Pre-feasibility Study
Biomass Power Plant
Fort Bragg, Mendocino County, California

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I. Executive Summary

Forest biomass represents a huge potential resource for energy production. Significant amounts of currently un-merchantable biomass are available from forest resource management and wood products manufacturing in the region. Biomass energy producing facilities could provide a potential economic use for this material at a time when need exists for economic stimulus in rural communities and for reduced fuels loading in the forest. Information about the amount of biomass feedstock available and the cost of feedstock delivered to the plant site is needed to encourage public understanding of the opportunity and private sector investment in biomass energy. This review surveys and compiles current studies regarding biomass-based electric production and specifically applies existing knowledge to a potential facility in Fort Bragg, California, where the City Council has expressed interest in the economic development potential of a possible biomass power installation.

This review will present information on biomass fuel characteristics, fuel costs, energy value, potential impacts, and possible incentives. Potential biomass fuels in the area vary in quality, particular moisture content which affects the energy produced per ton of dry weight. The available amounts of biomass are estimated to be able to fuel a 4.5 MW to 9.5 MW facility, with possibilities for an even higher production facility if fuel supply is larger.

Increasing the extraction of fuels to reduce fire fuel loading, enhance growth of commercial wood products through enhanced thinning, and similar activities are some methods for increasing the availability of biomass for fuel.

Costs of electricity generated from biomass are discussed, as well as issues that affect the value of biomass power. This paper touches on emerging biomass technologies. Finally, this report recommends:

- Developing additional clarity on the volume and delivery cost of available biomass near Fort Bragg.

- Conducting community education on the nature and role of biomass facilities.

- Encouraging subsidies to support biomass generation in rural lands.

II. Introduction

Biomass power generation is a proven, mature technology and is the single largest source of non-hydro renewable electricity.[1] About 9,733 megawatts (MW) capacity was installed in the United States in 2002. Biomass installations range from very small units of 5-10 kW capacity to large facilities 50 MW and larger in size. Commercial scale power is considered 10MW and larger.

The larger the plant, the greater the supply needed for available biomass. A typical 15 MW power plant would consume 8,000 bone dry tons (BDT) per year per MW, or 120,000 BDT total. It should be noted that by power plant standards a 15 MW facility is at the smallest possible end of the commercial spectrum. Existing studies conservatively estimate that from a low of 36,600 BDT to a high of 76,720 BDT biomass fuel annually, is readily available in the immediate Fort Bragg region. This is enough fuel for a facility of from 4.5 MW to 9.5 MW respectively. The State of California Energy Commission estimates indicate around 286,912 BDT, or enough to fuel a 35 MW power plant, are potentially available in the Fort Bragg area. A dependable and readily available fuel supply of at least 120,000 BDT annually will be needed to attract capital investment in a commercial scale facility.

Biomass fuel from our forested areas comes from residues of non-commercial wood. Residues can be gathered during milling, logging, thinning, and other forest management activities. With a biomass plant, efficient generation of forest residues is helpful for providing sustainable fuel supplies. For example, forest thinning in some countries, notably Finland, is more intense than thinning practices in the United States. In Finland, the trees are widely-spaced, yet the forests carry more usable wood per acre than here. The usable wood is concentrated in larger, higher quality trees since the Finnish countryside is regularly thinned--removing brush and weeds, culling weak trees, and making room for others to grow. If forest thinnings and residues were dedicated to power production, perhaps along the lines of Finnish experience, it is reasonable to conclude that a biomass facility of 10 MW to 15 MW could be sustained under favorable economic and social conditions.

Biomass electric production is an established technology with capital costs and production costs well understood. The levelized cost of electricity (COE) from a new biomass power plant generating only electricity for sale lies in the range of $0.06 to 0.08/kWh. Installed capital costs range from $1500 to $3000/kWe. This estimate excludes return on equity (profit), and assumes a relatively optimistic base fuel cost of $20/dry ton.

At the 15 MW scale, Steam Turbine Generation and Gasifier with Internal Combustion Engine Generation both require biomass cost to drop to zero in order to get near the 6 cents/kWh range. By contrast, California average wholesale price in 2006 was $47.55 per megawatt-hour, or 4.7 cents/kWh.[2] (LA Times, 2007). Most biomass power generators in California are now operating under fixed price contracts for $0.0537/kWh.[3]

In a 1999 study (Morris, 1999), a conservative analysis found the value of the environmental services associated with biomass energy production in the United States to be 11.4 cents/kWh. This value does not include the desirable benefits of rural employment, rural economic development, and energy diversity and security provided by biomass energy production. One could expect 5 to 6 direct jobs created per 1MW. Hence a 15 MW facility would create from 75 to 90 jobs. The combined economic and environmental benefits to a rural community certainly appear substantial.

Ownership and public subsidies matter. Public ownership of a utility reduces the need for profit greater than breakeven costs. It is interesting to note that production costs, without profit, are quite near power sales prices. Subsidies either to reduce capital cost, reduce biomass fuel cost or a "green power" surcharge will substantially tip the scales in favor of sustainable biomass generation facility located in Fort Bragg.

Figure 1 - California Average Electric Rates

Electrical Rates Before and After Restructuring

System Average Rates*	1994 cents/kWh (prior to restructuring)	2003 cents/kWh (after restructuring)
United States	6.91	7.3
CA Investor Owned Utilities	10.38	13.4 *(84% higher than US average)*
CA Publicly Owned Utilities	8.56	9.5 *(41% lower than IOU average)* *(30% higher than US average)*

**Source: Energy Information Agency Ratios EIA-861 for 2003 (latest information available)*

Courtesy Northern California Power Agency (NCPA)

III. Background

Biomass power generation experienced dramatic growth in the U.S. after the Public Utilities Regulatory Policy Act (PURPA) of 1978. PURPA guaranteed small electricity producers, of less than 80 MW, that utilities would purchase their surplus electricity at prices equal to the utilities' avoided-cost of producing electricity. Prior to PURPA, electric generating plants could only be owned and operated by utilities.

Regulatory changes, low utility buyback rates, and industry restructuring coupled with business uncertainties, have reversed the early industry growth and a number of biomass power facilities have been closed in recent years. Under current low avoided-costs, few renewable energy sources are able to compete with new natural gas turbines. The nearly two decade period from 1980 to 1999 saw the number of operating biomass facilities in California decline by 28 plants. Fourteen plants were idled while another fourteen were dismantled. More recently, three additional plants were closed: two for financial reasons and one because of fuel supply problems.[4] From a high of 62 plants, only 26 plants currently operate in California.

IV. Location

Immediately to the east of Fort Bragg lies a parcel owned by Georgia-Pacific Corporation now used as a storage area for waste bark. This approximately 200 acre parcel has a gently rolling topography, and has been previously disturbed by excavation and burial of waste bark. The property lies within a few thousand feet of major electric transmission lines and has private road access. Second growth forest shields the site from noise transmission and direct view from major roads. More direct road access from the site to State Highway 20 might be created from Summers Road located to the South and West of the parcel. Initial estimates suggest construction costs for such a road extension would be in the neighborhood of $2,000,000.

The parcel's seclusion, existing private roads, ready access to electric transmission lines and history of industrial disturbance, all weigh positively in favor of the site's potential development as a biomass power facility and/or associated industrial area. Co-location of additional industrial ventures that would generate either fuel supply or use excess heat would also add to the synergy of the location. For example, a mill or a waste transfer station could generate additional fuels. A lumber kiln or waste digester could utilize excess heat generated by biomass power generation.

V. Biomass Fuel Characteristics

A variety of conversion processes are used to convert biomass to either thermal energy, liquid, solid or gaseous fuels. These processes include thermal conversion via combustion or pyrolysis, chemical conversion, microbial conversion or fermentation, and physical conversion to pellets or cubes, i.e. densified fuels.

