Washington State Pulp and Paper Mill Boilers: Current and Potential Renewable Energy Production

Final Report

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Executive Summary

At the request of the Legislature, we have conducted a thorough investigation on the state of boilers in Washington State pulp and paper mills and the potential for these boilers to provide additional renewable energy and renewable fuels. The specific objective of the project is to assess the current energy profile of the Washington pulp and paper industry and to determine the renewable energy production of the industry with implementation of state-of-the-art technologies.

There are two phases to this investigation:

Phase 1. Assess the current energy production in Washington State pulp and paper mills. In this phase of the study, we determined the energy (steam and electricity) generation capability of Washington State pulp and paper mills. The sources and types of fuels used in various boilers were assessed and the age profile of boilers currently in pulp and paper mills was determined.

Phase 2. Assess the energy potential for Washington State pulp and paper industry with state-of-the-art technologies. In this phase of the study, calculations were made assuming Washington state pulp and paper mills install state-of-the-art power and recovery boiler technology. We calculated the amount of renewable energy generated and the increased biomass demand to generate this additional power. The capitol cost of installing this state-of- the-art technology was assessed.

The survey response from the mills was excellent, with 10 out of 11 mills responding with thorough information on their boiler and power generation capabilities. We find that Washington mills produce substantial amounts of renewable power but that the boilers and ancillary equipment are old. With this older equipment, the mills produce considerably less power than they could with new boilers, evaporators, and turbines. There appears to be some “low hanging fruit” with regard to increasing renewable power production from Washington pulp and paper mills. One kraft mill does not have a turbine for power production and one of the recycle/mechanical pulp mills appears to have a boiler that can generate high pressure steam, but would also need a steam turbine if electricity is to be generated. Washington pulp and paper mills also burn considerable amounts of fossil fuels in their biomass boilers. Use of more biomass in these boilers would also contribute to Washington’s renewable energy production without the expenditure of significant capital. Additional, but more modest, short-term improvements could be made in mills to increase cumulative renewable energy output further. Policy supports including incentives may be needed, however, to spur energy recovery investments in pulp and paper mills. Existing laws such as I-937 may inadvertently function as barriers to production of renewable power for the State and should be re-examined.

Longer term, there appear to be significant opportunities for increased production of renewable fuels and power in Washington pulp and paper mills. Installation of new technologies could result in greater renewable power production; about double of current levels. Installation of new conversion capabilities for production of clean biofuels in mills is also an opportunity. The potential for development of renewable fuels in pulp mills is especially compelling given the combined concerns of climate change mitigation and energy independence. Installation of new technologies, however, will be expensive and increased power or fuels production will necessitate greater availability of sustainable woody biomass feedstock supplies. The capital cost burden could be shared by the production of pulp and paper, renewable energy, and renewable fuels making it more cost effective than if stand alone facilities were constructed. Mill managers will need to be confident that prices for renewable products will be both adequate and reasonably secure before new investments in energy conversion capabilities can be made. The State could help mills to proceed with construction of new facilities by providing low-cost loans, production incentives, and accelerated reduced-cost permitting processes. Biomass supply assurances will be needed as well with state lands potentially providing a model for other ownerships. Policies that establish renewable energy standards and create value for the reduced carbon emissions associated with displacement of fossil fuels by renewables will contribute important market support. Biomass supply and cost are the most critical issues and will need both further research and policy attention. We recommend that a thorough investigation of the long-term benefits of different renewable energy options for Washington pulp and paper mills be undertaken as soon as possible. The potential for producing renewable transportation fuels in pulp and paper mills is especially compelling and warrants an in-depth analysis.

In general, pulp and paper mills should be viewed as under-used resources for the production of renewable energy and fuels. Washington could benefit from energy policies that recognize and reward current and potential contributions of the pulp and paper industry to the achievement of State energy objectives and sustainable use of forest resources.

Introduction

The pulp and paper industry is a significant producer of renewable energy and has the capability to increase energy production through investment in modern conversion technologies. With a mature, operating infrastructure capable of processing substantial volumes of biofuels, pulp and paper mills are logical facilities to be major producers of products, fuels, and electrical power from renewable biomass. The recovery of higher value paper products effectively underwrites the costs of converting process residuals to renewable energy. The pulp and paper mill of the future may produce a mix of energy products that significantly augments revenues generated by the pulp and paper that are currently sold.

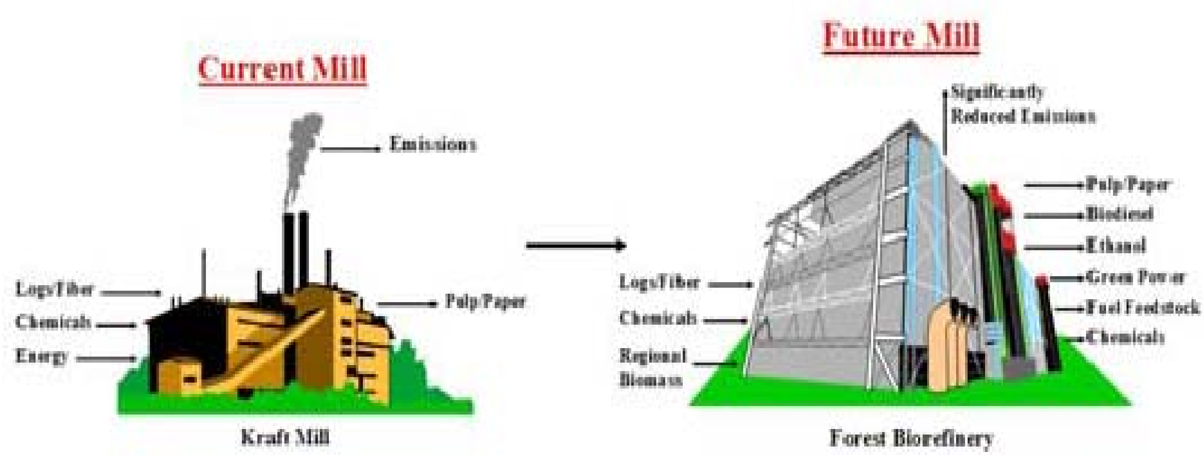

Figure 1. The Integrated Forest Biorefinery (Source: Eric Connor, ThermoChem Recovery International, Inc.)

Pulp mills are ideal sites for producing renewable power for several reasons. First, they have facilities to receive and process enormous amounts of biomass feedstock in various forms; chips, hog fuel, saw dust, and even logs. Some mills even process agricultural waste. They have a well trained work force of operators and engineers that are familiar with large unit operations that process cellulosic biomass. Pulp and paper mills have waste treatment facilities, access to large volumes of water, and are located on the power grid such that they can receive or provide large amounts of electrical power. Most significantly, pulp mills require large volumes of moderate and low pressure process steam to produce the high value pulp and paper products. This steam requirement allows for construction of large combined heat and power facilities which is well known to be an efficient and economical technology to produce power from renewable fuels. In a pulp and paper the energy from burning biomass does double duty; provides renewable and drives the production of the pulp and paper products.

Biopower, or biomass power, refers to electricity produced from biomass fuels such as residues from the wood, pulp and paper residues, residues from food production and processing, trees and grasses grown specifically as energy crops, and gaseous fuels produced from solid biomass, animal wastes, and landfills. Biomass is a proven renewable fuel source for electricity generation. Currently, more than 7,000 megawatts of biomass power are generated at more than 350 plants in the United States. A diverse range of biopower producers includes electric utilities, independent power producers, and the pulp and paper industry (http://www.nrel.gov/docs/fy00osti/27980.pdf). The pulp and paper industry is the largest producer of biomass electricity and heat and steam. It is estimated that the pulp and paper industry has the potential to expand generation capacity to as much as 20,000 megawatts of biomass power (http://www.resourceinvestor.com/News/2008/7/Pages/New-Energy-from-Paper---Pulp--Biorefineries--.aspx?k=pulp+and+paper).

The pulp and paper industry also consumes a large amount of energy to manufacture and produce paper and paperboard. Pulp and paper mills account for approximately 12% of total manufacturing energy use in the U.S. About 60-70% of total energy consumption in a pulp and paper plant, however, is from recovered waste (NWEEA 2000).

In addition to being the feedstock for pulp and paper production, biomass is also the major energy resource for the industry. Raw materials that can be combusted for energy purposes may include forest residues, forest thinning, and primary mill residues. Most of the biomass for Washington boilers comes from mill residues. Mill residues are waste wood from manufacturing operations that include sawmills, pulp and paper companies, and other millwork companies involved in producing lumber, pulp, veneers, and other composite wood fiber materials. Primary mill residues are usually in the form of bark, chips, sander dust, edgings, sawdust, or slabs. Wood waste materials are generally ground-up (“hogged”) to make a dense and homogeneous fuel that is about three inches and less in size. The close proximity of mill residues to generating facilities generally means this is a cost effective fuel for those facilities. Therefore nearly 98 % of all mill residues generated in the United States are currently used as fuel or as raw material for other processes. Because most primary mill residues are fairly dry after they have been through a manufacturing process, they fall at the upper level of the energy content range for wood (8,570 Btu/lb) (EPA 2007).

Additionally, pulp mills generate another process residual that is used as raw material for energy purposes; spent pulping liquors. Spent pulping liquors account for over 70% of the biomass-derived fuels used in the pulp and paper industry today. All black liquor and most mill residues are used at mill sites to fuel cogeneration systems, providing steam and electricity for on-site use (http://www.aceee.org/pubs/ie962.htm).

Energy in pulp and paper mills is used primarily as thermal energy in the form of steam. Steam is used in the heating of the wood chip digester, in the extraction of processing chemicals from the pulp, for recovering processing chemicals and in the drying of the pulp and paper. Steam is generated in a boiler system which consists of a furnace with heat exchanger coils to conduct water through the combustion chamber where it is turned into steam. The steam is then conveyed by pipes to the locations within the pulp mill where it is to be used. A large modern mill producing 2000 ton per day of pulp will produce over 1.3 million pounds of steam an hour.

