Woody Biomass Factsheet – WB3

Electricity from Woody Biomass

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Woody biomass and other biomass resources are unique in being one of the few renewable energy sources that can provide 24/7 baseload power, which means that electricity is made even when the sun does not shine and the wind does not blow[1]. Electricity from biomass also creates jobs, displaces electricity generated from fossil fuels, and provides a market for unwanted (residue and waste) material and in the case of woody biomass the material from wildfire vegetation management projects (fuels reduction). One of the disadvantages is that, unlike water power, solar and wind renewable electricity, biomass technology requires the purchase of fuel (biomass) [2, 3].

Principles of Biomass to Electricity

Biomass to electricity systems consist of three main components:

1. Energy conversion system – convert biomass to heat, steam, or combustible gases.
2. A prime mover (e.g., a turbine or engine) that uses the steam, heat, or combustible gas to produce electricity.
3. Air Emissions cleanup system to lower emissions to air quality standards

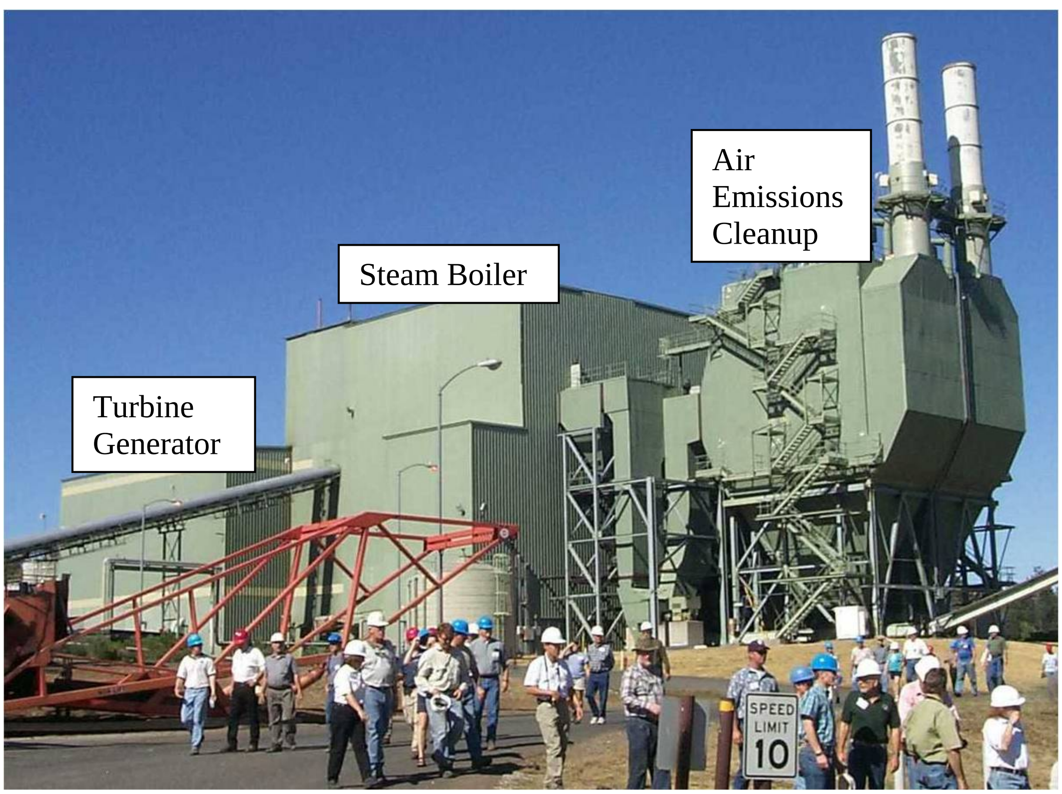

Figure 1. A typical 20 MW capacity biomass powerplant in California.

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Most biomass to electricity facilities use a biomass direct-fired combustion system to convert the biomass to useful energy. Biomass is combusted in a boiler to produce steam which is then passed through a turbine generator to produce electricity (Figure 1). Boiler steam output in pounds of steam per hour is a common way of measuring boiler size. A typical biomass boiler for a 20 MW capacity power plant is rated at about 200 thousand lbs/hr steam output. Once the steam has passed through the generator its temperature must be lowered to reintroduce it to the boiler. This heat loss reduces the overall efficiency of the energy conversion to about 17 to 25%. If the waste heat from the process is used productively, for example to dry lumber, then energy conversion efficiencies of almost 85% are possible [4]. A system that reuses the waste heat is described as combined heat and power (CHP) or cogeneration ('cogen') system [5].