Electrical energy and heat generation is most commonly accomplished through direct combustion of biomass in a boiler. In the combustion process, energy content, moisture content and chemical composition are the most important biomass characteristics affecting combustion processes.

The biomass gasification process releases a gas that may be further combusted to generate electricity. In this process, biomass particle size, energy content, moisture content and volatiles are the predominate characteristics affecting the gasification process.

Biomass fuel physical characteristics--such as particle size, density and moisture content--add important considerations for transportation and material handling. Nearly all biomass energy conversion processes will require some form of physical manipulation of the fuel. Commonly this includes sorting, storing, sizing, screening and moving the material from one location to another. Low bulk density materials occupy more space, hence costing more to deliver per unit of weight and increase feedstock costs.

Moisture content radically affects the quality of biomass fuel for combustion and gasification processes. Materials with lower moisture content cost less to transport and can reduce the size of handling, processing and energy conversion equipment needed for biomass power because a smaller overall volume of feedstock is required.

In the following illustration we use the wet basis method to determine moisture content. By way of example, a two-pound piece of wood contains of one pound of wood biomass and one pound of water. Using the wet basis method, the moisture content would be expressed as 50% that is, water is 50% of the total weight. The moisture content of freshly harvested forest and crop residue typically varies from 40% to 60% by weight, and can be higher if exposed to precipitation.

The higher heating value (HHV) is the amount of usable thermal energy that can be obtained from given volume of fuel while the lower heating value (LHV), by contrast, is equivalent to the HHV of the fuel minus the heat required to vaporize the liquid water of the fuel. When considered on a bone dry basis, "most biomass has about the same energy content (HHV) of 8,000 to 8,500 British thermal units per pound (Btu/lb).[5]

VI. Fuel availability

In 2006 TSS Consultants identified between 91,500 and 191,800 bone dry tons of woody biomass potentially available in Mendocino County. This volume is enough biomass fuel to generate 10 MW to 24 MW electric power. Timber harvest and forest product residuals represented roughly 87 percent of the total fuel available. [6] The TSS figures for timber harvest are based on historic timber harvest figures from 2001 to 2005 with estimates of residual yields of 0.9 BDT/MBF on 50% of land harvested. Estimates of fuels treatment were based on 800 acres of public and 260 acres of private lands yielding 13 BDT/acre and 10 BDT/acre respectively. The TSS estimates reflect biomass that is likely available under existing economic and social conditions. Table 1 shows a breakdown of fuel sources.

Table 1
Annual Woody Biomass Fuel Potentially Available Within Mendocino County (Expressed as BDT)

FUEL TYPE	LOW ESTIMATE	HIGH ESTIMATE
Timber Harvest Residuals	26,000	51,000
Fuels Treatment -Public	0	10,400
Fuels Treatment -Private	500	2,600
Urban Wood	8,000	9,000
Forest Products Residuals	55,000	115,000
Agricultural Byproducts	2,000	3,800
TOTALS	91,500	191,800

(TSS Consultants, 2006)

The total land area of Mendocino County is 3,509 square miles of which approximately 1,413 square miles lies within a 30-mile, straight line radius of Fort Bragg. This is roughly 40% of the total county area. Applying this crude multiple to TSS estimates of volume available, results in usable estimates from a low of 36,600 BDT (40% of 91,500), to a high of 76,720 BDT (40% of 191,800) could be available for use in a Fort Bragg biomass to power facility. These amounts of biomass would fuel a 4.5 MW to 9.5 MW facility respectively.

By contrast, the California Energy Commission estimates the potential Mendocino County biomass resources to be substantially higher and reflect biomass that could be utilized for power production or conversion if economic and social circumstances supported its harvest. (Table 2) Utilization of 50% (717,282 BDT) of the technical resource would theoretically support power production of about 90 MW for Mendocino County. Applying the crude discount of 40% of total volume for a 30 mile hauling radius, suggests that up to 286,912 BDT or fuel for 35 MW power production might be potentially available for the Fort Bragg area.

Table 2
Potential Mendocino County forest derived biomass
(Bone dry tons/year)[7]

Fuel Type	Gross Resource	Technical Resource
Logging slash	797,246	422,540
Forest thinnings	1,393,737	738,680
Sawmill residues	515,743	273,343
Total	2,706,726	1,434,564

Gross resource refers = total estimated annual biomass produced.
Technical resource = amount that can potentially be supplied – about 53% of gross.
Adapted from California Energy Commission, 2006.

By way of historical comparison, Georgia-Pacific ran a 15 MW wood-fired boiler until 2002, demonstrating the ability of the immediate region to fuel a plant of this scale in the recent past. It is likely reasonable to conclude that a biomass facility of some 10 MW to 15 MW could be sustained under favorable economic and social conditions.

VII . Potential additional fuels

The old Georgia-Pacific bark dump holds approximately 600,000 cubic yards bark of various grades and condition. Lab testing of three random samples indicates the bark has a potential fuel value of 5,755 Btu/lb with average moisture content about 68%. Given that most biomass boasts an energy content from 8,000 to 8,500 Btu/lb. the reclaimed bark can be considered a low grade fuel with an energy content of about 72% good clean biomass.

The buried bark requires excavation, washing to remove dirt and rock, and drying in preparation to be used as fuel. Using a generic bulk density of 205kg/m3 for softwood bark (FAO, 2004)[8], a cubic yard of dry bark weighs about 345 lbs, hence nearly 6 cubic yards are required to make a ton. The 600,000 cubic yards of bark comprises about 100,000 BDT of fuel after excavation, washing and drying and therefore a total fuel value of around 72,000 BDT comparable biomass or about 9MW for a single year.

If, hypothetically, a new mill in the range of 40 MMBF were to be commissioned in the area, it would result in around 18,000 BDT additional fuel, enough to fuel slightly over 2 MW per year. Mill residues repre-

“The supply of fuel has to be robust.”

Finland National Technology Agency, Helsinki 2004 sent the least cost fuels for power production and one of the best options for decreasing overall fuel costs for a power plant. Historically, mills and small scale heat and power generation were commonly bound together – timber milling creating cheap fuels while simultaneously requiring power and heat. The interrelationship today remains mutually supportive.

Additional fuels could also be had from more vigorous fuels reduction programs. TSS estimates a high of 13,000 BDT across Mendocino County – slightly more than 6% of the total high estimate of 191,800 BDT. This is based on 800 acres fuel reduction on public lands and 260 acres of private lands.

If subsidies for fuels reduction could be made available, then the total contribution could increase. For example, in a tripling of acres of fuel reduction to 2,400 acres public and 780 acres private lands, a high range of 39,000 BDT, equivalent to about 5MW, might be obtained. However, this contribution of fuels for total biomass power fuel would likely be dependent upon a continuing public subsidy.

VIII. Fuel Costs

The cost of fuel is one of the primary constraints facing biomass energy production. Each fuel type has an associated collection cost range. For any single facility fuel costs might range from zero to $60/BDT or even higher depending on the specific fuel resource. Higher fuel costs translate directly to more expensive electricity.

Fuel availability must also be ensured in all conditions regardless of season, weather, equipment failure, labor disputes or depression of forest products markets. In the case of forest fuels, providing a continual stream of fuel can be a difficult task, since the fuel is collected from a number of harvesting operations, fuel stores tend to be small, and working conditions are unfavorable during the wet seasons of the year.

