Sustainable Forests, Renewable Energy and the Environment

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Forest Biomass to Energy Project

Project Participants - Table S1 summarizes the major participants in the forest biomass to energy research project. This project was funded by a $2.0 million grant from the California Energy Commission with in-kind support from the USDA Forest Service Pacific Southwest Research Station and the California Department of Forestry.

Table S1 – Forest Biomass to Energy Research Project Participants

Organization	Research Roles
California Department of Forestry and Fire Protection (CDF)	Forest and Wildfire Modeling and Forest Remediation
California Energy Commission (CEC)	Program Management and Funding
California Air Resource Board (CARB)	Air Quality and Emissions Assessments
Department of Energy (DOE)	LCA Studies; Economic, Energy and Environmental Assessments of Biomass Conversion Technologies
Oregon State University (OSU)	LCA Modeling
Future Resources Associates (FRA)	Environmental Assessments
Renewable Energy Institute International (REII)	Testing of Forest Biomass to Energy Conversion Systems; Environmental Monitoring; Biomass Conversion Technology Modeling
TCW Economics	Economic Assessments
TSS Consultants	Life Cycle, Environmental and Economic Assessments; Forest Remediation and Wildfire Modeling, Air Emissions
University of California – Davis (UCD)	LCA Modeling and Data Management
University of Washington (UW)	LCA Modeling; Engineering Assessments
USDA Forest Service (USFS), Pacific Southwest Research Station	Program Management and Leadership; Life Cycle, Environmental and Conversion Technology Assessments; Wildfire Modeling and Forest Remediation

US Department of Energy (DOE); National Renewable Energy Laboratory (NREL)	LCA Modeling; Biomass Conversion Technologies

Conversion of Forest Remediation Biomass to Renewable Energy Products –

The five technologies investigated for the conversion of forest remediation biomass to electricity and/or biofuels include wood biomass combustion plants (I) for the production of electricity that have been built during the past five years (Mason, 2006); a next generation integrated gasification/combustion plant (II) for the production of electricity (Kunkel, 2007), a next generation thermochemical conversion plant (III) for the production of electricity (Schuetzle, June 2007), a next generation thermochemical conversion plant (IV) for the co-production of electricity and fuels (Schuetzle, October 2007), and a next generation biochemical (bio-refinery) conversion plant for the production of ethanol (NREL/DOE, 2006).

Table S2 summarizes the results of the technology evaluation (E1) in terms of products and product yields (electricity and bioalcohol fuels (ethanol)); the net energy efficiencies for the production of these products; and the emissions from these plants in terms of pounds of emissions per million BTU (lb/MMBTU) of net product output. Further details on these results are published elsewhere (Schuetzle, July 2007).

Table S2 – Technology Evaluation (E1)–Products and Product Yields, Net Energy Efficiency (E2) and Emissions (E3) for Current and Next Generation Technologies for the Conversion of Forest Remediation Biomass to Energy and Fuels

5E Assessment Results	**I).** Current Generation Biomass Combustion Power Plant	**II)**. Current Generation Integrated Gasification/ Combustion Power Plant	**III)**. Next Generation Thermo-Chemical Conversion Power Plant	**IV)**. Next Generation Thermo-Chemical Conversion Bioalcohol & Power Plant	**V)**. Next Generation Bio-Chemical Conversion Fuel & Power Plant
Plant Size	500 DTPD	500 DTPD	500 DTPD	500 DTP	2205 DTPD
Technology Evaluation (E1)					
Electricity (kWh/dry ton)	1000	1200	1400	550	205
Alcohol Fuel (gallons/dry ton)	DNA	DNA	DNA	80	59
Net Energy Efficiency (E2)	20%	22%	28%	50%	33%
Plant Emissions (E3) (lb/MMBTU output)					
NO_x	3.29E-01	6.68E-02	8.36E-03	4.69E-03	2.71E-01
SO_x	1.25E-01	1.00E-02	1.56E-03	8.72E-04	5.95E-01
PM	2.69E-01	3.00E-02	3.17E-02	1.77E-02	7.30E-02
CO	8.97E-01	7.00E-02	4.17E-02	2.32E-02	2.71E-01
VOC	8.47E-02	1.82E-02	3.11E-03	1.73E-03	2.30E-02
CO_2	972	886	694	303	481

DNA: Does not apply; ND: Not Determined; Dry Tons Per Day (DTPD); E1, E2 and E4 values are provided with $\pm$ 15% uncertainty and E3 values are given with $\pm$ 20% uncertainty.