Biomass can also be used in co-firing and gasification energy conversion systems. Mixing biomass with coal to co-fire a combustion system is becoming a common method to generate electricity in Europe. Gasification, a mature technology for producing a gaseous fuel from coal, also works with biomass and the future may see biomass gasification playing an important role in the electricity industry.

Table 1 shows the two major direct-fired boiler types used to combust biomass and produce steam for electrical generation (fixed bed and fluidized). In both systems the hot combustion gases pass through a heat exchanger made up of water-filled boiler tubes. The water in the tubes is converted into high pressure steam that then passes to the generator. There are distinct advantages and disadvantages between the two boiler types. Of the two, the fixed bed is generally less expensive but the fluidized bed is more efficient.

Table 1. Comparison of direct fired boiler types

Boiler type	Description
Fixed bed	Referred to as stoker boilers. May be fixed or traveling grate. Fuel is fed in and burns on the grate with air passing up through it. Additional ('overfire') air is added higher up in the boiler to complete combustion. Fuel may be introduced from underneath ('underfeed') or above ('overfeed').
Fluidized bed	Includes bubbling (BFB) and circulating fluidized bed (CFB) boilers. Fuel is burnt in a self-mixing suspension of gas and inert bed material (eg sand). Air is injected at the base of the boiler to keep the bed in a fluid state. The abrasive action of the inert particles assists with the combustion process (strips CO2 and char from biomass particles allowing easy access for oxygen to continue the burning). CFB boilers have a faster air velocity than BFB boilers. Fluidized bed boilers allow the combustion of feedstocks with variable properties (eg moisture content, particle size).

Steam is converted into electricity by passing through a turbine connected to a generator. This thermodynamic process is known as the Rankine cycle. There are three main types of turbine; condensing, extraction and back pressure. Condensing turbines are primarily used when the facility produces electricity only. The steam is condensed and cooled for reuse in the system. Extraction and back pressure turbines are typically used in CHP situations. In an extraction turbine steam is removed at a certain pressure, for use in another process, from an appropriate place on the turbine housing. Back pressure turbines exhaust the steam at a set pressure for use in another process.

An emerging turbine technology is integrated gasification combined cycle (IGCC). This allows increased electricity production. The biomass fuel is converted to a gas, which is combusted in a gas turbine, the hot exhaust gases are then used to heat water to raise steam which is then used to operate another turbine. This technology has been proven in natural gas power plants but challenges remain for its use in biomass power plants as a very clean gas is required in order to avoid damaging the fragile turbine blades.

Power Plant Scale

Biomass power plants in the USA range from around 5 MW to 110 MW with the average being around 20 MW. The largest facility in the world, located in Finland, is over 250 MW. There are currently many proposals in Europe for 300 MW and above biomass power plants. Economies of scale are gained as the size of the facility increases. A 5 MW facility might cost $3.5 million per MW of installed capacity (i.e. $17.5m total cost) whereas a 40 MW facility might be in the region of $2 million per MW (i.e. $80 million total cost).

Smaller scale power plants (from 15KW to 1 MW capacity) are certainly technologically feasible and many are found in areas of the world that are not connected to an electrical grid. These are often designed and used as CHP units and are a good solution to servicing a strong niche market. If excess electricity is produced it can often be sold to a utility but connecting to electrical grids (grid interconnect) is subject to many rules, regulations, and fees that may become prohibitively expensive. The grid interconnect potential must be carefully analyzed for each specific location.

Co-firing

Coal to electricity plants that co-fire their boilers with a proportion of biomass (1-20% substitution based on energy content of fuel) do it primarily to reduce their carbon dioxide from fossil fuel and sulfur dioxide emissions. Co-firing is a growing trend, particularly in Europe over the past 10 years, and it is likely to grow in the USA in the future. Climate change concerns and air emission regulations that mandate co-firing would likely lead to a future where most electricity from biomass will come from co-firing with coal.