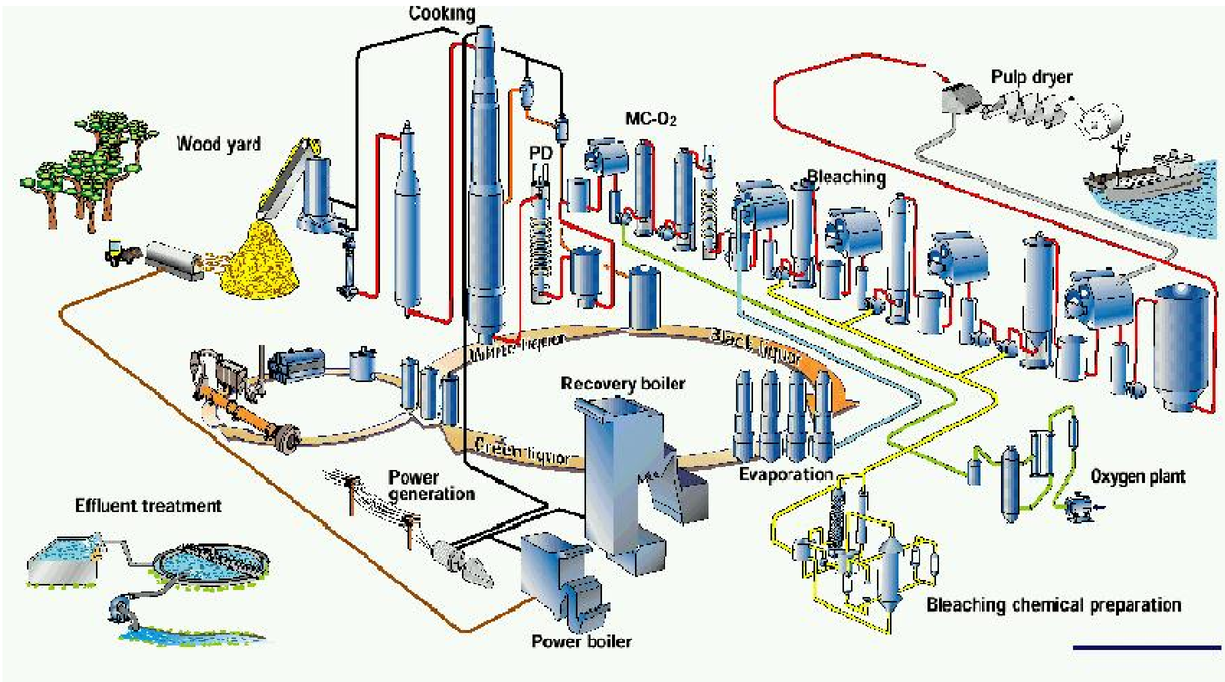

Figure 2. Pulp mill cycle (Source: Chemrec, Gasification Technologies Conference 2006).

With rising energy costs, the pulp and paper industry has been obliged to take measures in order to lessen the impact of energy requirements. As a result, the sector has increased the use of energy sources such as hogged wood, bark, residues and spent cooking liquor wherever possible, and is considering more efficient alternatives such as gasification systems in order to reduce operational energy costs.

Biomass can be converted into electricity in one of several processes. The majority of biomass electricity is generated today using a steam cycle. In this process, biomass is burned in a boiler to make steam; the steam then turns a turbine that is connected to a generator that produces electricity. Biomass can also be burned with coal in a boiler (in a conventional power plant) to produce steam and electricity. Co-firing biomass with coal is an affordable way for utilities to obtain some of the environmental benefits of using renewable energy.

Steam and Electricity Generation

Steam generators, or boilers, use heat to convert water into steam for a variety of applications. Primary among these are electric power generation and industrial process heating.

The process of generating electricity from steam comprises the following parts: a firing subsystem (biomass combustion), a steam subsystem (boiler and steam delivery system), a steam turbine with electric generator, as well as a feed water and condensate system.

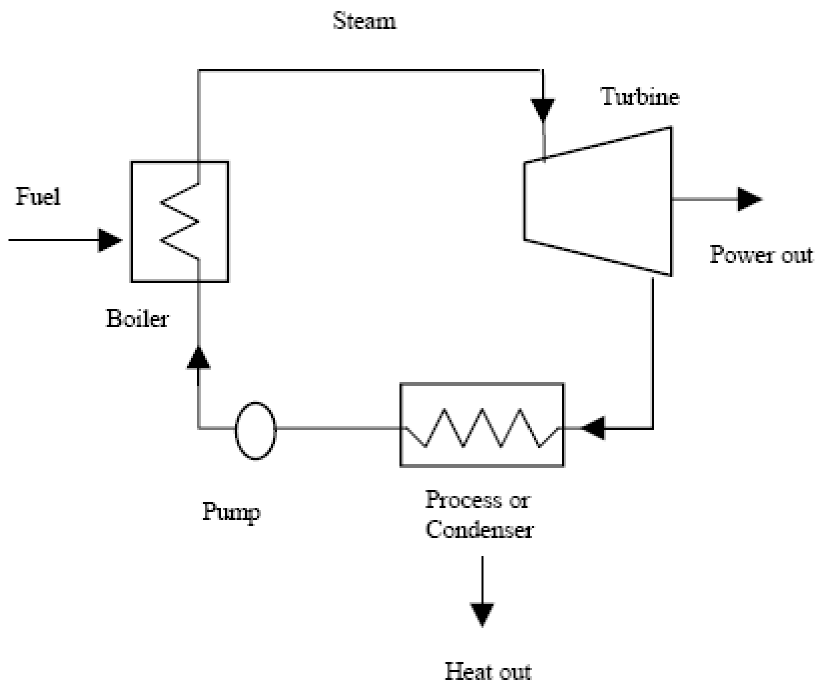

Figure 3. Simple Steam Turbine Power Cycle (Source: EPA, 2004)

The working principle is according to the classical Clausius-Rankine process. High temperature, high pressure steam is generated in the boiler and then enters the steam turbine. Steam turbines have a series of blades mounted on a shaft against which steam is forced, thus rotating the shaft connected to the generator. In the steam turbine, the thermal energy of the steam is converted to mechanical work. Low pressure steam exits the turbine. In pulp and paper mills steam is generally extracted from the turbine at about 150 – 200 pounds per square inch (psi) for use in higher temperature operations, such as the digesters, and at about 50 psi for use in lower temperature operations such as the evaporators. Some of the steam may also be condensed on the condenser tubes.

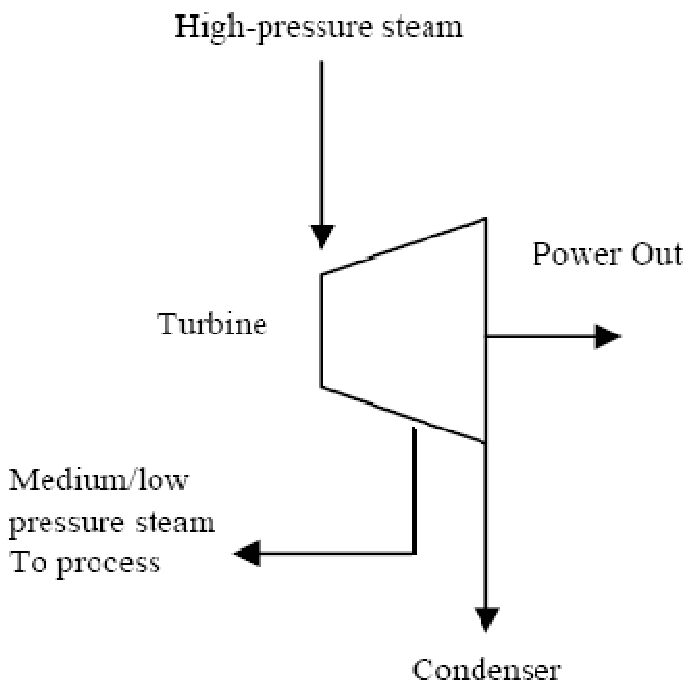

Figure 4. Extraction Steam Turbine (Source: NREL)

In order to produce electricity, a generator is needed. The generator converts mechanical energy into electrical energy. The generator has a series of insulated coils of wire that form a stationary cylinder. This cylinder surrounds a rotary electromagnetic shaft. When the electromagnetic shaft rotates, it induces a small electric current in each section of the wire coil. Each section of the wire becomes a small, separate electric conductor. The small currents of individual sections are added together to form one large current. The efficiency of electricity generation is quite low, with only about one-third of the energy in the fuel being converted to electrical power.

Pulp mills with electrical generation capacity are classic examples of combined heat and power facilities (CHP). High pressure steam is used to generate electricity, while the lower pressure steam drives the pulping and papermaking operations. Due to the utilization of heat from electricity generation and the avoidance of transmission losses because electricity is generated on site, CHP typically achieves a 35% increase in efficiency compared to power stations with stand alone boilers. The total energy efficiency of CHP installations can reach figures between 70 to 90%. This can allow economic savings where there is a suitable balance between heat and power loads (http://www.ccivalve.com/pdf/563.pdf) (EPA 2007).

Biopower Technologies

Biopower technologies convert renewable biomass fuels into electricity (and heat) using diverse unit operations such as boilers, gasifiers, turbines, generators, and fuel cells.

There are two main categories of biomass conversion technologies for power and heat production: direct-fired systems (stoker boilers, fluidized bed boilers and co-firing), and gasification systems (fixed bed gasifiers and fluidized bed gasifiers).

Most of today's biomass power plants are direct-fired systems, typically producing less than 50MW of electrical output. The biomass fuel is burned in a boiler to produce high-pressure steam that is used to power a steam turbine-driven power generator. In many applications, steam is extracted from the turbine at medium pressures and temperatures, and is used for process heat or space heating.

Boilers are differentiated by their configuration, size and the quality of the steam or hot water produced. Boiler size is most often measured by the fuel input in units of millions of British Thermal Units per hour (MMBtu/hr), but it may also be measured by output in pounds of steam per hour. Boiler size can also be related to power output in large boilers (typically, 100 MMBtu/hr heat input provides on the order of 10 MW electric output).

The most common types of boilers for biomass firing are stoker boilers and fluidized bed boilers, which are here described:

Stoker-Fired boilers (fixed bed): Water-cooled vibrating grate stoker-fired units may be the technology of choice in certain applications, particularly for wood and residues. Stoker boilers employ direct fire combustion of solid fuels with excess air, producing hot flue gases, which then produce steam in the heat exchange section of the boiler. The steam is used directly for heating purposes or passed through a steam turbine generator to produce electric power. Stoker-fired boilers were first introduced in the 1920s for coal, and in the late 1940s the Detroit Stoker Company installed the first traveling grate spreader stoker boiler for wood. Mechanical stokers are the traditional technology that has been used to automatically supply solid fuels to a boiler. All stokers are designed to feed fuel onto a grate where it burns with air passing up through it. The stoker is located within the furnace section of the boiler and is designed to remove the ash residue after combustion. Stoker units use mechanical means to shift and add fuel to the fire that burns on and above the grate located near the base of the boiler. Heat is transferred from the fire and combustion gases to water tubes on the walls of the boiler. Modern mechanical stokers consist of four elements, 1) a fuel admission system, 2) a stationary or moving grate assembly that supports the burning fuel and provides a pathway for the primary combustion air, 3) an overfire air system that supplies additional air to complete combustion and minimize atmospheric emissions, and 4) an ash discharge system. Stocker-fired boilers are generally inexpensive but do not work well if the moisture content of the feed is variable.