Figure 2 shows the relationship of biomass fuel cost to the levelized cost of energy for three sizes of power plants. As the fuel costs decrease, the levelized costs of energy also decrease. Figure 2 also demonstrates economy of scale - that when fuel costs are equal across the various plant sizes, the cost of energy from the larger plants can be expected to be significantly lower than energy produced by smaller plants. It is clearly important to keep the cost of forest biomass down to establish a sustainable biomass power industry.[9] Concurrently, it is important to appreciate the range of value and benefits that biomass utilization presents to rural communities.

Based on the TSS estimates, as shown in Table 3, the average cost of timber harvest and forest products residuals delivered would be near $21BDT, with a maximum delivery radius of about 30 miles. The national average cost for delivered woody biomass fuels is $21/BDT.[1]

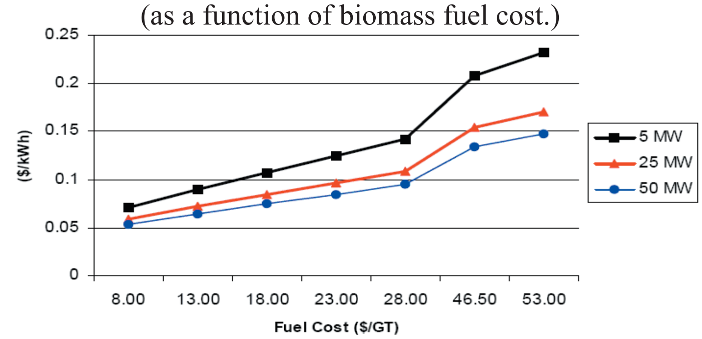
Table 3 - Collection/Processing/Transport Costs and Market Values for Woody Biomass Fuel
(Expressed as $/BDT) Sourced from Mendocino County

FUEL TYPE	LOW ESTIMATE	HIGH ESTIMATE
Timber Harvest Residuals	$42	$60
Fuels Treatment -Public	$50	$54
Fuels Treatment -Private	$28	$54
Urban Wood	$15	$24
Forest Products Residuals (market value)	$12	$30
Agricultural Byproducts	$24	$29

(TSS Consultants, 2006)[11]

The importance of using the least valued biomass for fuel is demonstrated in Figure 3. Not surprisingly it shows the cost of mill residues to be nearly zero and overall quantities also quite small. Historically mill residues were considered a byproduct of manufacture and therefore waste. Biomass in-forest residuals are substantially more expensive, yet respectable volumes are available for harvest and biomass power production. Developing harvest of forest thinnings for

Figure 2 - Cost of biomass electricity
(as a function of biomass fuel cost.)



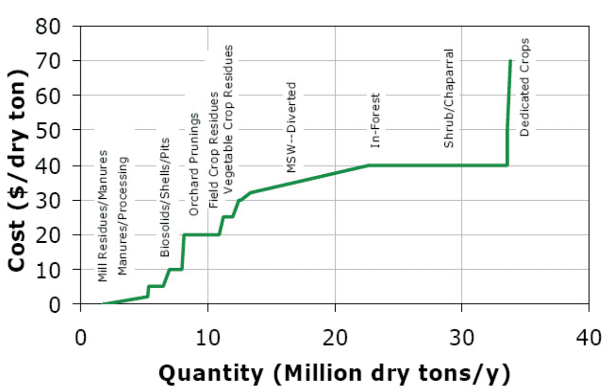
Adapted from McNeil Technologies, Inc., 2003 biomass is critical for the sustainability of a biomass power industry. Currently the U.S. lags in this arena while several European countries have invested heavily in developing new technologies for biomass fuel extraction. For example in Finland, the forest sector has worked diligently to "appreciate forest fuels as a natural and relevant product of sustainable forestry." Renewable energy has increasing status, and the production and use of forest chips are today acceptable and valued activities. Moreover one advantage of forest chips is the favorable input/output ratio of energy is 1/30[12]. Thus, the entire energy content of fuel, rather than a fraction thereof, can be used for replacing fossil fuels.

In 1999, the Finland National Technology Agency "Tekes" Wood Energy Program investigated the development of large-scale procurement systems for forest chips. New advanced technology was developed and transferred into the private sector. In addition to utilizing new transportation technique such as bundling, three new areas of forest fuel emerged resulting in substantial fuel quantity increases.

• Residue log technology – boasting flexible logistics, reliability and cleanliness, the residue log system was preferred by forest owners, contractors and supervisors. However, at the moment this technology is only feasible in large-scale operations. The capacity of the 24 balers operating in Finland in early 2004 is sufficient for processing a half of the logging residue recovery.

• Stationary crushers - made it possible to broaden the raw material base and receive solid biomass fuels

Figure 3 - Estimated overall statewide biomass resource cost curve (excludes storage and on-site processing and handling costs)



Adapted from California Energy Commission, 2005, Biomass Resources in California, pg 44

in almost any form, i.e. residue, logs, loose residues, un-delimbed tree-sections, stump and root wood, and recycled wood.

• Stump and root wood while not considered to be a realistic option for fuel production when first considered, stump and root wood rapidly became a preferred fuel at plants using a stationary crusher.[13]

In association with the Tekes program chip production technology and organizations developed rapidly. During the five-year period of the Tekes program, the use of forest chips quadrupled.

IX - Cost of Electricity from Biomass

The cost of generating electricity from biomass is well established by years of experience and numerous studies. Economies of scale strongly suggest that commercial power production starts at 10 MW. Labor costs differ only nominally between a 10 MW and 15 MW plant. If fuel supplies are available, a 15 MW plant or larger is preferred.

Motivated by the catastrophic forest fires during the summer of 2002 that hit the western United States as well as the increased frequency and severity of fires over the past decade, the United States Department of Agriculture (USDA), the United States Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL) commissioned the Antares Group, Inc., to perform an assessment of the use of forest thinnings to produce electric power. While there are many site-specific factors involved in developing a bio-power project, the 2003 study was intended to be the first part of a feasibility study for a biomass power facility. Technologies evaluated include solid and gaseous co-firing, combined heat and power, steam and gas turbine cycles, reciprocating engines, and feed water re-powering.

The two primary biomass energy conversion technologies are direct combustion and gasification. For a Fort Bragg based bio-power project, steam turbines and reciprocating engines are the most appropriate power generation technologies. Graphical relationships between capital costs, generation costs and biomass are reproduced in Figures 6 – 9.

Figure 4 - Biomass bundling

Bundling is a solution for boosting the large-scale use of forest biomass widely used in Finland. Courtesy Timberjack

The 2003 Antares study concluded:[14]

•Steam Turbine Distributed Generation appeared uneconomical for the plant sizes and systems analyzed; the smallest commercial plant currently in operation is 18.5 MW.

•The lowest cost of electricity (COE) generated by the 10 MW and 15 MW steam plants are 7.4 and 6.1 cents/kWh, respectively.

·•The 15 MW Internal Combustion Engine—100% syngas scenario with low capital and zero feedstock, achieved a positive net present value (NPV) of $13.7 million for electricity sales at 7.0 cents/kWh.

The Antares studies economic analysis demonstrates that bio-power has a difficult time competing on cost alone and like many other renewable energy sources, it would benefit from some external assistance, support or subsidy.

Figures 6 to 9 graphically demonstrate the relationships between capital cost, fuel cost and cost of electricity for the most appropriate technologies applicable for the lower end of commercial power production: steam turbine and biomass gasifier using internal combustion engines as the prime mover. These are useful for quickly evaluating alternative scenarios involving biomass cost and production scale.

