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Emission Reductions from Woody Biomass Waste for Energy as an Alternative to Open Burning

Bruce Springsteen, Tom Christofk, and Steve Eubanks
Placer County Air Pollution Control District, Auburn, CA

Tad Mason and Chris Clavin
TSS Consultants, Rancho Cordova, CA

Brett Storey
Placer County Planning Department, Auburn, CA

ABSTRACT

Woody biomass waste is generated throughout California from forest management, hazardous fuel reduction, and agricultural operations. Open pile burning in the vicinity of generation is frequently the only economic disposal option. A framework is developed to quantify air emissions reductions for projects that alternatively utilize biomass waste as fuel for energy production. A demonstration project was conducted involving the grinding and 97-km one-way transport of 6096 bone-dry metric tons (BDT) of mixed conifer forest slash in the Sierra Nevada foothills for use as fuel in a biomass power cogeneration facility. Compared with the traditional open pile burning method of disposal for the forest harvest slash, utilization of the slash for fuel reduced particulate matter (PM) emissions by 98% (6 kg PM/BDT biomass), nitrogen oxides (NO_x) by 54% (1.6 kg NO_x/BDT), nonmethane volatile organics (NMOCs) by 99% (4.7 kg NMOCs/BDT), carbon monoxide (CO) by 97% (58 kg CO/BDT), and carbon dioxide equivalents (CO_2e) by 17% (0.38 t CO_2e/BDT). Emission contributions from biomass processing and transport operations are negligible. CO_2e benefits are dependent on the emission characteristics of the displaced marginal electricity supply. Monetization of emissions reductions will assist with fuel sourcing activities and the conduct of biomass energy projects.

INTRODUCTION

Woody biomass waste material is generated as a byproduct throughout Placer County portions of the Sacramento Valley, foothills, and Sierra Nevada mountains from forest management projects, defensible space clearing, tree trimming, construction/demolition activities, and agricultural operations.

Forest management projects that produce woody biomass byproducts (tree stems, tops, limbs and branches, and brush) include fuel hazard reduction, forest health and productivity improvement, and traditional commercial harvest. These projects take place on private land and lands managed by various public agencies including the U.S. Forest Service (USFS), Bureau of Land Management, and state/federal parks. Forest fuel hazard reduction activities involving selective, targeted thinning treatments are implemented to lessen wildfire severity and improve forest-fire resiliency through reducing hazardous fuel accumulations resulting from a century of successful wildfire suppression efforts. Commercial timber harvests include thinning to improve health and productivity, and intensive management to optimize the yield of merchantable material for lumber production.

Defensible space clearings and fuel breaks in an expanding wildland urban interface area, including residential and commercial structures, produce woody biomass that typically includes deciduous and coniferous trees and brush.

Agricultural operations such as fruit and nut orchards and grape vineyards are a source of biomass wastes from annual pruning and periodic removal and replacement with more productive varieties or growing stock.

Open burning (in piles or broadcast burning) near the site of generation is the usual method of disposal for a significant quantity of the excess woody waste biomass throughout much of the western United States. A forest slash pile burn in the Lake Tahoe Basin is shown in Figure 1. The cost to collect, process, and transport biomass waste is often higher than its value for fuel or wood products because of the distance of the forest treatment activity location from the end user (e.g., mill, biomass energy facility), lack of infrastructure, and/or economics of biomass energy compared with fossil fuel generation. This limits the feasibility of using biomass waste for energy production although such use has significant environmental benefits.

IMPLICATIONS

Economic considerations frequently dictate the disposal of woody biomass wastes by open burning. The alternative use for energy provides significant reduction in criteria air pollutant and greenhouse emissions. Valuing these reductions will improve the economic viability and increase the use of biomass for energy as well as assist with forest and agricultural management objectives.

Figure 1. Open pile burn of forest fuel treatment woody biomass in Lake Tahoe Basin.

The Placer County Air Pollution Control District (PCAPCD), with responsibility for managing air quality in Placer County, shares regulatory authority over open burning with local fire agencies. Open burning is problematic because of the limited time of year it can be conducted, subsequent monitoring of smoldering piles for days after they are lit, and the production of significant quantities of air pollutant emissions and esthetically unpleasing residuals (blackened logs and woody debris). The PCAPCD expends significant resources reviewing smoke management plans, issuing burn permits, inspecting burn piles, and responding to complaints from smoke.