Gasification

It is possible to produce electricity on a smaller scale (15 kW and above) using gasification. Gasification is the high temperature conversion of carbonaceous feedstocks into a gaseous fuel.

It is an endothermic reaction requiring energy either from part of the fuel or from an external source. Gasification first developed as a way to convert coal into a fuel gas in the 1700s. Gasification of biomass was developed in the early twentieth century and has been in a state of development since. The gas produced consists of carbon monoxide, carbon dioxide, hydrogen, methane, nitrogen, water, and contaminants including tar and particulate matter. Char is a byproduct of the process. The gas can be burnt in a boiler or a propane burner as it is produced. In order to make electricity the gas is typically combusted in either an internal combustion engine or a turbine- generator. However, the gas requires cleaning to remove the particulates, tar and water which are damaging to engines and turbines. Despite many years of research and development there are few commercially proven gasifiers available and these are generally very expensive ($5 million to $10 million per MW installed cost). In 2011 there were four biomass gasification demonstration projects in California (see Table 2). In the future this technology may make smaller scale biomass to electricity feasible. It would also allow the use of IGCC turbines (see above) in biomass to electricity.

Table 2. Biomass gasification projects in California

Location	Vendor	Type of Gasifier	Size
Merced	Phoenix Energy	Downdraft	500 kW
Etna	Fluidyne	Downdraft	41 kW
Woodland	West Biofuels	Dual fluidized bed	200 kW
Winters	Community Power Corp.	Downdraft	50 kW

Biomass as a Feedstock

The technology to produce electricity from biomass is proven, biomass can provide baseload power, there are ample biomass resources, and biomass is not a fossil fuel. For all these reasons biomass should be a preferred feedstock – why isn't it? The following three topics are considered barriers to increased use of biomass to produce electricity.

- Availability and cost of the biomass
- Combustion emissions (gaseous and ash) as compared to other fuels and renewable resources
- Equipment and maintenance costs associated with the complex and variable characteristics of biomass feedstocks

These concerns can be adequately addressed resulted in biomass feedstock being a reasonable renewable energy resource choice. The availability of biomass resources was discussed in Woody Biomass Factsheet- WB1 [6]. Emissions and costs are discussed below.

Feedstock Requirements

The typical fuel specification for biomass power plants requires a particle size no bigger than 3 inches in the largest dimension. Bark and foliage are acceptable meaning that chipped biomass from the forest is a suitable fuel. Power plants in California also source fuel from sawmills (wood chips, bark, sawdust, shavings), agricultural operations (orchard trimmings, nut shells, olive pits etc) and urban waste streams (wood and green waste). Power plants with stoker boilers mix fuel from different sources to achieve a moisture content of approximately 30%. Biomass fuel value in California typically ranges from $15 to $60 per bone dry ton (BDT) delivered to the plant. The estimated costs of producing the biomass fuel ranges from near zero to more than $70/BDT as summarized in Table 3 [7].

Table 3. Relative costs of biomass feedstocks in California

Feedstock	Estimated Cost to Produce ($/BDT)
Mill residues	0 - 10
Agricultural residues	5 - 30
Municipal solid waste	32 -40
Forest residues	35 - 45
Chaparral	40 - 50
Dedicated crops (including trees)	40 - 70

Power plant developers generally look for a fuel coverage ratio of 2.5-3:1 (meaning that there is 2.5 to 3 times the amount of fuel available that is needed for the project). A typical biomass power plant requires 8,000-10,000 BDT per year of fuel for each 1 MW of installed capacity (e.g. a 20 MW plant would need 160,000-200,000 BDT per year). Biomass fuel for power plants less than 50 MW capacity is typically sourced from within a 50 miles radius of the facility. Larger power plants will require much larger areas to source the fuel. A 200 MW plant would need at least 1.5 million BDT of biomass per year – a major challenge to source.

Emissions

The products of combustion are heat, gaseous products, and ash. The type and amount of products emitted are dependent on the fuel characteristics. A summary of emissions from various fuel types is shown in Table 4 [8]. Of greatest concern to the environment and climate change issues are the gaseous air emissions.