The 2003 Antares analysis is supported by data from the 2006, California Energy Commissions, "Biomass Resources Assessment in California" which reports;

"The cost of generating electricity from biomass depends on capital, fuel, and non-fuel operating and maintenance expenses. Levelized cost of electricity (COE) from a new biomass power plant generating only electricity for sale lies in the range of $0.06 to 0.08/kWh for installed capital costs of $1500 to 3000/kWe . This estimate excludes return on equity (profit), and assumes a relatively optimistic base fuel cost of $20/dry ton. The estimate also assumes 20% net efficiency, 5% interest on debt, 85% capacity factor, no capacity payments, 20 year economic life, straight line depreciation and 2.1% annual escalation in operating and maintenance costs but no escalation in fuel cost. Addition of 15% return on equity at an equity ratio of 25% adds $0.015/kWh to the COE. The COE exclusive of fuel cost over the same capital cost range varies from about $0.040 to 0.055/kWh. Sensitivity of COE at this efficiency is approximately $0.001/kWh for each $1/BDT change in fuel cost. Average biomass fuel cost for the solid-fuel direct combustion sector has ranged between $22/BDT and $40/BDT since 1986, the latter sufficient to increase COE to $0.10/kWh."[19]

At the 15MW level, both the Steam Turbine Generation and Internal Combustion Engine Generation

Figure 5 – Commercial biomass power plant

Okeelanta biomass power plant near South Bay, Florida. Photo / Lonnie Ingram

Installed capital costs for commercial biomass installations range from 1.5 million to 3 million per megawatt.

Figure 6 - 10MW Steam Turbine Generation Costs vs. Biomass Cost[15]

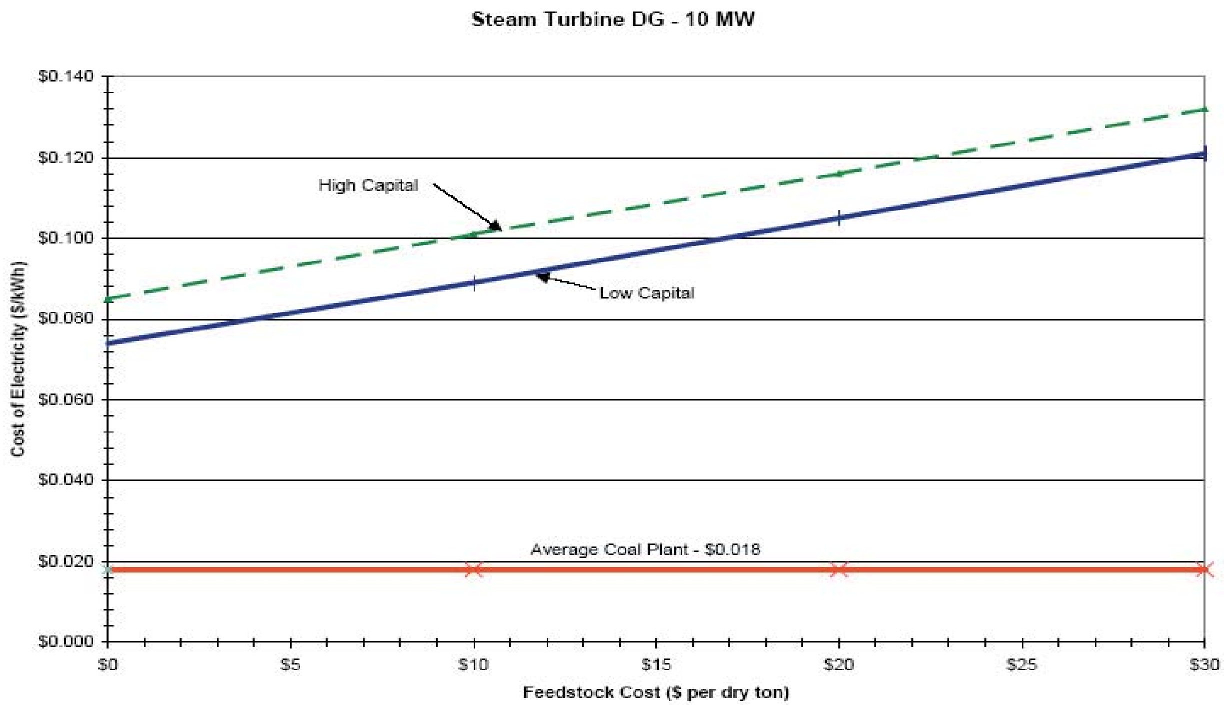


Figure 7 - 15MW Steam Turbine Generation Costs vs. Biomass Cost[16]

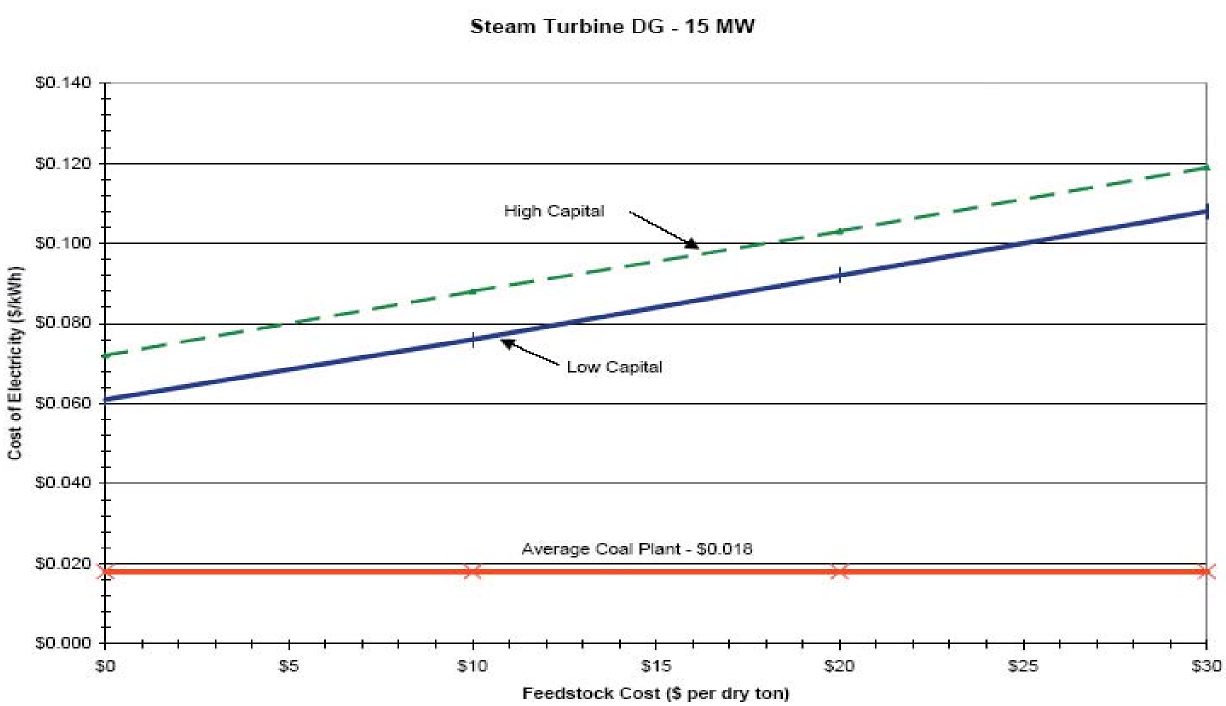


Figure 8 - 10MW Internal Combustion Engine Generation Costs vs. Biomass Cost[17]