PCAPCD[1,2] and others[3,4] report that the utilization of woody biomass waste for energy as an alternative to open burning can provide significant air emissions mitigation for criteria pollutants, air toxics, and greenhouse gases, along with energy benefits through production of renewable energy in a well-controlled conversion process. To quantitatively value these benefits, PCAPCD is developing an emission reduction accounting framework and has sponsored several biomass waste-for-energy field operations to evaluate alternatives to minimize open burning.

EMISSION REDUCTION ACCOUNTING FRAMEWORK

The emission reduction framework is intended to provide a basis for financial support for the utilization of biomass wastes for energy in which the biomass waste under "baseline, business as usual" conditions would have been open-burned. This requires an evaluation of the economics of the biomass management alternatives and institutional and regional practices to demonstrate that the biomass waste would be open-burned without the additional financial contributions from a biomass project proponent. Biomass must also be shown to be a byproduct of forest or agricultural harvest projects that meet local, state, and federal environmental regulations, including the National Environmental Policy Act, the California Environmental Quality Act, and/or Best Management Practices. The biomass must also be demonstrated to be excessive to ecosystem needs.

Net emission reductions are considered to be the difference between the biomass energy project and the open burning baseline. As shown in Figure 2, the biomass project boundary includes processing (loading and chipping), transport, and the energy conversion plant. The baseline considers biomass open burning and the marginal generation of energy that was displaced by the biomass project. Table 1 details the project activities and data requirements for emissions reduction determinations that are real, permanent, quantifiable, verifiable, and enforceable.

Emissions from the forest management projects and agricultural operations that generate the excess biomass waste (e.g., chain saws and yarders) are not considered in the accounting framework because biomass removal is required for management purposes and will occur regardless of which biomass disposal option is pursued. Biomass waste that falls under the framework must have economic value that is less than the cost to process and transport (it must be a disposal burden). The biomass removal operations must be required for reasons (e.g., fire hazard reduction, forest management, timber production, or food production) that are unrelated to any potential biomass value. Furthermore, emission contributions from the biomass removal operations are minor compared with processing, transport, or open burning.[3,4]

Emissions from operations to process and transport fossil fuels, which are used in the baseline to provide equivalent energy and in the biomass project to facilitate wood chip transport and biomass processing/loading equipment, are not considered because of the difficulty of accurately defining their energy usage and emission characteristics.

It is anticipated that reductions resulting from biomass utilization projects may be banked or sold for air emissions and/or greenhouse gas mitigation obligations.

DEMONSTRATION PROJECT

PCAPCD and the County of Placer Biomass Program teamed with USFS, Sierra Pacific Industries (SPI), and the Sierra Nevada Conservancy to sponsor an on-the-ground biomass waste-for-energy demonstration project. The project targeted woody biomass waste piles that were originally generated from two USFS fuel reduction stewardship contracts implemented in 2007 on the Tahoe National Forest, American River Ranger District, which is located above Foresthill, CA. The stewardship contracts involved the thinning treatment of over 1215 ha of mixed conifer and ponderosa pine stands with 500-1000 trees/ha (preharvest). The thinning prescription had a target of

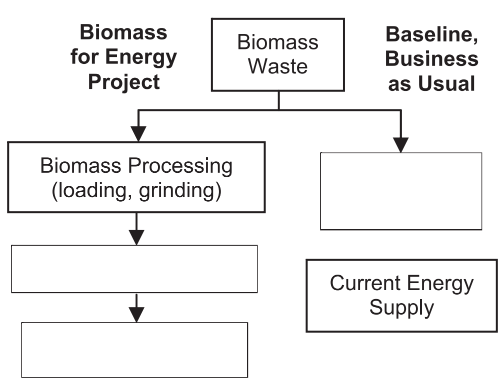

Figure 2. Biomass-for-energy project emission reduction procedure.

Table 1. Project data and monitoring.