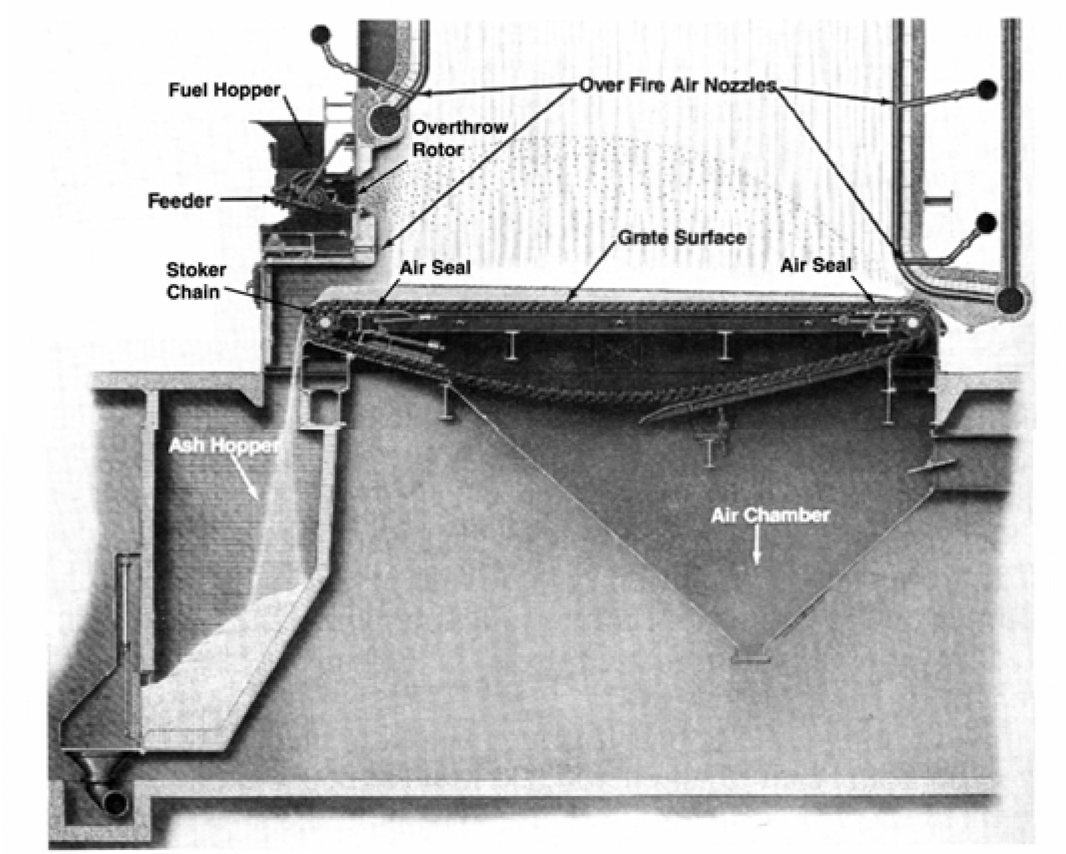

Figure 5. Cut-Away View of a Traveling Grate Stoker Boiler (Source: ORNL 2002)

Fluidized Bed Boilers: Fluidized bed boilers are the most recent type of boilers developed for solid fuel combustion. The primary driving force for their development has been to reduce SO_2 and NOx emissions originally from coal combustion. In this boiler, fuel is burned in a bed of hot inert, or incombustible, particles suspended by an upward flow of combustion air that is injected from the bottom of the combustor to keep the bed in a floating or "fluidized" state. The scrubbing action of the bed material on the fuel enhances the combustion process by stripping away the CO_2 and solids residue (char) that normally forms around the fuel particles. This process allows oxygen to reach the combustible material more readily and increases the rate and efficiency of the combustion process. One advantage of mixing in the fluidized bed is that it allows a more compact design than in conventional water tube boiler designs. Natural gas or fuel oil can also be used as a start-up fuel to preheat the fluidized bed or as an auxiliary fuel when additional heat is required. The effective mixing of the bed makes fluidized bed boilers well-suited to burn solid refuse, wood waste, waste coals, and other nonstandard fuels.

The fluidized bed combustion process provides a means for efficiently mixing fuel with air for combustion. When fuel is introduced to the bed, it is quickly heated above its ignition temperature, ignites, and becomes part of the burning mass. The flow of air and fuel to the dense bed is controlled so that the desired amount of heat is released to the furnace section on a continuous basis. Typically, biomass is burned with 20 percent or higher excess air. Only a small fraction of the bed is combustible material; the remainder is comprised of inert material, such as sand. This inert material provides a large inventory of heat in the furnace section, dampening the effect of brief fluctuations in fuel supply or heating value on boiler steam output.

Fuels that contain a high concentration of ash, sulfur, and nitrogen can be burned efficiently in fluidized bed boilers while meeting stringent emission limitations. Due to long residence time and high intensity of mass transfer, fuel can be efficiently burned in a fluidized bed combustor at temperatures considerably lower than in conventional combustion processes (1,400 to 1,600° F compared to 2,200° F for a spreader stoker boiler). The lower temperatures produce less NOx, a significant benefit with high nitrogen-content wood and biomass fuels. SO_2 emissions from wood waste and biomass are generally insignificant, but where sulfur contamination of the fuel is an issue, limestone can be added to the fluid bed to reduce sulfur emissions. Fuels that are typically contaminated with sulfur include construction debris and some paper mill sludge.

Atmospheric fluidized bed boilers are divided into two specific subcategories: bubbling-bed and circulating-bed units; the fundamental difference between them is the fluidization velocity (higher for circulating-bed). The type of fluid bed selected is a function of the as-specified heating value of the biomass fuel.

- *Bubbling fluidized bed boilers* are most commonly used with biomass fuels, including a wide range such as wood, wood waste, sludge, and residues. This technology is generally selected for fuels with lower heating values. Design features include an open bottom design which is particularly well suited for biomass fuel applications that contain non-combustible debris. Bubbling fluidized beds are good for mills with variable moisture biomass and for wet materials such as waste treatment sludge. In these cases, the bed acts as a heat sink and evens out moisture in biomass

- *Circulating fluidized bed boilers* separate and capture fuel solids entrained in the high-velocity exhaust gas and return them to the bed for complete combustion. The circulating bed is most suitable for fuels of higher heating values. This technology provides the owner flexibility in specifying a variety of fuels (ideal for firing with coal, biomass, or a combination of both). It presents a compact design with low maintenance and very low emissions, although higher costs.

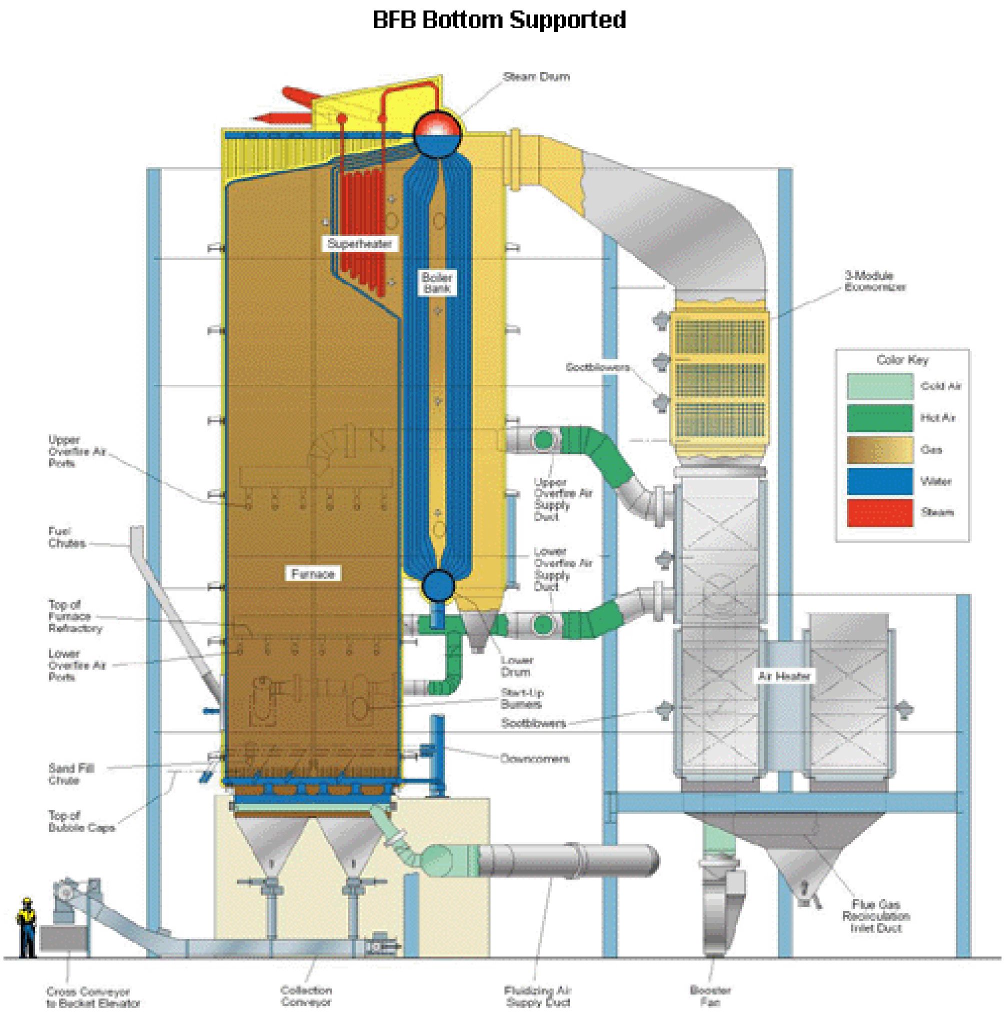

Figure 6. Bubbling Fluidized Bed Boiler, bottom supported (Source: Babcock & Wilcox 2009)

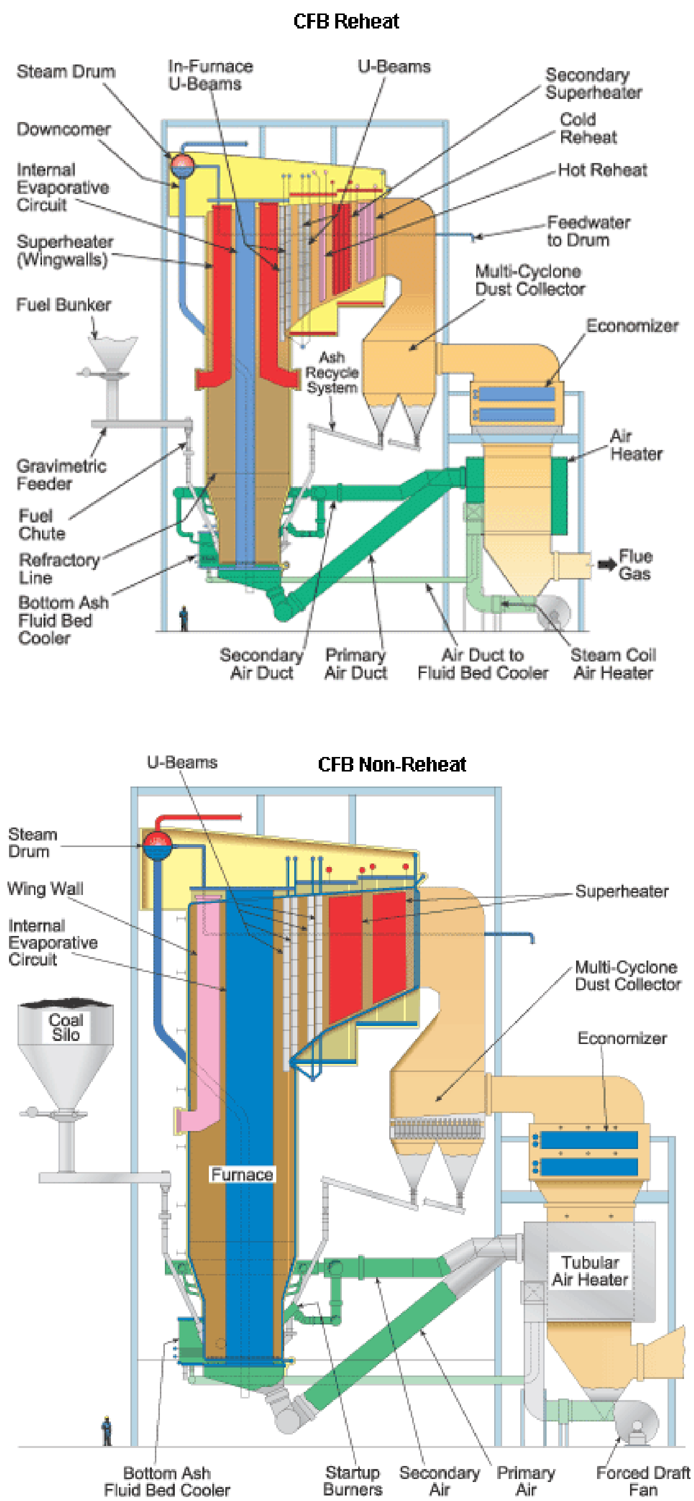

Figure 7. Circulating Fluidized Bed Boilers (Source: Babcock & Wilcox 2009)