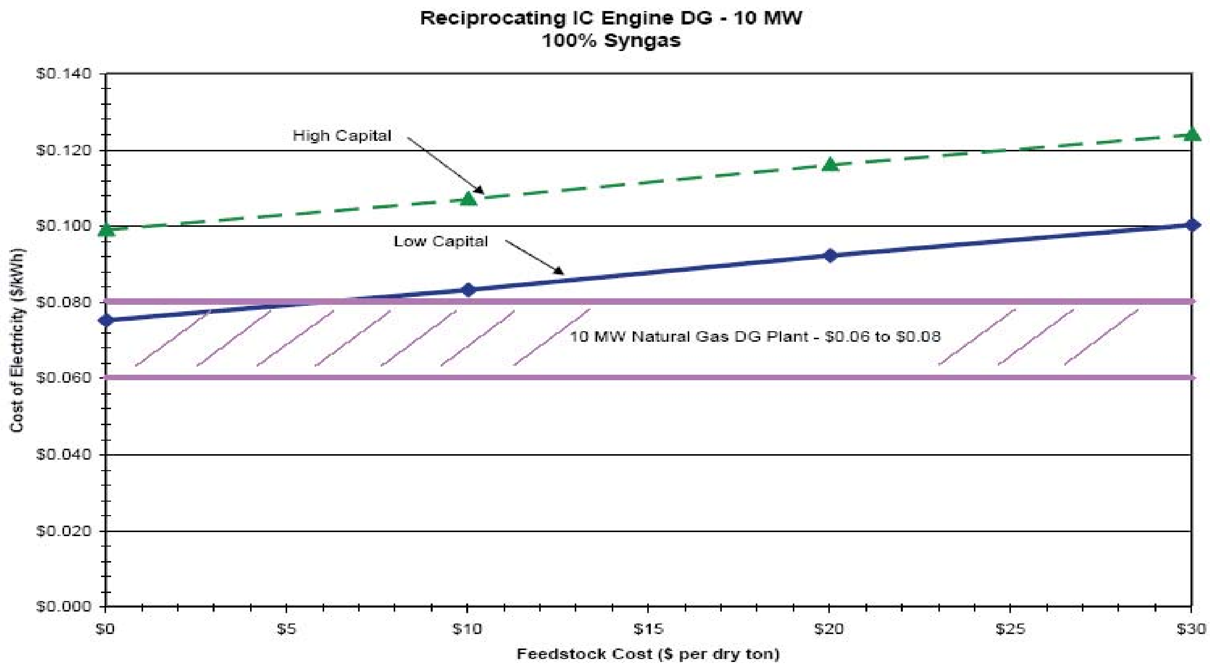
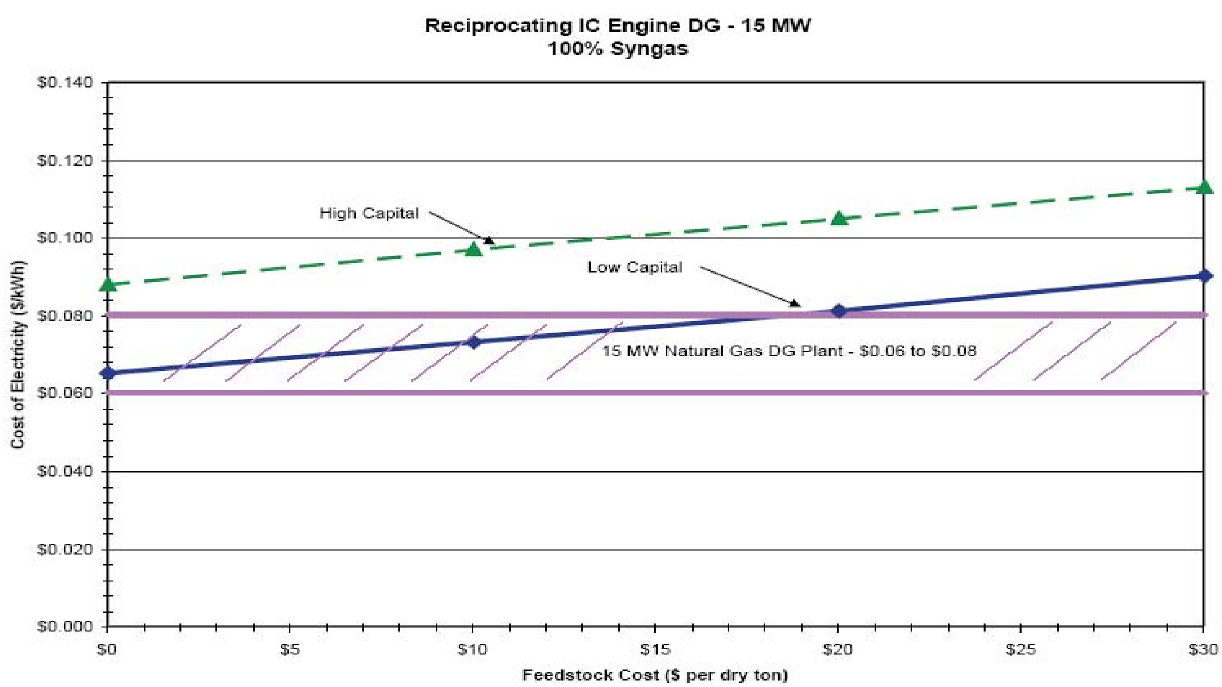


Figure 9 - 15MW Internal Combustion Engine Generation Costs vs. Biomass Cost[18]



"At the 15MW level, both the Steam Turbine Generation and Internal Combustion Engine Generation require biomass cost to drop to zero in order to get near the 6 cents/kWh range."

require biomass cost to drop to zero in order to get near the 6 cents/kWh range. In contrast, California average wholesale price in 2006 was $47.55 per megawatt-hour, or 4.7 cents/kWh[20] (LA Times, 2007). Most biomass power generators in the state are mostly now operating under fixed price contracts for $0.0537/kWh.[21]

The cost of power generation from biomass remains high for two reasons: First, biomass is a low-density fuel, so fuel production, handling, and transportation are more expensive than for fossil fuels; and second, biomass power generating facilities tend to be small because of the dispersed nature of the resource, hence it is most difficult to capture the economies of scale typical of fossil fuel-fired generating facilities. The inherent characteristics of biomass leave power generation at a distinct disadvantage in a market recognizing economic cost alone. And yet economic cost alone does not fully reflect several advantages that biomass power can provide.

X - Value of Biomass Power

Economic Impacts

Biomass utilization benefits include the creation and retention of local jobs in rural economies. Direct employment for biomass power systems is estimated at between five and six full time jobs created for each MW of installed production capacity. Depending upon power plant scale, this employment figure includes 15 to 20 or more personnel at the power plant and the balance of jobs in fuel processing and delivery.[22] Morris, 1999, calculated for the State of California "total employment equal to 4.9 fulltime jobs per each megawatt of net plant generating capacity." [23] Using the Morris ratio a 15MW plant should provide employment for about 73 people.

McNeil et. al., estimating fuel procurement employment, assumed that a six-person crew could produce approximately six full chip vans per day including felling, skidding, chipping and three daily round trips per driver. Assuming a chip van will hold 23 GT of biomass, a 5-MW power plant that consumes 80,000 GT/year of fuel would need two crews operating to provide its fuel. Hence, 12 people would be employed in the fuel procurement sector of a 5-MW plant. Using the same assumptions, a 15-MW plant that consumes 240,000 GT/year would require 5 crews, for 36 employees in fuel procurement alone.[24]

Environmental Impacts

Environmental benefits resulting from biomass power production are clearly valuable to society, yet precisely how valuable remains a complex question. Smoke emissions from open burning of biomass residues produces massive pollutants containing particulate matter and greenhouse gasses. Biomass entombed at landfills speeds the depletion of landfill capacity and generates higher greenhouse gas emissions compared to controlled combustion in power plants. Failure to thin and remove excess biomass from overgrown forests depresses forest health, forest productivity, degrades watershed functioning while increasing fuel loads and risks of catastrophic wildfires.