Table 4. Emissions from steam boilers fired by various fuels

Air Emissions	Type of Combustion for Steam Boiler		
	Biomass-Fired (lb/million Btu)	Coal-Fired (lb/million Btu)	Natural Gas (lb/million Btu)
CO	0.60	0.02 – 0.7	0.06
CO_2 (fossil origin)	0	178 - 231	117.6
CO_2 (non fossil)	195	0	0
NOx	0.2 – 0.5	0.3 – 1.1	0.03 – 0.3
SOx	0.02	1.3	0.0005
VOC	0.02	0.002 – 0.048	0.005
Methane	0.02	0.002	0.002
Particulates	0.05 – 0.56	0.4 – 2.4	0.007

Air – Air emissions from biomass power plants include the gaseous products of sulfur dioxide (SO2), nitrogen oxide (NOX), carbon dioxide (CO_2), and water vapor. These are similar to other solid fuels except that biomass produces much lower levels of sulfur dioxide emissions than the combustion of coal and the CO_2 emissions are not from fossil fuel sources. Emissions are reduced through managing the combustion process and through costly treatment of the flue gas. Nitrogen oxide is typically controlled using selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR). SCR involves the use of a catalyst and ammonia or urea while SCNR involves the injection of specific nitrogenous reagents to drive a reaction that will reduce the amount of nitrogen oxide in the emissions. Particulate matter is controlled using fabric filters (bag houses) or electrostatic precipitators (ESP) that impart a negative electric charge onto the particles which then moved to electrically grounded plates for collection. The plume that is often seen above power plants is actually water vapor from the steam turbine system. Visible emissions from the smokestack are a very uncommon occurrence and only happen when the combustion process is out of control or the emissions treatment process has failed.

Ash – Ash is the residual material left over after combustion. It generally consists of non-combustible minerals in the fuel in oxidized or salt form and may contain some partially combusted organic matter. In biomass power plants ash may be collected in two places. Fly ash (small particles) will be carried into the flue system and are removed by the emissions control equipment (eg, bag house or electrostatic precipitator). Bottom ash (larger particles) will accrue at the bottom of the boiler. Bottom ash is sometimes disposed of in landfills but it may often be used as a soil amendment or fertilizer in agriculture or as fill for road construction [9].

Heavy metals may be found in the fly ash which means that it requires careful disposal and is not suitable for use as a fertilizer. It may be possible to use biomass fly ash as filler for cement which is the primary use for fly ash from coal combustion plants. There is currently no standard for use of biomass ash as a cement additive and the presence of alkalis and chlorides in the ash are likely to adversely impact cement properties [10].

Woody vs. Other Biomass Resources

By definition, all forms of biomass are low value, low quality residues or waste materials that can be a feedstock for combustion or gasification pathways to produce electricity. Woody compares favorably in these ways:

- Woody biomass from forests can have positive environmental benefits by providing markets for the residues of forest management practices and by reducing the risk of forest wildfires.
- Woody biomass, as manufacturing residues and consumer waste, is available year round and its availability is not tied to crop cycles and growing seasons as are agricultural residue.
- Woody biomass has a more favorable moisture content compared to dry agricultural residues that need to have moisture added for optimal combustion.
- Woody biomass can be diverted from landfills and put to a beneficial use.

Markets and Customers for Woody Biomass Electricity

Electricity markets are either serviced by private or public utility providers or self provided by industry and agriculture facilities. Technically, customers for biomass produced electricity can be anywhere as it is possible to 'wheel' electricity over the grid to any customer subject to costs and regulations. Biomass fueled power plants need to be near the biomass fuel but the customer can be anywhere. Powerplants are either stand alone or CHP. As discussed earlier utilization of the heat from the process will dramatically improve overall energy conversion efficiency and therefore project economics. Customers for heat, however, need to be as close to the heat source as possible as there are physical limits as to how far hot water or steam can be piped. Specially designed CHP systems can deliver heat to communities through district heating arrangements. This type of system is very popular in much of northern Europe.

Potential customers in California for heat and/or electricity produced from biomass are numerous and can be found on or off the electrical grid as shown in Table 3 [11].