Regardless of configuration, biomass boilers can be engineered to produce steam at almost any pressure. In pulp and paper mills steam from the biomass boiler is usually combined with that from the recovery boiler and then sent to the steam turbine. The biomass boiler and recovery boiler steam pressures are usually the same. In older mills, this pressure may be in the range of 500 to 800 psi. In new mills this pressure is typically over 1200 psi and may go as high as 1500 psi. In mills without recovery furnaces the steam requirements are less and these mills will have smaller boilers, typically less than 100,000 lbs/hr, and will operate at pressures in the range of 100 – 300 psi depending on the process steam requirements.

Boiler efficiency is typically defined as the percentage of the fuel energy that is converted to steam energy. Major efficiency factors in biomass combustion are moisture content of the fuel, excess air introduced into the boiler, and the percentage of uncombusted or partially combusted fuel. The general efficiency range of stoker and fluidized bed boilers is between 65 and 85 % efficient. Fuel type and availability have a major effect on efficiency because fuels with high heating values and low moisture content can yield efficiencies up to 25 % higher than fuels having low heating values and high-moisture contents. Biomass boilers are usually run with a considerable amount of excess air so that they can achieve complete combustion, but this has a negative impact on efficiency. Fossil fuels are typically fired into biomass boilers for control purposes, process upsets, and start-ups. The amount of fossil fuel used in the boiler will vary depending on the variability of the biomass feed. For control purposes, only about 5% of fuel energy needs to come from fossil fuels.

The primary difference in efficiency between a stoker boiler and a fluidized bed boiler is the amount of fuel that remains unburned. The efficiency of fluidized bed boilers compares favorably with stoker boilers due to lower combustion losses. Stoker boilers can have 30 to 40 % carbon in the ash, and additional volatiles and CO in the flue gases. Fluidized bed boiler systems typically achieve nearly 100 % fuel combustion. The turbulence in the combustor combined with the thermal inertia of the bed material provide for complete, controlled, and uniform combustion. These factors are essential for maximizing thermal efficiency, minimizing char, and controlling emissions.

Recovery Boilers

The recovery boiler has two main functions: to recover the inorganic cooking chemicals used during pulping, and to make use of the chemical energy in the organic fraction to generate steam for the mill. Black liquor, the by-product of chemical pulping, comprises almost all the inorganic cooking chemicals along with the lignin and other organic compounds separated from the wood during pulping in the digester.

Black liquor, washed and extracted from the pulp, generally contains 14% to 17% dissolved solids, composed of about 1/3 inorganic chemicals which were in the white liquor added to the digester, and 2/3 of organic chemicals extracted from the wood (lignin, hemicellulose and sugars, extractives, organic acids, etc).

Since the initial concentration of weak black liquor is approximately 15% dry solids in water, it needs to be concentrated to firing conditions (60-80% dry solids) in the evaporation plant before being sent to the recovery boiler.

Evaporation of spent pulping liquors is one of the highest consumers of steam in pulp and paper mills. Thermal efficiency, processing capacity and maximum total dry solids contents attainable in evaporators and concentrators are often limited by soluble scale fouling.

The concentration of black liquor is normally carried out in multiple effect evaporators using moderate pressure steam (50 psig) from the turbine extraction. In multiple effect evaporators, steam is used in the first effect and boiling vapor from each effect is condensed in the next effect with the vapor from the last effect condensed by a water condenser. The pressure decreases progressively to about 4 psi absolute in the condenser. The number of effects is limited by the viscous, fouling nature of the black liquor, and the boiling point rise as the solids are increased. Kraft black liquor evaporators are generally limited to eight effects with a maximum expected economy of 6 pounds of water evaporated per pound of steam. The maximum evaporator temperature is limited to 300ºF in the first effect to minimize fouling of the black liquor.

A recent trend for mills has been to increase the black liquor solids to improve their boiler's thermal efficiency, increase liquor throughput, and reduce environmental emissions. A concentrator is used at the end of the evaporator train to bring the dissolved solids up to approximately 80%. In conventional evaporator trains the black liquor is sent to the recovery furnace at about 65% solids.

The recovery boiler is essentially a steam generator using black liquor as its fuel. The black liquor is burned at about 65% to 80% solids and the boiler has a recovered energy efficiency of about 65% (Hough 1985). The operating pressure of new boilers has increased to allow maximum electrical power generation by passing the steam through a turbine generator. Modern recovery boilers can generate steam up to 1500 psi and 900^{o}F.

In addition to converting the combustible materials extracted from wood into useable steam energy, the recovery boiler regenerates the cooking chemicals used for the production of pulp. Sulfur compounds are reduced to sodium sulfide, and sodium organic compounds to sodium carbonate; the recovered chemicals are then discharged from the furnace bottom as a molten smelt. The smelt is dissolved in a weak wash solution from the recausticizing plant to become green liquor, subsequently reacted with lime to form white liquor, the name of the fresh cooking liquor. Lime mud formed in the causticizing reaction is separated, washed, thickened, and converted to lime in the lime kiln.

Many features of the recovery boiler are similar to other boilers except for the lower sections of furnace; where the black liquor spraying and firing takes place. Recovery boilers have two main sections: a furnace section and a convective heat transfer section. All mixing and combustion of the fuel and air should be completed in the furnace section. About 40% of the heat transfer from the combustion gas should also be completed in the furnace. Heat transfer to the boiler water to form high pressure steam is then completed in the convective heat transfer section.

The calorific value of black liquor ranges from 5,800 to 6,600 Btu/lb of dry solids. The burning of black liquor in a modern recovery boiler will produce between 12,000 and 14,000 pounds of steam per ton of pulp.

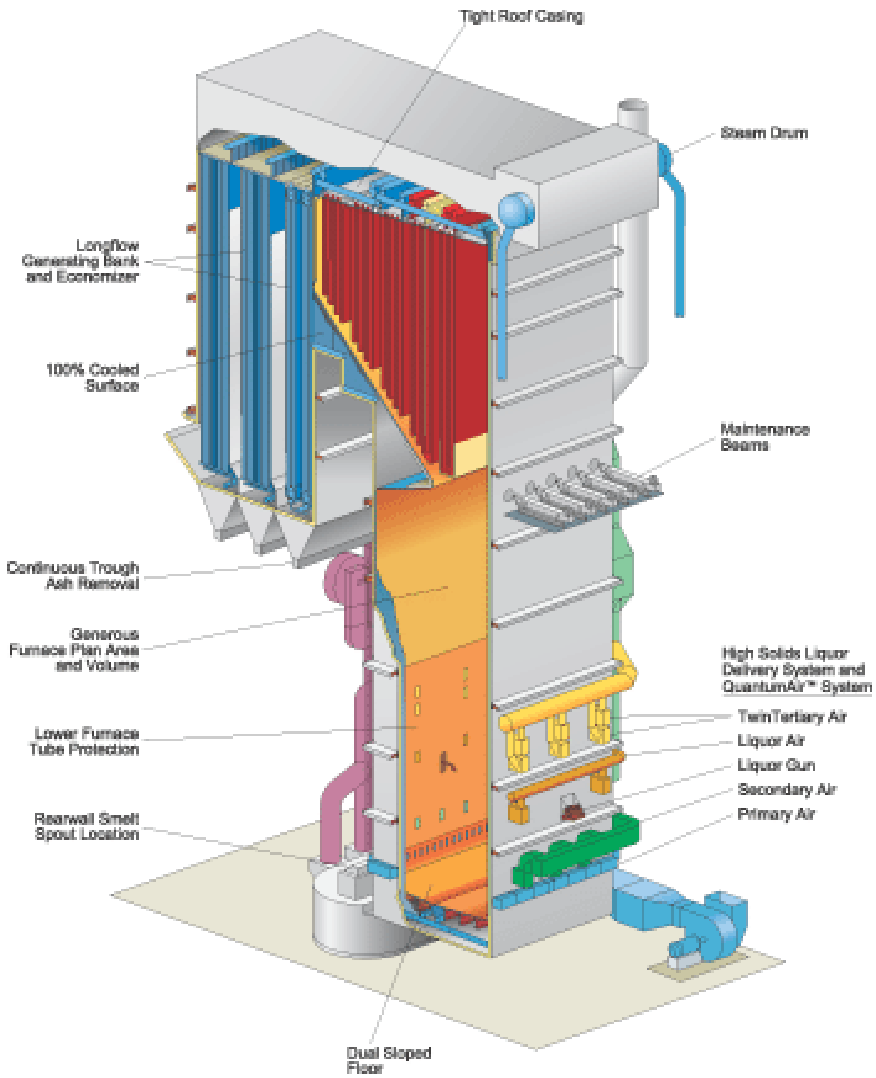

Figure 8. Pulp mill recovery boiler (Source: Babcock & Wilcox, 2009)

Lime Kilns

Another unit operation in the pulp mill that requires large amounts of energy is the lime kiln. Lime reburning is performed in a rotary kiln, where calcium chemicals are converted for reuse in the causticizing process. In the kiln, calcium carbonate is calcined to lime or calcium oxide by the removal of carbon dioxide with heat. The calcination of lime commences at about 1500 °F (300 °C). In a rotary kiln, the maximum temperature is about 2100 °F (1150 °C), and the total energy requirements ranges from 7 to 12 million Btu/ton of lime depending on the moisture content of the lime entering the kiln and the length of the kiln. There is interest in reducing the initial moisture content of the mud to reduce energy consumption in the kiln. Kilns are generally fueled with oil or natural gas. New technology is being developed, however, that permits firing the kiln with recovered lignin (METSO LignoBoost. http://www.metso.com/pulpandpaper/recovery_boiler_prod.nsf/WebWID/WTB-090526-22575-B3707/$File/Lignoboost%2020090526.pdf) or with gases produced by biomass gasification.