In a conservative analysis by the National Energy Laboratory in 1999, the total value of the environmental services associated with biomass energy production in the United States is 11.4 cents/kW. This figure includes none of the benefits accrued to a rural community such as employment, economic development, energy diversity and security. [25]

Watershed Impacts

Watershed health is directly linked to forest health and appropriate forest management. Reducing risk of catastrophic wildfire not only protects lives and property but prevents or reduces discharges of debris and sedimentation into water bodies. Wildfire decreases the soil's ability to absorb and hold water and exposes mineral soils which too often contributes to the potential for mass soil wasting and mudslides following wildfires.

Thick and excessively dense forest stands compete for sun, water and soil nutrients restricting water yield from forests to riparian areas and reservoirs. Under these conditions forest productivity and diversity in flora and fauna are limited. "Forest and fuels management in strategic areas can help reverse these negative impacts." [26]

Appropriate use of forest management tools including thinning, pruning, prescribed burning as well as taking no action in currently healthy stands helps prevent catastrophic wildfires and helps create and maintain resilient watersheds, which in turn support communities, wildlife and recreational opportunities and enhance overall forest aesthetics. Synergistically, these environmental effects create socioeconomic issues for communities, ranging from water availability, to sustained timber production, through non timber forest products creation and recreational opportunities.

Other water quality impacts from a biomass plant are expected to be mitigated by permits from the regional water quality control board.

Air Quality Impacts

Biomass power plants fall under the authority of California Public Utilities Commission and Mendocino Air Quality Management District. Under Rule 1-220(c), New Source Review Standards, Power Plant Review Procedures. A facility will need to utilize Best Available Control Technology (BACT) to control NOx, SOx, and particulate matter emissions. As a rule, the larger the facility the more cost effective pollution treatment becomes.

It is sometimes useful to compare potential biomass emissions with coal emissions because both are solid fuels using similar conversion technologies to produce power. Burning biomass to generate power typically produces less SO_2 emissions than coal because biomass sulfur content is typically lower than coal. Typical biomass contains only 2% to 6% of sulfur found in coal. The biomass sulfur content translates to emissions of about 0.12 to 0.50 lb SO_2/MMBtu.

NOx emissions will usually be lower for biomass than for coal, due to lower fuel nitrogen (N), however this may be insignificant given the small difference in NOx emissions and similar compliance costs.

While biomass power production is frequently touted as carbon neutral since the CO_2 released by combustion was removed from the atmosphere in the recent past via photosynthesis, other carbon flows are very much involved, including CO_2 emissions associated with fossil fuels used in harvesting, processing and transport. In practice, although it is certain the net amounts of CO_2 emitted from a biomass power plant is less than a fossil power plant, it must be recognized that the total picture is a bit more complicated.

Morris et. al., 1999, found the total value of the environmental services associated with biomass energy production in the United States is 11.4 cents/kW. Of this value nearly 7.4 cents/kW, appears to be reduction of greenhouse gas emissions. [27]

In summary, improvements in air quality can be anticipated through efficient combustion, reduced greenhouse gas contributions as compared to some fossil fuels and the potential avoidance of forest fire activity and out of control smoke pollution.

XI - External assistance, supports and subsidies

External assistance in the form of public subsidies and other supports can assist in reducing the capital required and the overall risk of developing a new facility. Renewable energy grants and loan guarantees are broadly available to local governments and cooperatives.

Major Federal biomass power incentives have been legislated in recent years. Incentives are offered in the form of direct grants, loans or tax credits. A sizable portion of direct grants have been for research to find strategies around road blocks for the development of liquid fuels. A "Comprehensive Guide to Federal Biofuel Incentives" has been prepared by the Office of Senator Maria Cantwell. This guide covers the wide range of various bioenergy and biofuel programs and incentives available. This useful guide can be downloaded at:
http://cantwell.senate.gov/services/Biofuels/Comprehensive_Guide_to_Federal%20Biofuel_Incentives.pdf

Tables #4 and #5 summarize key points of various programs and credits.

Table 4 - Renewable Energy Grants and Loan Guarantees (adapted from Cantwell, 2006)

Rural and Remote Community Electrification Grants	DOE in consultation with USDA & DOI	Increase energy efficiency, site or upgrade transmission & distribution lines, or modernize electric generation facilities	Local government entity, utility or irrigation district, cooperative or nonprofit in a rural area	FY2006 through FY2012 Funds not appropriated in FY2006
Biomass Commercial Use Grant Program	USDA or DOI	Use of biomass to produce electric energy, sensible heat or transportation fuels; Grants are authorized for up to $20 per green ton of biomass.	Any individual or entity in a preferred community*	FY2006 through FY2016 Funds not appropriated in FY2006
Improved Biomass Use Grant Program	USDA or DOI	Offset the costs of R&D projects to improve the use of and/or add value to biomass; Grants may not exceed $500,000	Any individual or entity in a preferred community*	FY2006 through FY2016 Funds not appropriated in FY2006

* Preferred communities include local government and municipalities near Federal land whose population is less than 50,000 and Indian tribes.

Table 5 - Renewable Electricity Production Tax Credit (adapted from Cantwell, 2006)

Qualifying Resource	Service Date	Amount of Credit*	Credit Period
Closed-loop Biomass (Organic material from plants planted solely to produce electricity)	December 31, 1992 to January 1, 2008	1.5 cents per kWh	10 years after service date
Closed-loop Biomass modified to co-fire with coal and/or biomass	In service before January 1, 2008	1.5 cents per kWh times the ratio of the closed-loop biomass thermal content to that for all other fuels in the facility	10 years after the placed in service date but beginning no earlier than October 22, 2004
Open-loop Biomass (Cellulosic waste material, agricultural livestock waste or non-hazardous lignin waste material)	Before January 1, 2008	0.75 cents per kWh	10 years for service dates after August 8, 2005; if before, 5 years beginning on January 1, 2005
Open-loop Biomass using agricultural livestock waste nutrients	October 22, 2004 to January 1, 2008 (capacity of at least 150kW)	0.75 cents per kWh	10 years for service dates after August 8, 2005; 5 years if service date is after August 8, 2005; Credit period begins on January 1, 2005 if service date is before January 1, 2005
Poultry Waste	December 31, 2003 to January 8, 2008	0.75 cents per kWh 1.5 cents per kWh if placed in service after January 1, 2005	10 years for service dates from October 22, 2004 to January 1, 2005 or after August 8, 2005; 5 years for service dates from January 1, 2005 to August 8, 2005
Municipal Solid Waste (includes landfill gas and trash combustion facilities and new units placed on existing facilities)	October 22, 2004 to January 1, 2008	0.75 cents per kWh	10 years if service date is after August 8, 2005; 5 years if service date is earlier; Credit period begins on January 1, 2005 for units placed in service prior to January 1, 2005

* The inflation adjustment factor for the year 2005 is: 1.2528; making the credit for electricity sold in 2005 1.9 cents for wind energy, closed-loop biomass, geothermal and solar, 0.9 cents for open- loop biomass, small irrigation power, municipal solid waste and hydroelectric power, and $5.481 per ton for refined coal.

Figure 10 - Increased fuels due to Sudden Oak Death mortality.