Table 3: Potential customers for heat and/or electricity in California

Customer Category	Examples	Heat or Electricity?
Regulated utility – Investor owned (IOU)	Pacific Gas & Electric, San Diego Gas & Electric, Southern California Edison	Electricity
Unregulated utility	Municipal Utility Districts (e.g. Sacramento Municiple Utility District), Public Utility Districts (e.g. Trinity County PUD), Community Choice Aggregators (e.g. Marin County)	Electricity
Industry and agriculture	Forest products manufacturing facilities (sawmill, veneer mill, pellet mill), dairies, oilfields (for enhanced oil recovery)	Electricity and/or heat

Biomass to Electricity in California

Electricity from biomass supplies around 2% of California's electricity. At the time of writing (September 2011) there are approximately 30 operational plants in California with over 600 MW of capacity, where one MW of electricity is enough power for approximately 800-1000 homes. Size ranges from a capacity of 4 to 50 MW with the average size being 20 MW. About one third of the biomass power plants are CHP, mostly associated with sawmills. A dynamic map showing the location and details for the biomass power plants in California is at http://ucanr.org/BiomassPower.

California's Renewable Portfolio Standard (RPS) has a target of 33% of electricity coming from renewable sources (including small scale hydro, solar, wind, and biomass) for the three large investor owned utilities (IOUs) by 2020 [12]. Currently the IOUs source 17% of their electricity from renewables. The RPS requirements mean that biomass to electricity projects in the state remain attractive to investors. Current trends, driven by the RPS, include sales of existing facilities, the restart of older plants, new build projects, co-firing with biomass and conversion of coal or other petroleum burning plants to biomass fuel. The existing facilities and new ones will continue to provide a market for chipped woody biomass.

The price of electricity (and a market for heat if CHP), the availability of an adequate fuel supply, financing, and potential benefits to the environment and community are the most important factors in deciding if a potential biomass to electricity project is viable. In addition, electricity sales prices and the availability of an interconnection to the electricity grid are important factors to consider in any project. A thorough analysis of all these factors will determine when and where the next generation of biomass to electricity projects are developed.

List of References

1. Zerbe, J.I. 2006. *Thermal energy, electricity, and transportation fuels from wood.* Forest Products Journal. 56(1):6 - 14.
2. Grammelis, P. 2011. *Solid Biofuels for Energy: A Lower Greenhouse Gas Alternative*. Green Energy and Technology: Springer. p.
3. Anon. 2006. *The Landolt-Börnstein Database - Renewable Energy*. Numerical Data and Functional Relationships in Science and Technology (New Series), Subvolume 3C. Subseries: Advanced Materials and Technologies: Springer. p.
4. Walker, J.C.F. 2006. *Primary wood processing : principles and practice*. Dordrecht, the Netherlands: Springer. 595 p.
5. Anon. 2007. *Biomass Combined Heat and Power Catalog of Technologies*. US Environmental Protection Agency. Combined Heat and Power Partnership Accessed. http://www.epa.gov
6. Shelly, J.R. 2011. *Woody Biomass: What is it -- What do we do with it?* University of California. Woody Biomass Factsheet. unpublished. Berkeley, CA. 8 p. Accessed.
7. Williams, R.B. 2008. *An Assessment of Biomass Resources in California, 2007*. Draft Report. California Biomass Collaborative. California Energy Commission. PIER Collaborative Report. March. California Energy Commission. Sacramento, CA. 130 p. Accessed. http://biomass.ucdavis.edu/files/reports/2008-cbc-resource-assessment.pdf.
8. Anon. 2003. *Clearinghouse for inventories and emission factors*. AP42, Fifth Edition. U. EPA US Environmental Protection Agency. Accessed May 2009. http://www.epa.gov/ttnchie1/ap42/ch01/.
9. Insam, H. and B.A. Knapp, eds. *Recycling of biomass ashes*. 2011, Springer.
10. Anon. 2008. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. ASTM International. Accessed. http://www.astm.org.
11. Anon. 2007. *Integrated Energy Policy Report 2007 Summary*. California Energy Commission. Accessed. http://energy.ca.gov
12. Anon. 2011. *California Renewables Portfolio Standard (RPS)*. California Public Utilities Commission Accessed. http://www.cpuc.ca.gov/PUC/energy/Renewables/index