Modern pulp mills

New pulp mills are massive operations that produce significant quantities of heat and power. For example, the Botnia mill in Fray Bentos, Uruguay started operation in November 2007. The Fray Bentos pulp mill is one of the most modern pulp mills in the world, with a capacity of 1,000,000 tons/year of fully bleached pulp (See: http://www.celso-foelkel.com.br/artigos/outros/Botnia-Saarela-First%20year%20operation.pdf and http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_Oct2006/$FILE/Uruguay_CIS_Oct2006.pdf).

The evaporation plant of this mill consists of seven effects with internal stripping of volatile gases and the ability to segregate condensate streams. The black liquor is concentrated to 80% solids content to be fired in the recovery boiler. The Andritz recovery boiler in this mill has a capacity of 4,450 solid tons/day, with an estimated boiler efficiency of 73%. Steam is produced at a pressure and temperature of 1,360 psi and 900 ºF, with a generation capacity of 1,440,000 lbs/hour. The kiln is heated using heavy oil as well as the by-product methanol from black liquor evaporation and hydrogen from the chlorate plant of the chemical island. A complete system for the collection of odorous gases and incineration in the recovery boiler (with backup alternatives in the auxiliary boilers) ensures low odor emissions from the mill. The steam from the recovery boiler is sufficient for the turbo generator to generate enough electricity to power the entire mill. Electric power is generated by two Siemens 80 MW turbines, of which one is an extraction back pressure turbo generator and the other an extraction back pressure turbo generator with condensing tail. The average generated power is over 120 MW, while the mill electrical power consumption oscillates around 104 MW. This makes the facility a net exporter of power (likely around 15 MW, but as high as 30 MW could be possible) and therefore electricity can be sold to the national grid.

Figure 9. Botnia S.A., new pulp mill in Fray Bentos, Uruguay (Source: Pöyry Forest Industry Oy)

Motivation and Objectives for this Study

Washington State is well-positioned to be a leader in the production of renewable energy. Accordingly, the legislature, the governor, and the voting public have committed to increase renewable energy as a State policy priority.

In November 2006, Washington State voters passed Initiative I-937. This initiative imposes targets for energy conservation and use of eligible renewable resources on the State's electric utilities that serve more than 25,000 customers. Specifically, these utilities, both public and private, must secure 15 % of their power supply from renewable resources by 2020. The utilities must also set and meet energy conservation targets starting in 2010. Interim targets are included in the initiative. Seventeen of Washington's 62 electrical utilities qualify for I-937 compliance. These utilities account for about 80 % of the state's load. The initiative was designed to build on the renewable hydropower tradition in Washington and further develop the state's other renewable resources - solar, tidal, ocean wave, geothermal, bioenergy, and wind. However, I-937 specifically excludes municipal solid waste, black liquor, and biomass from old growth trees. (Bonneville Power Administration. Washington State Energy Initiative I-937 http://www.bpa.gov/corporate/pubs/issue_briefs/06/ib112906.pdf). The pulp and paper industry does not appear to be considered a potential contributor to the state's renewable power future plans, even though it is the largest source of biomass-based power in Washington today.

Hydro-power has been a clean and inexpensive source of renewable energy for Washington for many years but is unlikely to experience significant expansion in the future. In contrast to hydro-power, our second largest source of renewable energy, woody biomass, offers many opportunities for expansion in both magnitude and energy type. A Washington State University (WSU) assessment of organic material resources potentially available for bioenergy production in Washington State identified wood residues from timber harvesting and processing as the single largest source of biomass; more than equal to the volume of all other sources combined (municipal, agricultural, and animal wastes) (Frear 2008) (Frear, Zhao et al. 2005). Woody biomass is uniquely versatile in that it can be converted to: (1) electrical power with steam and heat as a byproduct, (2) liquid and gaseous fuels (e.g., ethanol and syngas products) to reduce reliance on fossil fuels for transportation applications, and (3) valuable industrial chemicals.

The pulp and paper industry is the largest converter of wood biomass to energy in Washington and is a significant contributor to the State economy. The pulp and paper industry creates 7400 high-wage annual jobs (average wage is greater than $60,000 per year) and generates an annual payroll of $450 million. Mason and Lippke (Mason and Lippke 2007) found that for every direct job generated by the pulp and paper industry, there are 4.3 indirect jobs that result in the broader economy.

While existing infrastructure represents considerable investment in renewable energy generation, preliminary estimates have suggested that improvements in conversion efficiencies coupled with investments in replacement of dated equipment could potentially double energy yields from pulp and paper mills. Improved energy production from pulp and paper mills could result in many public benefits including increased renewable power generation, ensured industry viability in the face of global competition, retention and creation of high wage jobs, rural economic development, and new markets for forest residuals. To test this hypothesis and inform implications for future energy policy, we have completed a comprehensive analysis of the current energy production from the pulp and paper industry in Washington State.

The objective of this project is to assess the current energy profile of the Washington pulp and paper industry and to determine the potential renewable energy production of the industry with implementation of state-of-the-art technologies.

The project has two phases:

Phase 1: Assess the current energy profile of Washington State pulp and paper mills. In this phase of the study, we determined the energy generation (steam and power) capability of Washington State pulp and paper mills. The sources and types of fuels used in various boilers have been assessed in the study. The age profile of boilers currently in pulp and paper mills has also been determined.

Phase 2: Assess the energy potential for Washington State pulp and paper industry with state-of-the-art technologies. In this phase of the study, calculations were made assuming Washington State pulp and paper mills acquire state-of-the-art technology power and recovery boiler technology. We assumed that all boilers producing steam for pulp and paper mills also produced electrical power at levels possible with current technology. The capitol cost of installing this state-of-the-art technology was assessed and the biomass supply required to operate all these boilers without fossil fuels has been determined. Finally, we assessed the potential of technologies that would allow pulp mills to operate fossil fuel dependant unit operations, such as the lime kiln, on biomass produced fuels.

Results and Discussion

Boiler Survey

A survey was constructed to assess current energy profiles of pulp and paper mills in Washington State. A copy of the survey is shown in Appendix I. The survey was previewed by David Sjoding of the Washington State University Energy Extension office and by Steven DuVall from Longview Fibre Company. David and Steven made several valuable suggestions that we incorporated into to the survey. The survey was then emailed out to the 11 pulp and paper mills in Washington State. The Norpac mill was coupled with the Weyerhaeuser Longview mill since they have shared heat and power facilities. Follow up email and phone calls were made to facilitate completion of the surveys. Follow up phone calls were also made to select mills to clarify responses or gain further information.

The response of the survey was excellent. Ten out of the eleven mills provided responses and the surveys were thoroughly completed. We greatly appreciate the time the engineers and operators at the ten mills devoted to completeing the survey.

Survey Results

The following are the results of the survey. Please note that the survey results were considered confidential so we are only providing aggregated data to maintain confidentiality.

The range of production capacity of Washington mills is large from only 60,000 tons per year to over one million tons per year of paper and market pulp. Six of the mills produce chemical (kraft or sulfite) pulp and four of the mills had mechanical pulping capability. One of the mills runs strictly off of recycled fiber and one mill purchases all their fiber. The range of boiler sizes and types are equally broad. Some mills have only fossil fuel boilers and some biomass and fossil fuel boilers. All the chemical pulp mills have recovery, biomass, and fossil fuel boilers. The following provides specific information and data on the different types of boilers used in Washington State pulp and paper mills.

Fossil fuel boilers

Fossil fuels boilers are generally used as supplemental steam sources, with biomass and recovery boilers being the primary sources, in Washington State mills. These boilers are generally small and lower pressure. Only one Washington mill relies solely on a fossil fuel boiler for its process steam. Washington mill fossil fuel boilers are old. The average age is forty seven years old. The newest boiler is 13 years old and the oldest is 57 years old. The generally accepted lifetime of a boiler is 30 – 40 years; however, with rebuilds and renovations a boiler can last almost forever.

The current steam production from all the fossil fuel boilers is 1.3 million lbs per hour while the maximum capacity is 2.7 million lbs per hour. The large excess in fossil fuel boiler capacity is consistent with their use as supplemental steam supply. The average steam production is 133,000 lbs/hour and the range is 15,000 up to 400,000 lbs/hour. The steam pressure of most of the fossil fuel boilers is in the range of 150 – 400 psi. Two mills, however, had higher pressure fossil fuel boilers producing steam at 600 and 800 psi. Figure 10 shows the current and maximum steam capacity of the fossil boilers in the mills from our survey. The total amount of energy produced currently from Washington fossil fuel boilers is 4.6 million MMBtu/year[2].

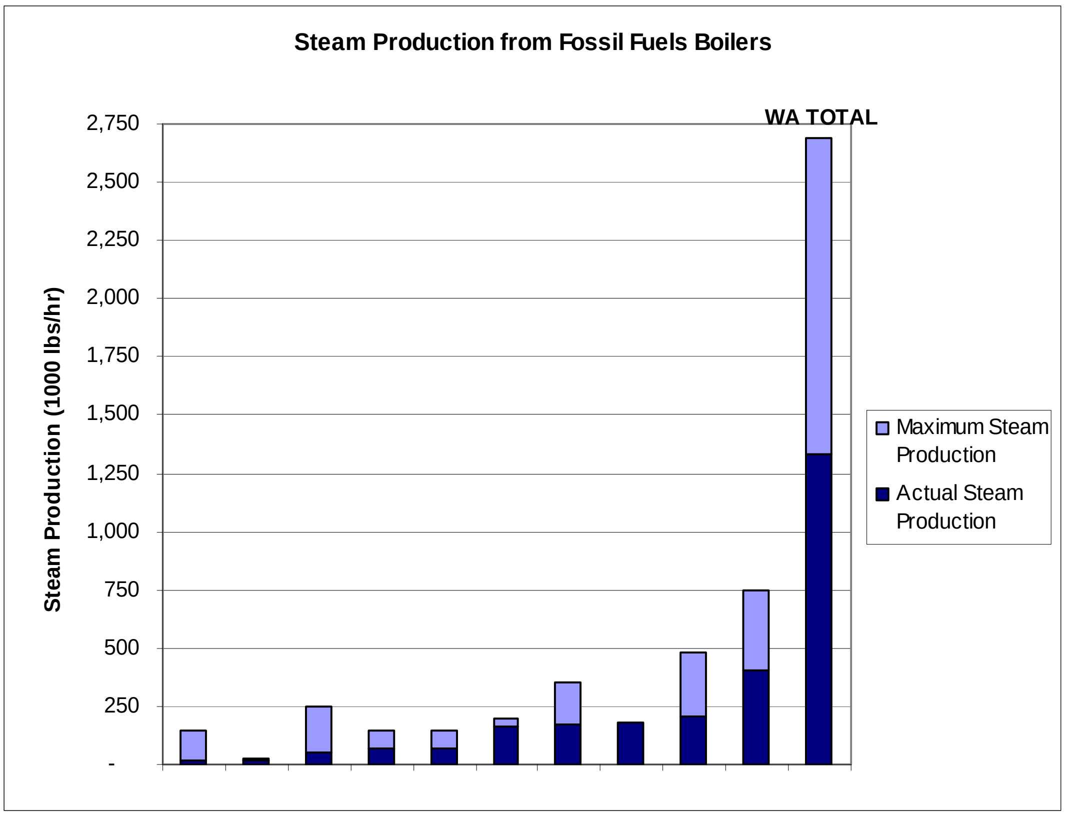

Figure 10. Current and Maximum Steam Production from Fossil Fuel Boilers

Biomass boilers

Biomass boilers provide significant quantities of heat and power for Washington pulp and paper mills. These boilers are typically larger and higher pressure than the fossil fuel boilers but their capacity range is very large. Washington biomass boilers are old. The average age is 35 years old with the oldest being 61 and newest being 8 years old. Generally accepted lifetime for biomass boilers is 30-40 years.