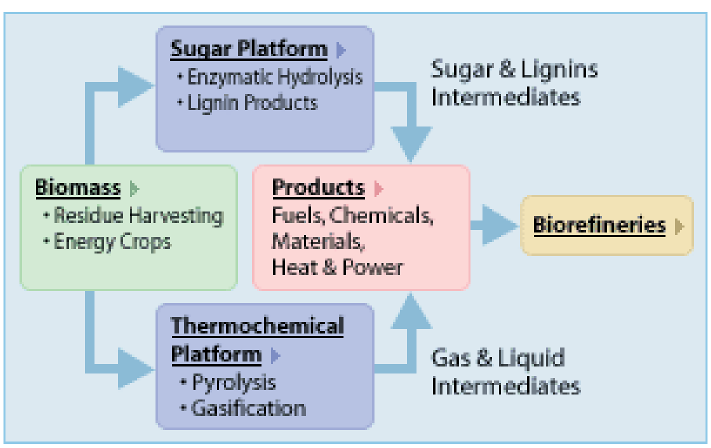
XII - Utility Green Pricing Programs

A growing number of utilities offer green pricing programs. Currently Alabama, Florida, Iowa, North Carolina, have utilities that offer green pricing utilizing biomass power resources. Two California utilities offer "green power" options based on wind, landfill gas and hydro. These are: 1) Los Angeles Department of Water and Power's Green Power for a Green LA program, based on wind and landfill gas with a premium of 3.0 cents/kWh and 2) Sacramento Municipal Utility District's Greenergy program based on wind, landfill gas, hydro, with a premium of 1.0 cents/kWh. If a "green pricing" program included a biomass option in the range of 2.0 cents/kWh, it would add around $2,000,000 yearly in revenue adding handsomely to the profitability of a Fort Bragg based power enterprise.

XIII - Emerging biomass technologies

A discussion of biomass to energy conversion needs to include an overview of emerging and potentially competitive conversion technologies that may soon compete directly with the well established direct combustion technology. The National Renewable Energy Lab (NREL) describes conversion pathways of fermentation, hydrolysis, pyrolysis and gasification. These pathways are graphically represented in figure 10 below.

Figure 11 – Biomass to Energy Pathways



Courtesy U.S. Department of Energy, http://www1.eere.energy.gov/biomass/

Cellulosic Ethanol

Fuel ethanol can be made from biomass by breaking down the naturally occurring polymer known as cellulose. All cellulosic biomass, such as agricultural forestry residues, industrial waste, trees, and grasses, can be broken down into component sugars and then fermented to make ethanol. Corn-derived ethanol has a net energy balance of 20,000 to 25,000 Btu per gallon. By contrast cellulosic ethanol has a net energy balance of more than 60,000 Btu per gallon, a startling increase in yield and system efficiency.

Testifying to the U.S. Senate Committee on Energy and Natural Resources in 2006, Dr. Michael Pacheco, Director of the National Bioenergy Center, indicated; "Our goal is to reduce the cost of producing cellulosic ethanol from $2.25 a gallon in 2005, to $1.07 in 2012. To get there we are working to greatly increase production efficiencies, and boost the average yield from 65 gallons per ton as it is today, to 90 gallons per ton in 2012."[28] Hence, one ton of biomass can now be converted to about 65 gallons of ethanol with a value of around $130. If increases in efficiency are obtained and utilized the yield could rise to 90 gallons of ethanol per biomass ton, while the value would fall to about $90.

Pyrolysis Oil

Pyrolysis Oil is a dark-brown liquid made from plant material by heating biomass particles in the absence of oxygen. Biomass is vaporized and condensed into a liquid called pyrolysis oil or bio-oil. This liquid product can be readily stored and transported. With it origins in biomass, pyrolysis oil is a renewable liquid fuel. Pyrolysis oil has undergone testing in engines, turbines and boilers, and has also been upgraded to high quality hydrocarbon fuel. The oil can also be used as feedstock for reprocessing into other chemicals and compounds.

Fast pyrolysis has now achieved a commercial success for production of chemicals and is now being actively developed for producing liquid fuels. Two Canadian firms, DynaMotive Energy Systems and Ensyn Technologies currently operate commercial plants.

A 2006 European market study for bio-oil found pyrolysis oil currently competitive with oil and gas in many European markets, while char, another byproduct of the pyrolysis process, can compete with all fossil fuels.

Table 6 - Pyrolysis Oil cost vs. other fuels (adapted from Bradley, 2006)[29]	Euros/GJ
Delivered Costs:	
Pyrolysis Oil- small tankers	6.42 - 10.46
Pyrolysis Oil- large tankers	4.82 - 7.75
Char	1.51 - 2.57
Wood pellets Canada	6.5
Prices:	
Heavy Fuel Oil	5.53 - 9.08
Natural Gas	6.01 - 11.50
Coal	1.52
Pellets	6.8-7.4

Bradley reports that "it is anticipated that supply of Pyrolysis Oil will grow slowly for 1-2 years, reaching 240,000 tonnes by 2008, as investors vie for opportunities to build, biomass supply is arranged, and markets and prices become more transparent. Then, Pyrolysis Oil supply is projected to increase rapidly, reaching 5 million tonnes by 2012."[30]

Fast pyrolysis of woody biomass typically results in yields of 70% pyrolysis oil, 14% char and 13% non-combustible gasses by weight. One ton of wood can be converted to 1400 lbs. of bio-oil or about 140 gallons containing 10.8 gigajoule (GJ) energy. Based on the values in Table #6, energy values only, bio-oil from one ton of wood should be valued at about $61.00.

Charcoal and Direct Carbon Fuel Cells

A fuel cell can be thought of as a battery to which fuel can be added. A carbon fuel cell directly converts the chemical energy of carbon to electricity with a high degree of efficiency and without creating many of the by products caused by conventional combustion. Because carbon fuel cells have potential to convert the chemical energy of carbon into electric power with efficiencies approaching 100% there has been continual investigation into them since the reaction was first described in 1896.

Lawrence Livermore National Laboratory, SRI International along with numerous other institutions and research firms have designs and working models of carbon fuel cells based on different approaches to the chemical reaction. A broad range of fuels have been tested including coal, coke, plastic, mixed waste and biomass. Researchers at Hawaii Natural Energy Institute have fabricated a moderate-temperature, aqueous-alkaline direct carbon fuel cell that uses charcoal as its fuel.

To fuel a charcoal burning carbon fuel cell Dr. Antal and his team at Hawaii Natural Energy Institute developed a rapid carbonization process that rapidly turns biomass into charcoal. The process is known as Flash Carbonization and reaches conversion levels of 30%-40% by weight often in less than 1 hour.

In the not too distant future, direct carbon fuel cell technology could offer clean and efficient conversion of biomass to electricity via charcoal. For example, one bone dry ton of wood (18GJ) converted to 800 lbs charcoal (10.80 GJ) converted to electricity at 90% efficiency = 2,700 kWh. By contrast, steam-driven turbine-generators with a conversion efficiency of 30 percent would deliver 1,500 kWh.

Figure 12 - Wood chip useful as fuel and feedstock for other conversion technologies.

IX. Conclusions

- Conversion technology is mature and well established with numerous biomass power facilities in place. Economics drive system scale up in size and devalue biomass prices.

- The available forest biomass resource within hauling distance of Fort Bragg is likely sufficient to support a modest biomass power plant of 10 MW to 15 MW given favorable economic and social conditions. Long term prices and volumes available need to be clarified by biomass suppliers.

- Desirable benefits such as rural employment, rural economic development, and energy diversity and security are provided by local biomass energy production. One could expect 5 to 6 direct jobs created per 1MW. For a 15 MW facility, from 75 to 90 jobs could be created - a substantial boost to the local economy.

- The net environmental impacts appear positive with the total value of the environmental services associated with biomass energy production estimated at 11.4 cents/kW. Impacts to watersheds are secured though application of established resource management methods and tools. Air quality benefits from efficient combustion and pollution controls. Longer term air quality is protected from reduced smoke through uncontrolled forest fires.

- Costs of capital, fuel ($30BDT) and operations suggest a final cost of electricity around 10.0 cents/kWh, a figure that could be lowered by subsidies on either capital or fuel.

Figure 13 – Forest residue bundles

French forest residue bundles containing about 1MW energy each. Courtesy Timberjack, 2005

X. Recommendations

- ***Strategize and develop forest fuel harvest capacity***
It is advantageous to be clear on how much biomass can be delivered at what price.