Table S3 summarizes the results of the economic assessments (E4) for these five technologies. The data presented in this table for technologies I-IV was based upon conversion plants that process 500 dry tons per day (DTPD) of forest biomass within a

30-40 mile radius of the forest remediation activities at a cost of $45.00/dry ton (DT) delivered to the plant site. Unfortunately, data was only available for a 2205 DTPD next generation bio-chemical conversion fuel and power plant (technology V).

The 2007 projected wholesale cost of electricity and ethanol in California is $0.070-$0.80/kWh and $1.85-$2.10/gallon (WSJ, Feb. 2007). Since the current generation biomass combustion power plant produces electricity at a cost that averages $0.091/kWh, this approach would not be economically viable without economic incentives. Technologies II and III have the capabilities to produce electricity at $0.076/kWh and $0.071/kWh, respectively. These technologies will also need some economic incentives as necessary to provide investors with a 20% or greater return on investment.

The next generation bio-chemical conversion fuel and power plant (2,205 DTPD biomass input) can currently produce ethanol at about $2.24/gallon. In addition to not being economically feasible at this time, this size plant is too large to be sited near the origin of the forest remediation biomass resources.

The next generation thermochemical conversion plant (500 DTPD) is the only technology that has the capability of co-producing ethanol ($1.12/gallon) and electricity ($0.071/gallon) at a price that will produce a good return on investment (>30%), without financial and tax incentives.

Table S3 – Economics (E4) for Current and Next Generation Technologies for the Conversion of Forest Remediation Biomass to Energy and Fuels

5E Assessment Results	**I).** Current Generation Biomass Combustion Power Plant	**II)**. Current Generation Integrated Gasification/ Combustion Power Plant	**III)**. Next Generation Thermo-Chemical Conversion Power Plant	**IV)**. Next Generation Thermo-Chemical Conversion Fuel & Power Plant	**V)**. Next Generation Bio-Chemical Conversion Fuel & Power Plant
Plant Size	500 DTPD	500 DTPD	500 DTPD	500 DTPD	2205 DTPD
Economics (E4)					
Capital Cost, $M	55	59	60	66	205
Operating Cost, $M/yr	14.9	15.1	16.4	14.9	107.0
Electricity Production Cost ($/kWh)	$0.091	$0.076	$0.071	$0.071	DNA
Alcohol Production Cost ($/gallon)	DNA	DNA	DNA	$1.12	$2.24

DNA: Does not apply; ND: Not Determined; Dry Tons Per Day (DTPD); E1, E2 and E4 values are provided with $\pm$ 15% uncertainty and E3 values are given with $\pm$ 20% uncertainty.

If only 30% of the DOE/USDA estimates of 368 million DT of forest waste available in the U.S. each year were to be converted to energy with these technologies, they have the potential to produce 9.2-10.4 billion gallons of ethanol and 67-80 billion kWh of electricity.

If forest remediation is widely implemented in California, we estimate that 40 million dry tons per year of forest waste will be available for conversion to biofuels and bioenergy by 2025. If enough thermochemical conversion plants were built by this time to accommodate the conversion of this amount of biomass, then 2.38 billion gasoline equivalents of biofuels and 22 billion kWh of bioelectricity could be co-produced. This amount of biofuel would correspond to 12% of California's vehicle fuel requirements (~20 billion gallons/year) by 2025. In addition, the bioelectricity co-produced from these plants could provide biopower for 3.6 million California homes.

This forest biomass, in addition to other available biomass wastes in California (e.g. agriculture, sewage sludge, industrial and municipal waste), could total 130 million dry tons per year by 2025, resulting in a total biofuel production of 7.74 billion gallons of gasoline equivalents, which could meet 39% of California's vehicle fuel requirements. In addition, 50 kWh of bioelectricity could be produced for 11.7 million California homes.

Other technologies not examined in this study may become cost effective with technological advances that increase energy efficiencies, reduced capital and operating and maintenance costs (O&M), and tax and other incentives. However, the cost-competitiveness of these technologies may be increased substantially by calculating the full environmental benefits and life-cycle costs of energy production. The Biomass to Energy project quantifies many of the life cycle and non-market benefits and costs associated with forest biomass removal. By using an LCA approach, the project demonstrates how environmental trade-offs and benefits may be more accurately counted in order to appreciate the full impacts of linking renewable bio-energy production to forest remediation.

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