[2] MMBtu/year = millions of Btu/year

The current steam product from all the biomass boilers is 2.3 million lbs/hour with the total capacity being 3.5 million lbs/hour. There appears to be substantial excess biomass boiler capacity in Washington State mills. The average steam production in the biomass boilers is 231,000 lbs/hour and the range is from 18,000 to 560,000 lbs/hour. The pressure of the biomass boiler is generally higher than in the fossil fuel boilers with most of the mills running over 400 psi, sufficient to drive an electrical generating turbine. One mill operates a biomass boiler at 1250 psi. Another mill operates their biomass boiler in a low pressure mode, at only 225 psi, but has the capacity to run at 1000 psi. Figure 11 shows the current and maximum steam capacity of the biomass boilers in the mills from our survey. The total amount of energy produced currently from Washington biomass boilers is 26 million MMBtu/year.

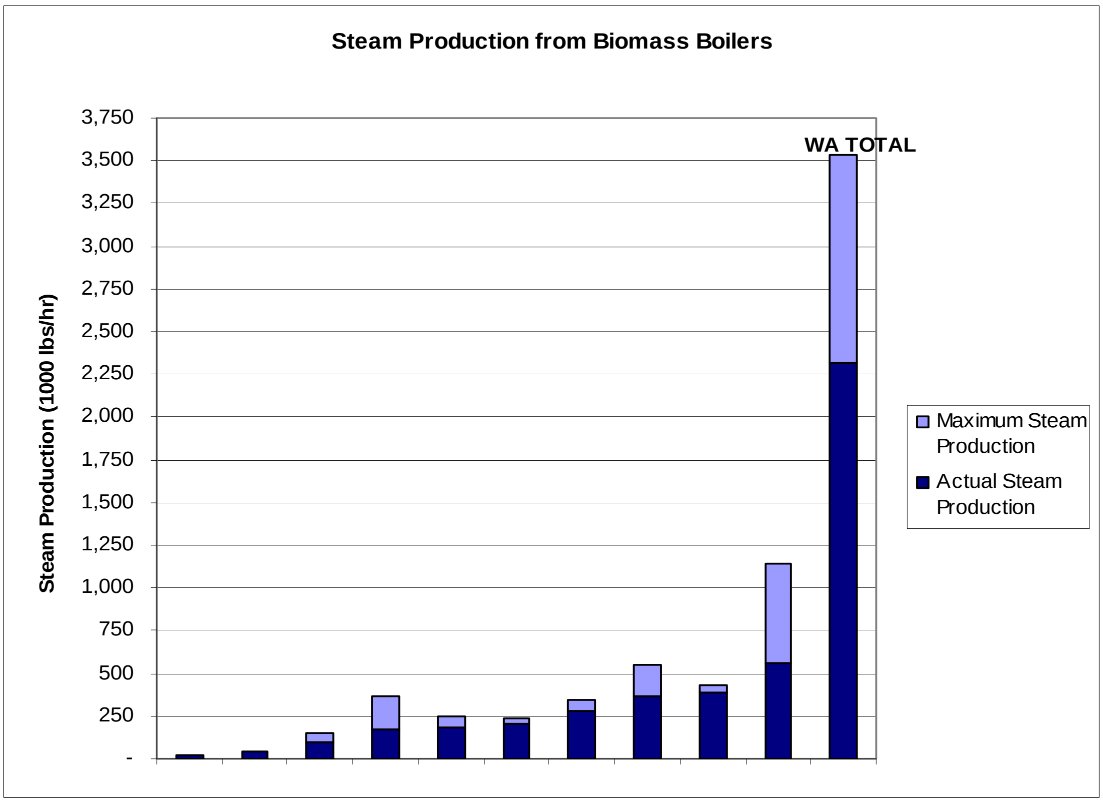

Figure 11. Current and Maximum Steam Production from Biomass Boilers

Washington biomass boilers burn a lot of different types of fuels. They all burn hog fuel but most of the boilers also burn waste treatment sludge. The total amount of biomass consumed by the biomass boilers is 1.4 million tons per year. Of that, 112,000 tons per year is from sludge. To put this figure in perspective, Frear et al. (Frear, Zhao et al. 2005) published that there are 5.3 million tons of forest-based mill residues available for energy production in Washington State.

Biomass boilers also burn a substantial amount of fossil fuel. Of the 26 million MMBtu of energy from biomass boilers, roughly 5 million MMBtu came from burning fossil fuels. Fossil fuel usage in biomass boilers is normally due to process control needs, accommodating wet fuel, start-ups, and failures of the biomass feed system. These demands for fossil fuel, however, generally account for 5% of the total boiler energy, not the 19% as we found in the survey. We anticipated that this high fossil fuel usage in the biomass boilers would be attributable to inadequate hog fuel supplies. Surprisingly, only one of the mills in the survey specifically noted that they used fossil fuel because of inadequate biomass supply. Conversations with mill personnel, however, showed that they were concerned about the cost and supply of hog fuel for their biomass boilers. This concern would certainly become greater if the biomass boilers were operating at full capacity.

To completely replace fossil fuels in Washington biomass boilers would require an additional 280,000 tons of biomass per year. Fuel oil and natural gas were mentioned as the two main fossil fuels for biomass boilers. One mill, however, reported using substantial quantities of coal as the fossil fuel for their boiler.

Recovery boilers

Almost all chemical pulp mills have recovery boilers to regenerate pulping chemicals and provide steam and power for the mill. (A notable exception to this was the Georgia Pacific mill in Bellingham that did not burn the waste organics but instead produced sulfonated lignin products and ethanol from the carbohydrates in the spent pulping liquor). Mechanical pulp mills and mills that operate on 100% recycled fiber do not have recovery furnaces. Six of the mills in our survey have recovery boilers. The average age of the recovery boilers is 36 years. The oldest one is 48 years old (although it is a very small unit) and the youngest 17 years old. Thirty – forty years is also considered a reasonable life time for recovery boilers.

Current steam production from recovery boilers is 3.3 million lbs steam/hour and the maximum is 4.2 million lbs of steam per hour. It should be noted that half of that excess capacity is from one mill. The 3.3 million lbs per hour is notable especially when you consider that only six of the ten mills in the survey have recovery boilers. Clearly recovery boilers are substantial sources of renewable energy. The average steam production from the recovery boilers is 550,000 lbs/hour and the range is from 276,000 to 990,000 lbs/hour. The pressures in the recovery boilers are high, generally in the 600 – 800 psi range, although one boiler operates at 400 psi and one very small (the oldest recovery boiler) operates at only 275 psi. Figure 12 shows the current and maximum steam capacity of the recovery boilers in the mills from our survey. It can be seen that most of the boilers are at or near capacity. It is common in pulp mills for the recovery boiler to be the production limiting unit operation. The total amount of energy produced currently from Washington recovery boilers is 36 million MMBtu/year.

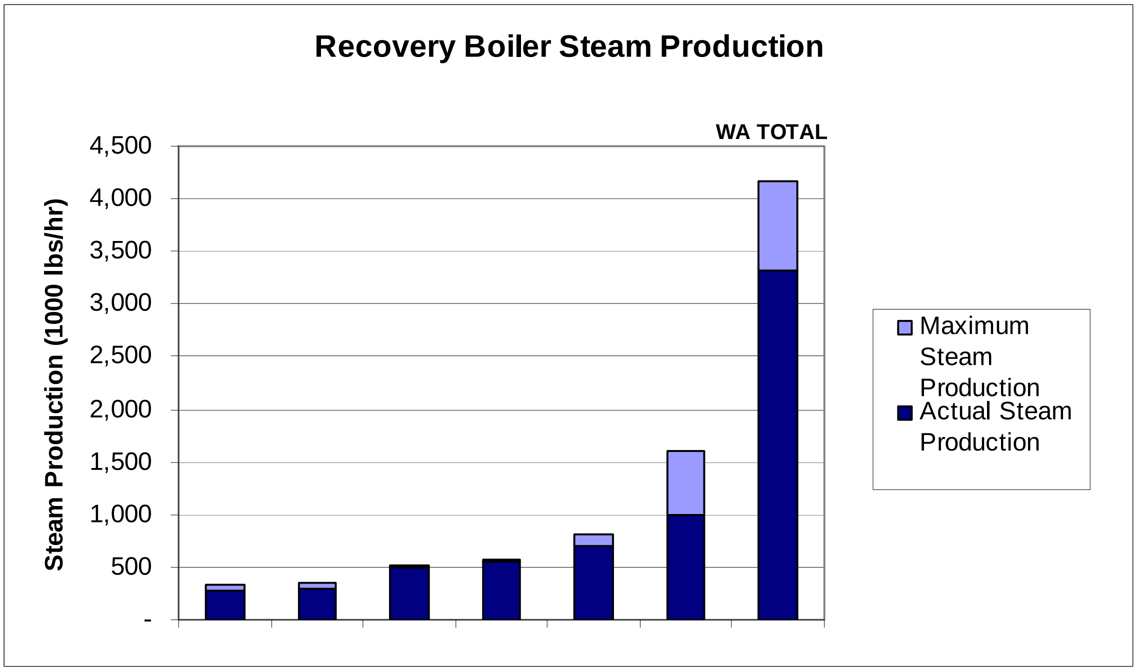

Figure 12.Current and Maximum Steam Production from Recovery Boilers

The amount of fossil fuel used in recovery boilers is generally small and that was found to be the case for Washington State mills. Of the 36 million MMBtu/year produced, only 563,000 MMBtu/year is produced by burning fossil fuels. This small amount of fossil fuel is used to help control the boiler, to supply a higher heating value fuel to the boiler, and for start-up and shut down operations. The black liquor fed to the boilers for most of the mills is in the range of 65 – 70%. One mill reported a low 52% black liquor dissolved solids. As noted in the introduction, modern mills can have black liquor solids of over 80%. A high black liquor solids means more of the black liquor energy will be used for making steam instead of evaporating the remaining water in the black liquor.