- ***Community Education***
Familiarity encourages acceptance. Large noisy industrial installations are intimidating to many. Socio-political and community acceptance are recognized as being important for success of bioenergy projects. The strength of public opinion opposed to the use of residues from native forest logging operations for energy should not be discounted. While lack of agreement on exactly what is to be considered waste is to be expected, opposition may well diminish where slash destined for open incineration is being discussed.

- ***Champion Subsidies***
Multiple federal programs have been authorized to encourage the use of biomass fuels and growth of a biomass industry; however several have remained unfunded. Contacting legislators to encourage full appropriations for these programs could provide the resources needed to encourage development of commercial biomass power production in Fort Bragg. Three examples follow:

BIOMASS COMMERCIAL USE GRANT PROGRAM
Administered by: Department of Agriculture
Annual funding: **Funds authorized but not appropriated for FY2006**
Established: Section 210, Paragraph (b) of the Energy Policy Act of 2005
Scheduled termination: Authorized from 2006 to 2016
Description: Authorizes placement of grants to improve the commercial value of forest biomass for electric energy, useful heat, transportation fuels, and other commercial purposes. Biomass commercial use grants may be made to any person in a preferred community that owns or operates a facility that uses biomass as a raw material to produce electric energy, sensible heat, or transportation fuels. To help offset the

purchase cost of biomass, a qualified entity may receive up to a $20 per green ton for biomass delivered.
Qualified applicant: Preferred communities are Indian tribes and local government and municipalities near public land with less than 50,000 people.
For more information: Contact USDA Rural Development at http://www.rurdev.usda.gov/rd/energy/

IMPROVED BIOMASS USE GRANT PROGRAM

Administered by: Department of Agriculture
Annual funding: **Funds authorized but not appropriated for FY2006.**
Established: Section 210, Paragraph (c) of the Energy Policy Act of 2005
Scheduled termination: Authorized from 2006 to 2016
Description: The Improved Biomass Use Grant Program is available to entities in preferred communities to offset the cost of projects to develop or research opportunities to improve the use of, or add value to, biomass. Criteria for awarding the grants include: (1) the anticipated public benefits of the project; (2) opportunities for the creation or expansion of small businesses and micro-businesses; (3) the potential for new job creation; (4) the potential for the project to improve efficiency or develop cleaner technologies for biomass utilization; and (5) the potential for the project to reduce the hazardous fuels from the areas in greatest need of treatment.
Qualified applicant: Preferred communities include local government and municipalities near public land whose population is less than 50,000 and Indian tribes.
For more information: Contact USDA Rural Development at http://www.rurdev.usda.gov/rd/energy/

RURAL AND REMOTE COMMUNITIES ELECTRIFICTION GRANTS

Administered by: Department of Energy in consultation with the Department of Agriculture and the Department of Interior
Annual funding: **No funds appropriated for FY2006**
Established: Section 209 of Energy Policy Act of 2005
Scheduled termination: Authorized through 2012
Description: The DOE Secretary is authorized to allocate grants each fiscal year to increase energy efficiency, site or upgrade transmission and distribution lines serving rural areas, or to provide or modernize electric generation facilities that serve rural areas. The grants are to be based on a determination of cost-effectiveness and the most effective use of the funds to achieve grant objectives. Preference shall be given to renewable energy which is defined as electricity generated from a renewable energy source or hydrogen produced from a renewable energy source. Renewable energy sources include wind, ocean waves; biomass, solar, landfill gas, incremental hydropower, livestock methane, or geothermal energy.
Qualified applicant: Eligible organizations include a local government or municipality, peoples' utility district, irrigation district, and cooperative, nonprofit, or limited-dividend association in a rural area, a city, town, or unincorporated area of not more than 10,000 inhabitants.
For more information: Contact DOE Office of Energy Efficiency and Renewable Energy at http://www.eere.energy.gov/information-center/

Common Energy Conversion Factors

(Courtesy http://bioenergy.ornl.gov/papers/misc/energy_conv.html)

Quantities
1.0 joule (J) = one Newton applied over a distance of one meter (= 1 kg m2/s2).
1.0 joule = 0.239 calories (cal)
1.0 calorie = 4.187 J
1.0 gigajoule (GJ) = 109 joules = 0.948 million Btu = 239 million calories = 278 kWh
1.0 British thermal unit (Btu) = 1055 joules (1.055 kJ)
1.0 Quad = One quadrillion Btu (1015 Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent (boe)
1000 Btu/lb = 2.33 gigajoules per tonne (GJ/t)
1000 Btu/US gallon = 0.279 megajoules per liter (MJ/l)

Power
1.0 watt = 1.0 joule/second = 3.413 Btu/hr
1.0 kilowatt (kW) = 3413 Btu/hr = 1.341 horsepower
1.0 kilowatt-hour (kWh) = 3.6 MJ = 3413 Btu
1.0 horsepower (hp) = 550 foot-pounds per second = 2545 Btu per hour = 745.7 watts = 0.746 kW

Energy Costs
$1.00 per million Btu = $0.948/GJ
$1.00/GJ = $1.055 per million Btu

Biomass energy
Cord: a stack of wood comprising 128 cubic feet (3.62 m3); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approx. 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg
1.0 metric tonne wood = 1.4 cubic meters (solid wood, not stacked)
Energy content of wood fuel (HHV, bone dry) = 18-22 GJ/t (7,600-9,600 Btu/lb)
Energy content of wood fuel (air dry, 20% moisture) = about 15 GJ/t (6,400 Btu/lb)
Energy content of agricultural residues (range due to moisture content) = 10-17 GJ/t (4,300-7,300 Btu/lb)
Metric tonne charcoal = 30 GJ (= 12,800 Btu/lb) (but usually derived from 6-12 t air-dry wood, i.e. 90-180 GJ original energy content)
Metric tonne ethanol = 7.94 petroleum barrels = 1262 liters
ethanol energy content (LHV) = 11,500 Btu/lb = 75,700 Btu/gallon = 26.7 GJ/t = 21.1 MJ/liter. HHV for ethanol = 84,000 Btu/gallon = 89 MJ/gallon = 23.4 MJ/liter
ethanol density (average) = 0.79 g/ml (= metric tonnes/m3)
Metric tonne biodiesel = 37.8 GJ (33.3 - 35.7 MJ/liter)
biodiesel density (average) = 0.88 g/ml (= metric tonnes/m3)

Fossil fuels
Barrel of oil equivalent (boe) = approx. 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. “Petroleum barrel” is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels oil are equivalent to one tonne of oil (metric) = 42-45 GJ.
Gasoline: US gallon = 115,000 Btu = 121 MJ = 32 MJ/liter (LHV). HHV = 125,000 Btu/gallon = 132 MJ/gallon = 35 MJ/liter
Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)
gasoline density (average) = 0.73 g/ml (= metric tonnes/m3)
Petro-diesel = 130,500 Btu/gallon (36.4 MJ/liter or 42.8 GJ/t)
petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m3)
Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.
Metric tonne coal = 27-30 GJ (bituminous/anthracite); 15-19 GJ (lignite/sub-bituminous) (the above ranges are equivalent to 11,500-13,000 Btu/lb and 6,500-8,200 Btu/lb).
Note that the energy content (heating value) per unit mass varies greatly between different “ranks” of coal. “Typical” coal (rank not specified) usually means bituminous coal, the most common fuel for power plants (27 GJ/t).
Natural gas: HHV = 1027 Btu/ft3 = 38.3 MJ/m3; LHV = 930 Btu/ft3 = 34.6 MJ/m3
Therm (used for natural gas, methane) = 100,000 Btu (= 105.5 MJ)

Rule of thumb consumption rate of 8,000 BDT/year per MW.

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