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BIOMASS TO ENERGY:

FOREST MANAGEMENT FOR WILDFIRE REDUCTION, ENERGY PRODUCTION, AND OTHER BENEFITS

APPENDIX 10

PIER FINAL PROJECT REPORT

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Appendix 10: Power Plant Analysis for Conversion of Forest Remediation Biomass to Renewable Fuels and Electricity

1. Report to the Biomass to Energy Project (B2E)

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Notice of Change in Scenario Naming Conventions

Key assumptions, modeling structures and terminology were altered and refined to accommodate new thinking during the course of this study. The reader will observe in the appendices that the scenarios are referred to as "Scenarios 1, 2 and 3" or "S1, S2 and S3."

In both the main text of the Final Report and in the Life Cycle Assessment appendix (Appendix 4), the former Scenario 1 (S1) was renamed to the "Reference Case." Scenario 3 (S3) has been renamed the "Test Scenario." Scenario 2 (S2), focused on the relative contributions and impact of Industrial Private Forestry (IPF) has been eliminated from most of the analyses that make up the entire study. These changes better reflect the focus of the study, which is fundamentally about the landscape level changes in wildfire, habitat, and other dynamics. The modification of terminology do not substantively affect the findings or recommendations of the study.

Two current and three next generation conversion technologies were investigated for the conversion of forest remediation biomass to electricity and/or biofuels. These technologies included current wood biomass combustion plants (I) for the production of electricity (Mason, 2006); a current 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, April 2008), a next generation thermochemical conversion plant (IV) for the co-production of fuels and electricity (Schuetzle, April 2008), and a next generation biochemical (bio-refinery) conversion plant for the production of ethanol (NREL/DOE, 2006 and Abengoa, 2007).

Table 1 summarizes the results of the technology evaluation (E1) in terms of products and product yields (electricity and ethanol or diesel fuels); 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, April 2008).

Table 2 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 450 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).

Table 1 – 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 Fuels and Electricity

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 & Biomsss Combustion Power Plant
Plant Size	450 DTPD	450 DTPD	450 DTPD	450 DTPD	2205 DTPD
Technology Evaluation (E1)					
Electricity (kWh/dry ton)	1000	1200	1400	550	205
Alcohol Fuel (gallons/dry ton)	DNA	DNA	DNA	80	59
Diesel Fuel	DNA	DNA	DNA	50	DNA
Average Net Energy Efficiency (E2)	20%	22%	28%	50%	33%
Average 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-02
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	884	694	389	589

DNA: Does not apply; ND: Not Determined; Dry Tons Per Day (DTPD); E1, E2 and E4 values are provided with ± 20% uncertainty and E3 values are given with ± 25% uncertainty.

Table 2 – 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	450 DTPD	450 DTPD	450 DTPD	450 DTPD	2205 DTPD
Economics (E4)					
Capital Cost, $M	61	54	51	67	205
Operating Cost, ($M/yr)	15.9	14.1	14.4	15.5	107.0
Average Electricity Production Cost ($/kWh)	$0.13	$0.12	$0.097	$0.072	DNA
Average Diesel Fuel Production Cost ($/gallon)	DNA	DNA	DNA	$1.95	DNA
Average Alcohol Fuel Production Cost ($/gallon)	DNA	DNA	DNA	$1.36	$2.24

DNA: Does not apply; ND: Not Determined; Dry Tons Per Day (DTPD); E1, E2 and E4 values are provided with ± 20% uncertainty and E3 values are given with ± 25% uncertainty.

The 2008 average wholesale cost of electricity and ethanol in California was $0.077/kWh. The average wholesale cost of ethanol and diesel fuel was $1.98/gallon and $3.45/gallon, respectively. Since the current generation biomass combustion power plant produces electricity at a cost that averages $0.13/kWh, this approach would not be economically viable without economic incentives. Technologies II and III have the capabilities to produce

electricity at $0.12/kWh and $0.097/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 (within a 30 mile radius) of the forest remediation biomass resources.

The next generation thermochemical conversion plant (450 DTPD) is the only technology that has the capability of co-producing ethanol fuel ($1.36/gallon) or diesel fuel ($1.95/gallon), and electricity ($0.072/KWh) at a price that will produce a good return on investment (approximately 25%), without financial and tax incentives.

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, or 5.75-6.50 billion gallons of diesel, 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, green waste, industrial and sorted/processed 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 renewable electricity 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. This project has quantified some of the life cycle and non-market benefits and costs associated with forest biomass removal. By using an LCA approach, the environmental trade-offs and benefits can be more accurately counted in order to appreciate the full impacts of linking renewable bio-fuel and bio-energy production to forest remediation.

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3. References

Jenkins, B.M. et al., *Assessment of Biomass Resources and Power Generation Potential in California*, California Biomass Collaborative, University of California, Davis (2005) (http://biomass.ucdavis.edu)

Mann, M. K., Spath, P.L., *Life Cycle Assessment of a Biomass Gasification Combined-Cycle Power System*, National Renewable Energy Laboratory, Golden, CO, NREL/TP-430-23076 (1997)

Mann, M.; Spath, P., *Life Cycle Assessment Comparisons of Electricity From Biomass, Coal, and Natural Gas*, *AICHE 2002 Annual Meeting*, Indianapolis, IN, November 3-8 (2002).

Mason, T., (2006), *Wind and Biomass Electrical Generation*, TSS Consultants, 2724 Kilgore Road, Rancho Cordova, CA 95670 (2005)

Schuetzle, D., Caldwell, M., Ganz, D., Tamblyn, G., Tornatore, F., Jacobson, A., *An Assessment of Biomass Conversion Technologies and Recommendations in Support of the Deployment of a 450 Ton/Day Integrated Biofuels and Energy Production (IBEP) Plant for the Generation of Ethanol, Electricity and Heat from Rice Harvest Waste and other Agriculture Biomass Resources in Gridley, California, Gridley Biofuels Project,* Phase I Interim Report, Department of Energy, Contract #DE-FC36-03G013071, www.reiinternational.org, April, 2008).

Schuetzle, D., Tamblyn, G., Tornatore, F. and MacDonald, T., *Alcohol Fuels from Biomass – Assessment of Production Technologies,* Western Governor's Association, National Biomass State and Regional Partnership Report, www.westgov.org, (July, 2008).

Schuetzle, D., *Gridley Ethanol Demonstration Project Utilizing Biomass Gasification Technology: Pilot Plant Gasifier and Syngas Conversion Testing*, NREL Technical Report #510-37581, Golden, CO; prepared under TSS Consultants Subcontract to NREL No. ZCO-2-32065-01 (February 2005).