Steam turbines

Six out of the ten mills in the survey produce electricity from steam turbines. Of the four mills that do not generate electricity, only one was a chemical pulp mill with a recovery boiler. We did not get a good survey response on the age of the turbines, but the data suggests that many of the turbines are quite old. One new turbine was installed this year, however. The total power generated by Washington pulp and paper mill steam turbines is 220 MW and the maximum capacity is 280 MW. Additional power generating capacity would require capital expenditures for new equipment. As with the boilers, there is quite a range of turbine size and capacities. The average power production from Washington turbines is 37 MW but individual mills range from 5.5 MW to 70 MW.

Lime kilns

Lime kilns also use significant amounts of fossil fuels, so we examined their energy usage. The five kraft mills that responded to the survey have a total lime capacity of 1,300 tons lime/day. The average lime production in Washington mills is 262 tons lime per day. The range of lime production is from 125 tons/day to 325 tons/day. Washington mills report using both natural gas and oil to fire the kiln. The total fossil fuel energy used in Washington mill kilns is approximately 2,650,000 MMBtu/year. This is about one-half the energy used in state fossil fuel boilers and about one-half the fossil fuel usage in Washington biomass boilers. Given the fossil fuel consumption in boilers and the difficulty in running a kiln on a non-fossil fuel it does not make sense to pursue technologies that permit using bio-based fuels in the lime kiln until more has been done to get the boilers off of fossil fuels.

Survey conclusions

The excellent survey response provides us accurate data on the boilers and their fossil fuel usage in Washington pulp and paper mills. The most striking result of the survey was the age of boilers in Washington mills. While these old boilers can be maintained to operate indefinitely, their age suggests that better energy efficiency and renewable power production would be a definite possibility if they were to be replaced. Most of the mills are producing electric power with their boiler steam. The one chemical pulp mill not producing steam represents an opportunity for Washington State to have more renewable power, probably on order of 20MW or more, without consuming additional biomass. The I-937 renewable energy law prohibiting black liquor from being a renewable fuel may be a barrier to bringing this additional 20 MW on line. Another mill that does not generate power indicated that their biomass boiler could be operated at 1000 psi. It appears that this mill could also be producing renewable electricity with moderate capital expenditures; they would need to purchase and install a new turbine but not a new boiler. Additional power production from Washington pulp and paper mills would require purchase of new boilers, which is discussed in the next section of the report.

Washington pulp and paper mills burn a fair amount of fossil fuel in their fossil fuel boilers and in their biomass boilers. The energy from fossil fuels is about the same in these two boilers, approximately 5 million MMBtu/year. To get the biomass boilers completely off of fossil fuels would require an additional 280,000 tons/year of hog fuel (or other biomass fuel) per year. This is a substantial amount of biomass but not large compared to the 5.3 million tons/year that should be available. A relatively direct route for Washington to have more renewable heat and power is for the pulp and paper mills to use as much biomass in their boilers as possible.

Finally, mill lime kilns are another big user of fossil fuel but not near as large as the biomass or fossil fuel boilers. Adding unit operations and modifying kilns to be able to burn bio-based fuels appears to be a more difficult route to reducing the total amount of fossil fuel used in the mill. These modifications would only make sense if a mill wanted to increase pulp production but was recovery furnace limited.

Energy production capability

The second phase of the project was to assess the renewable power potential of Washington's pulp and paper industry. For this analysis we calculated the power production if Washington mills had state-of-the-art boilers and turbines. Operating parameters for a state-of-the art mill were estimated based on literature data and information supplied by Harris Group engineers. We defined the state of the art mill as having a high performance recovery and biomass boilers that operate at 1470 psi. We assumed that negligible amounts of fossil fuel are used in either boiler. For the chemical pulp mills we assumed that the black (or red) liquor feed – in lbs black liquor solids/hour - were the same as they currently produced but that mills had evaporation capacity to achieve 80% black liquor solids. It was assumed that 3.2 lbs of steam was generated per pound of black liquor solids fired in the boiler. This value is based on data from a new boiler and is consistent with that used by Larson for modern recovery boilers (Larson, Consonni et al. 2003).

The steam generated from the biomass boiler was calculated as the difference in total steam requirement of the mill, obtained from the survey data, and the steam generated from the recovery boiler. The steam generated in the biomass boiler was also assumed to be at 1470 psi. For mills without recovery boilers it was assumed that all the steam to run the mill is produced in a biomass boiler operating at 1470 psi. A ratio of 4.8 lbs of steam produced per pound (oven dry) of feed was assumed. This value was taken from a modern softwood pulp mill but may be quite variable depending on the heating value of the biomass.

The final assumption in the calculation was that 0.074 MW of electricity was produced for each 1000 lbs/hr of steam sent to the turbine. This value, based on new turbine data, is also consistent with that used by Larson (Larson, Consonni et al. 2003).

With these assumptions we calculated the amount of renewable power Washington mills could produce, how much biomass would be required, and the total cost to make these extensive modernizations.

It was found that the total electrical power from Washington mills could be increased to 520 MW with new boilers. This is more than double the 220 MW currently generated by Washington pulp and paper mills. The amount of biomass needed to generate this additional power was also found to be substantial. 3.8 million tons of biomass per year would be required if the mills were producing 520 MW of renewable power, a little less than three times the 1.4 million tons of biomass consumed currently. The additional biomass is a result of the increased electrical generation and elimination of all fossil fuels in the boilers. 3.8 million tons is a significant fraction of the 5.3 million tons of mill residuals available in Washington State (Frear, Zhao et al. 2005) and may be difficult to acquire at a reasonable price. Other wood biomass sources, such forest thinning and logging residues, may increase the available biomass to over 8 million tons per year but the cost, quality, and availability of these materials is not well characterized.

The cost to install new unit operations was calculated to be $2.3 billion dollars for all the mills. This includes new biomass boilers and back pressure turbines for all the mills and new evaporators and recovery boilers for the chemical pulp mills. This translates to roughly $4,400/kW of power generation. While this cost is high for combined heat and power plants – a typical range is $2,000 - $3,000/kW (EPA 2008) – it is not extreme. Increased cost of steel and other construction materials have raised the cost of CHP systems close to this $4,000/kW (Sjoding 2009). Further, much of the cost is the expensive unit operations, evaporators and recovery boilers, that are needed to deal with spent liquors and to recover pulping chemicals. In addition, the analysis includes some very small (one as small as 1.2 MW) power plants that would be very expensive on a per kW basis due to economies of scale.

In a more complete economic analysis a significant fraction of the capital cost for the new boilers would be allocated to the production of pulp and paper. This allocation would be especially significant if replacement of the boiler was necessary to continue production of pulp and paper. Given the age of Washington boilers, necessary replacement may become a realistic scenario over the next decade. Increasing demand for and value of renewable power could also make replacement of aging boilers with new high pressure units an attractive investment.

Another important consideration is the potential for using completely new and different technology instead of replacing biomass boilers with high pressure versions of current installations. Biomass gasification systems that produce Fischer Tropsch fuels are a reasonably well developed technology (http://www.tri-inc.net/index.html). Large demonstration facilities of these systems are being installed at New Page (500 tons/day) and Flambeau River (1000 tons/day) mills in Wisconsin. With this technology biomass is converted into hydrocarbon fuels, tail gas – for use in the lime kiln, electricity, and steam for the mill. The high value of all these products may make this a more attractive technology to pursue. A recent study completed by the University of Washington concludes that the conversion of residual biomass to transportation fuels should be Washington's highest priority to meet the policy goals of green house gas emissions reductions, energy independence, and sustainability (http://www.ruraltech.org/pubs/reports/2009/wood_to_energy/index.asp). Installation of gasification technology to replace aging boilers could be a cost-effective and efficient means for Washington to produce renewable transportation fuels.

Another benefit of gasification, in contrast to high pressure boilers, is its relatively low operating temperature, ~600^{o}C. These low temperatures permit use of agricultural residues with high silica content – such as wheat straw - without concerns of silica building up on heat transfer surfaces. Silica can be a significant problem in higher temperature biomass boilers. The ability to use agriculture residues could appreciably expand the available biomass feedstock resource. Frear (Frear, Zhao et al. 2005) for example, estimates that 1.6 million tons of wheat straw are available for energy production in Washington State. Further research is needed to assess whether gasification technology would be a good investment for Washington pulp and paper mills.

Other technologies to produce fuels from biomass may be integrated into pulp and paper mills. Research has shown that steam explosion pretreatment followed by hydrolysis and fermentation (the so called sugar platform) is an efficient method to produce ethanol from mixed biomass feedstocks (Bura, Berlin et al. 2006) even recalcitrant softwood biomass (Ewanick, Bura et al. 2007). Integration of a biorefinery using this technology into a pulp and paper mill would be beneficial for both operations because of the shared resources and a broader range of product streams. There are no current demonstration facilities, however, that use the sugar platform to produce fuels that are integrated into pulp and paper mills.

This analysis clearly shows that there is considerable potential for expansion of renewable power and renewable fuels production in pulp and paper mills, however, expensive investments in equipment upgrades will be required. A significant fraction of the cost of new installations may reasonably be allocated to the pulp and paper products if current boilers need replacement for the mill to continue operation. None the less, mills would need to be confident that sufficient quantities of biomass along with adequately priced energy markets would be available. Given current low fossil energy price differentials and confusing energy laws such as I-937, new policy commitments will likely be needed to support renewable energy investments by the pulp and paper industry. Careful analyses of potential scenarios are needed to address these concerns.

Conclusions and Recommendations

We have been able to develop an accurate picture of the state of boilers and power generation in Washington pulp and paper mills. We find that Washington mills produce substantial amounts of renewable power but that the boilers and ancillary equipment are old. With this older equipment, the mills produce considerably less power than they could with new boilers, evaporators, and turbines. There appears to be some “low hanging fruit” with regard to increasing renewable power production from pulp and paper mills. One kraft mill does not have a turbine for power production and one of the recycle/mechanical pulp mills appears to have a boiler that can generate high pressure steam, but would also need a steam turbine if electricity is to be generated. Additional but more modest short-term improvements could be made in other mills to increase cumulative renewable energy output further. Policy supports including incentives may be needed to spur energy recovery investments. Existing laws such as I-937 may inadvertently function as barriers to production of renewable power for the State.

Longer term, there appear to be significant opportunities for increased production of renewable fuels and power at Washington pulp and paper mills. Installation of new technologies could result in more renewable power production and/or new conversion capabilities for development of clean biofuels. The potential for development of renewable fuels in pulp mills is especially compelling given the combined concerns of climate change mitigation and energy independence. Prioritization of State renewable energy objectives is worthy of further investigation. Installation of new technologies, however, will be expensive and increased power or fuels production will necessitate greater availability of sustainable woody biomass feedstock supplies. Mill managers will need to be confident that prices for renewable products will be both adequate and reasonably secure before new investments in energy conversion capabilities can be made. The State could help mills to proceed with construction of new facilities by providing low-cost loans, production incentives, and accelerated reduced-cost permitting processes. Biomass supply assurances will be needed as well with state lands potentially providing a model for other ownerships. Policies that establish renewable energy standards and create value for the reduced carbon emissions associated with displacement of fossil fuels by renewables will contribute important market support. Biomass supply and cost issues are challenging and will need both further research and policy attention. We recommend that a thorough investigation of the long-term benefits of different renewable energy options for Washington pulp and paper mills should be undertaken as soon as possible. The potential for producing renewable transportation fuels in pulp and paper mills is especially compelling and warrants an in-depth analysis.

