floor Unloader

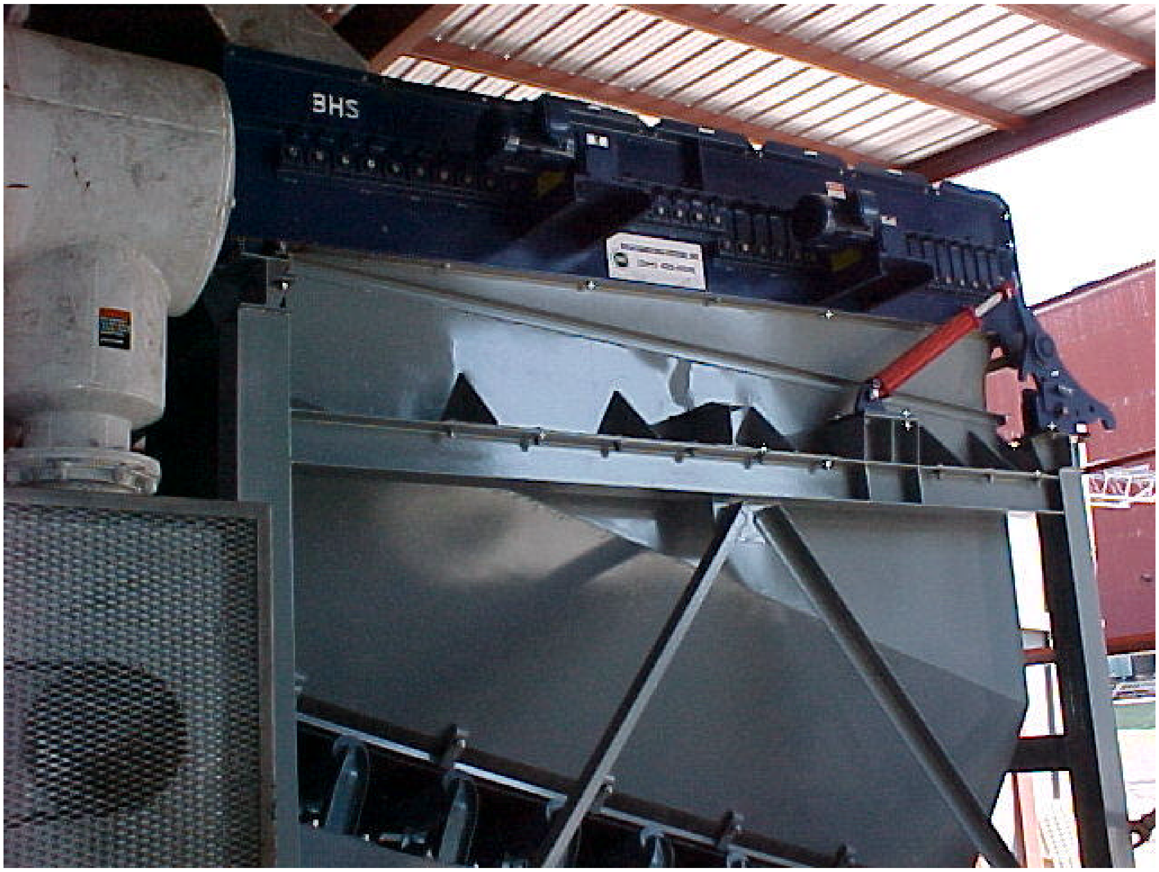

Figure 18. The New Disc Screen for the Albright Project.

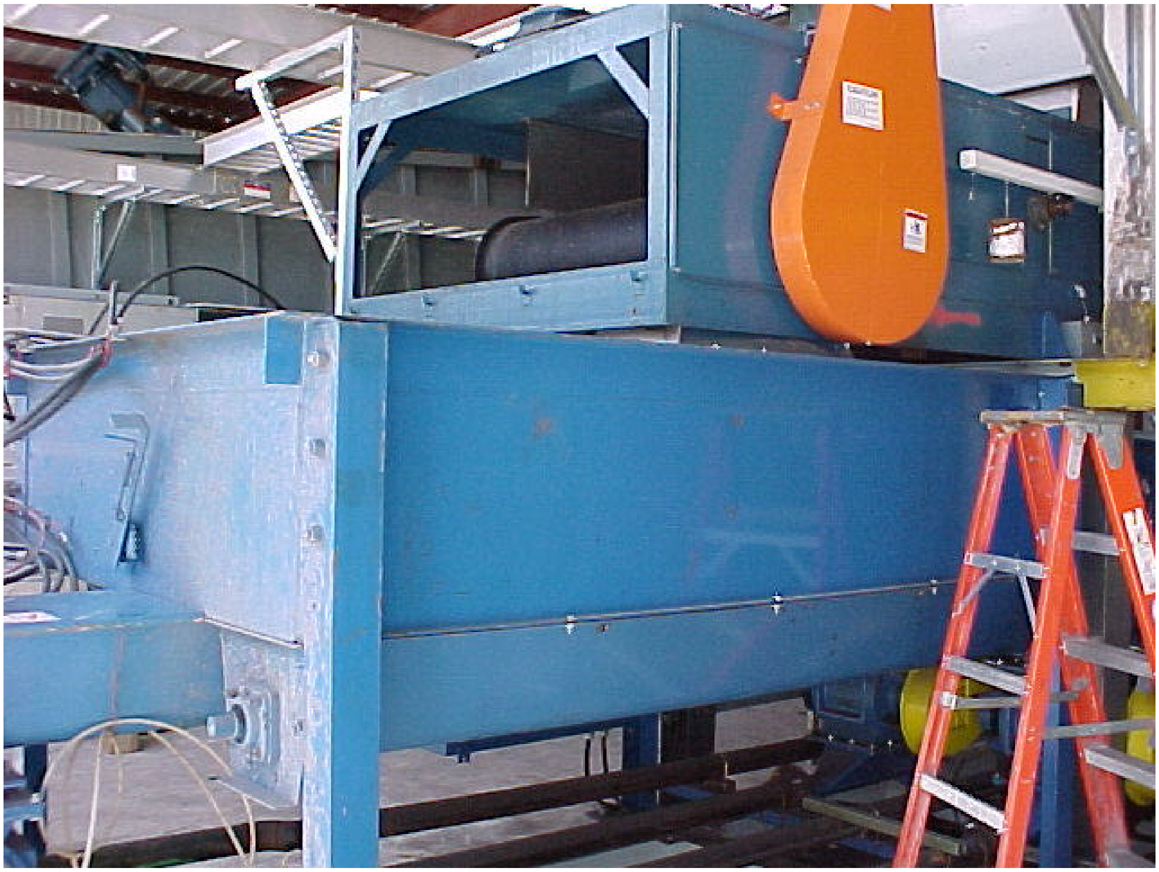

Figure 19. The Sawdust Distribution and Pneumatic Transport System Including Metering Conveyor

2.4. EXPECTED TECHNICAL PROGRESS DURING THE FOURTH PROJECT QUARTER

The fourth project quarter, from April 1, 2001 through June 30, 2001 is expected to see the following progress, as shown in Table 4.

Table 4. Anticipated Progress at Willow Island and Albright Demonstration Sites

Progress at Willow Island	Progress at Albright
Excavation	Completion of Construction
Pouring of All Foundations	Baseline Testing
Receipt of All Process and Mechanical Equipment	Short Term Testing for Environmental Impacts
Installation of All Process Equipment	
Baseline Testing	

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