In general, pulp and paper mills should be viewed as under-used resources for the production of renewable energy and fuels. Washington could benefit from energy policies that recognize and reward current and potential contributions of the pulp and paper industry to the achievement of State energy objectives and sustainable use of forest resources.

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Appendix I:
Survey and cover letter sent to pulp and paper mills

If you have an interest in enhancing the contribution of the pulp paper industry to our states renewable energy goals, please fill out this UW/College of Forest Resources survey.

Survey for the Renewable Energy Potential of the Washington Pulp and Paper Industry

Dear Company Representative,

The WA State Legislature has commissioned the College of Forest Resources to conduct an objective study of the potential for the pulp and paper industry to help meet Washington's renewable fuel and energy standards. This study will include an assessment of the current potential of the industry to supply renewable energy, which we define as energy derived from burning black liquor and biomass (e.g. hog fuel). We want to know what type of boilers you have in your facility and whether the limitation on producing more renewable energy currently is a consequence of biomass availability. In addition, we will assess how much renewable energy could be produced in Washington State mills if they had state-of-the-art boilers (recovery and biomass) and steam turbines. ***The results of this survey will provide a definitive assessment of the potential of the pulp and paper industry to be a significant contributor to Washington's renewable energy portfolio.***

Please take a few minutes to fill out and return this important questionnaire. We would appreciate getting your response by 15 April 2009 such that we can finish our study by June 2009. We understand that you may have already provided some boiler data to the Washington State Energy Office. We are now working with them on this project and we have populated this survey (in red) with their data. Please confirm the accuracy of the data already in the survey and fill in as much of the remainder as possible.

Your participation in this survey will ensure that future policies or regulations considered by the Legislature will be informed by a current understanding of the potential for renewable energy production from the pulp and paper industry. ***PLEASE BE ASSURED THAT YOUR RESPONSES WILL BE KEPT COMPLETELY CONFIDENTIAL.*** To ensure respondent anonymity in the final report, all survey data will be summarized to reflect industry activities. All information collected from this survey will be analyzed and aggregated at the College of Forest Resources prior to presentation to the State Legislature and State Agencies.

If you have any questions, please contact Dr. Rick Gustafson, Denman Professor of Bioresource Science and Engineering at 206-543-2790, pulp@u.washington.edu.

Thank you for taking the time to provide this important information.

SURVEY OF BOILERS AND POWER GENERATION
IN WASHINGTON STATE PULP AND PAPER MILLS

GENERAL INFORMATION

1) What is the name of your company?

2) What is the name of your mill?

3) What is the location of your mill?

4) What is the approximate annual production of the following products from you mill?

Product	Production (tons/year)
Market Pulp	
Newsprint	
Publication papers	
Paper	
Fine paper	
Liner board	
Corrugating medium	
Tissue and toweling	

5) If you have a pulp mill please indicate the production of the following pulp types.

Pulp type	Production (tons/year)
Kraft	
NSSC	
Thermo mechanical	
Recycle (OCC & DLK)	

SURVEY OF BOILERS AND POWER GENERATION
IN WASHINGTON STATE PULP AND PAPER MILLS

BIOMASS BOILER INFORMATION

If you have one or more boilers that burn biomass as its primary fuel please complete the following; otherwise please go to page 6.

1) How many boilers that burn biomass as its primary fuel do you have at your mill?

2) Please provide the following general information for each of the biomass boilers in your mill.

	Boiler #1	**Boiler #2**	**Boiler #3**
Boiler manufacturer			
Start-up date			
Mill unit number			
Type of Boiler[1]			

[1] For example: Stoker, bubbling fluidized bed, circulating fluidized bed, gasifier, etc.

3) Please provide the following operating data for each of your boilers

Boiler #1				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
Boiler #2				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
Boiler #3				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	

BIOMASS BOILER INFORMATION (continued)

4) Please provide the following information on the fuels you burn in your biomass boiler

Boiler #1			
Primary Fuel Information			
Type of Biomass Fuel (e.g. Hog fuel, sludge)	Consumption (tons/yr)	Moisture content (%)	Biomass Source
Auxiliary fuel information			
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)		

Reasons for using auxiliary fuel: Insufficient biomass at reasonable price, need for higher energy fuel for boiler efficiency, other:

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Boiler #2			
Primary Fuel Information			
Type of Biomass Fuel (e.g. Hog fuel, sludge)	Consumption (tons/yr)	Moisture content (%)	Biomass Source
Auxiliary fuel information			
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)		

Reasons for using auxiliary fuel: Insufficient biomass at reasonable price, need for higher energy fuel for boiler efficiency, other:

____

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BIOMASS BOILER INFORMATION (continued)

Boiler #3			
Primary Fuel Information			
Type of Biomass Fuel (e.g. Hog fuel, sludge)	Consumption (tons/yr)	Moisture content (%)	Biomass Source
Auxiliary fuel information			
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)		

Reasons for using auxiliary fuel: Insufficient biomass at reasonable price, need for higher energy fuel for boiler efficiency, other:

____

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SURVEY OF BOILERS AND POWER GENERATION
IN WASHINGTON STATE PULP AND PAPER MILLS

FOSSIL FUEL BOILER INFORMATION

If you have one or more boilers that burn fossil fuel as its primary fuel please complete the following; otherwise please go to page 8.

1) How many boilers that burn fossil fuel as its primary fuel do you have at your mill?

2) Please provide the following information general information for each of the fossil fuel boilers in your mill.

	Boiler #1	Boiler #2	Boiler #3
Boiler manufacturer			
Start-up date			
Mill unit number			
Type of Boiler			

3) Please provide the following operating data for each of your boilers

Boiler #1				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
Boiler #2				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
Boiler #3				
Boiler Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	

FOSSIL FUEL BOILER INFORMATION (continued)

4) Please provide the following information on the fuels you burn in your fossil fuel boiler

Boiler #1	
Fossil fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)
Boiler #2	
Fossil fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)
Boiler #3	
Fossil fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)

SURVEY OF BOILERS AND POWER GENERATION
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RECOVERY FURNACE INFORMATION

If you have one or more recovery furnaces please complete the following; otherwise please go to page 10.

1) How many recovery furnaces do you have at your mill?

2) Please provide the following general information for each of the recovery furnaces in your mill.

	Furnace #1	Furnace #2	Furnace #3
Furnace manufacturer			
Start-up date			
Mill unit number			

3) Please provide the following operating data for each of your recovery furnaces

Recovery Furnace #1				
Furnace Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
% excess air into furnace:				
Recovery Furnace #2				
Furnace Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
% excess air into furnace:				
Recovery Furnace #3				
Furnace Operation (wks/yr):				
Steam production (lbs/hr)	Typical:		Maximum:	
Steam temperature (^{o}F)	Typical:		Maximum:	
Steam pressure (psi)	Typical:		Maximum:	
% excess air into furnace:				

RECOVERY FURNACE INFORMATION (continued)

4) Please provide the following information on the fuels you burn in your recovery furnace

<table>
<tr><th colspan="3">Furnace #1</th></tr>
<tr><td colspan="3">Black Liquor Information</td></tr>
<tr><td colspan="2">Average black liquor flow rate (lbs/hour)</td><td></td></tr>
<tr><td colspan="2">Black liquor (% solids)</td><td></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Auxiliary fuel information</td></tr>
<tr><td>Type of Fuel
(e.g. oil, natural gas)</td><td colspan="2">Consumption (please provide units)
Please indicate type of oil you are burning (and heating value if known)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><th colspan="3">Furnace #2</th></tr>
<tr><td colspan="3">Black Liquor Information</td></tr>
<tr><td colspan="2">Average black liquor flow rate (lbs/hour)</td><td></td></tr>
<tr><td colspan="2">Black liquor (% solids)</td><td></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Auxiliary fuel information</td></tr>
<tr><td>Type of Fuel
(e.g. oil, natural gas)</td><td colspan="2">Consumption (please provide units)
Please indicate type of oil you are burning (and heating value if known)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><th colspan="3">Furnace #3</th></tr>
<tr><td colspan="3">Black Liquor Information</td></tr>
<tr><td colspan="2">Average black liquor flow rate (lbs/hour)</td><td></td></tr>
<tr><td colspan="2">Black liquor (% solids)</td><td></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Auxiliary fuel information</td></tr>
<tr><td>Type of Fuel
(e.g. oil, natural gas)</td><td colspan="2">Consumption (please provide units)
Please indicate type of oil you are burning (and heating value if known)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="3"></td></tr>
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SURVEY OF BOILERS AND POWER GENERATION
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LIME KILN INFORMATION

If you have one or more lime kilns please complete the following; otherwise please go to page 12

1) How many lime kilns do you have at your mill?

2) Please provide the following general information for each of the kilns in your mill.

	Kiln #1	Kiln #2	Kiln #3	Kiln #4
Kiln manufacturer				
Start-up date				
Mill unit number				
Lime Production (tons/day)				

3) Please provide the following operating data for each of your kilns

Lime Kiln #1	
Kiln Operation (wks/yr):	
Lime mud moisture (%):	
Hot end temperature (^{o}F):	
Cold end temperature (^{o}F):	
Kiln fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)
Lime Kiln #2	
Kiln Operation (wks/yr):	
Lime mud moisture (%):	
Hot end temperature (^{o}F):	
Cold end temperature (^{o}F):	
Kiln fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)

LIME KILN INFORMATION (continued)

Lime Kiln #3	
Kiln Operation (wks/yr):	
Lime mud moisture (%):	
Hot end temperature (^oF):	
Cold end temperature (^oF):	
Kiln fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)
Lime Kiln #4	
Kiln Operation (wks/yr):	
Lime mud moisture (%):	
Hot end temperature (^oF):	
Cold end temperature (^oF):	
Kiln fuel information	
Type of Fuel (e.g. oil, natural gas)	Consumption (please provide units) Please indicate type of oil you are burning (and heating value if known)

SURVEY OF BOILERS AND POWER GENERATION
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STEAM TURBINE INFORMATION

If you have one or more steam turbines please complete the following.

1) How many steam turbines do you have at your mill?

2) Please provide the following general information for each steam turbine in your mill.

	Turbine #1	Turbine #2	Turbine #3
Turbine manufacturer			
Start-up date			
Mill unit number			
Ave. power generated (MW)			
Max. power generated (MW)			
Type of turbine[3]			
Turbine inlet steam pressure (psi)			
Turbine outlet steam pressure (psi)			
Boilers that supply steam to this turbine (please refer to the boiler identification used earlier in the survey)			

3. Backpressure (non-condensing), condensing, reheat turbine, extracting type turbine.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY. If you would like a copy of the summary results, please include your name and email address and we will send you the summary report.

Name:

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Address:

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