Parameter	Method, Frequency
Biomass weight delivered to energy conversion facility	Transport vehicle weight scale, each separate delivery
Biomass moisture	Representative sample, when biomass source changes
Biomass heating value	Representative sample, when biomass source changes
Transport vehicle miles traveled and gas mileage	Vehicle odometer, fuel dispensing
Processing equipment diesel engine operating hours and fuel usage	Engine hour meter, fuel dispensing
Energy production efficiency of energy conversion facility	Fuel input and useful energy output
Emission factors for open pile burning	Literature review
Emission factors for fossil fuel combustion engines	Engine manufacturer, literature
Emission factor for grinding	Literature review
Emission factor for transport over unpaved roads	Literature review
Emission factors for biomass energy conversion facility	Source testing, annual
Emission factors for displaced energy	Marginal energy supply analysis, source testing

180–250 trees/ha at 7.6-m spacing through selected removal of trees 10–51 cm in diameter at breast height (DBH). Removed biomass that was greater than 15 cm DBH and greater than 3.1 m long was transported to a sawmill for processing into lumber products. The stewardship contracts called for unmerchantable slash to be piled at the site for later open burning, the traditional method of disposal.

For the demonstration project, a forest products contractor, Brushbusters, Inc., was retained to process and transport the woody biomass waste piles for use as fuel in a cogeneration facility located at a SPI lumber mill in Lincoln, CA. At each landing slash pile location, excavators were used to transfer the piles into a horizontal grinder. Wood chips from the grinder were conveyed directly into chip vans and transported to the SPI Lincoln mill, a 97-km one-way trip. Equipment and engines used for the chipping and transport operations are described in Table 2.

The SPI Lincoln sawmill facility includes a wood-fired boiler that produces steam for use in lumber drying kilns and a steam turbine that produces up to 18 MW of electricity. The boiler is a McBurney stoker grate design with a firing rate capacity of 88 MW that produces 63,560 kg of steam at 90 bar and 510 °C. It is fueled by biomass wastes including lumber mill wood wastes generated on-site (primarily sawdust), agricultural wastes including nut shells and orchard removals and prunings, wood waste from timber operations, and urban wood waste (tree trimmings and construction debris). The boiler utilizes selective noncatalytic reduction for control of nitrogen oxides (NO_x), multiclones, and a three-field electrostatic precipitator for particulate matter (PM) control. The net boiler heat rate is 16.8 MJ of heat input per kWh electric net, a net efficiency of 22%.

Table 2. Equipment and engines for biomass processing and transport.

Equipment	Vendor, Model, Year	Engine, Model, Horsepower
Horizontal grinder	Bandit Beast, model 3680, 2008	Caterpillar C18, Tier III, 522 kW
Excavator	Linkbelt, model 290, 2003	Isuzu CC-6BG1TC, 132 kW
Excavator	Linkbelt, model 135, 2003	Isuzu BB-4BG1T, 66 kW
Chip van	Kenworth, 1997	Cummins N14, 324 kW
Chip van	Kenworth, 2006	Caterpillar C13, 298 kW

During the period of April 14, 2008 through December 12, 2008, on 86 separate work days, 6096 bone-dry metric tons (BDT) (9537 green tons [GT]) of forest slash were collected, processed, and transported. A total of 444 separate chip vanloads were delivered to the SPI boiler, with each delivery averaging 13.7 BDT (21.5 GT).

The biomass processing machines (a grinder and two excavators) each worked a total of 265 hr and produced biomass fuel at the rate of 36.3 GT per hour of equipment operation. Diesel engine fuel consumption for the grinder and two excavators averaged 2.92 and 0.79 L/GT, respectively. This is comparable with the grinder fuel usage of 2.1 and 3.1 L/GT reported in other studies.[3,4] Chip transport truck/trailer diesel fuel usage averaged 1.9 km/L over the 193-km round trip (4.6 L/GT), also comparable to other studies.[3,4]

Biomass fuel delivered to the boiler had an average heating value of 20.9 MJ/kg, a moisture content of 36.1%, and an ash content of 2% dry weight. The boiler produced 7710 MWh of electricity utilizing biomass fuel from this project.

The biomass project significantly reduced the utilization of fossil fuels. The project required 511 MJ of diesel/BDT, but it displaced the need for 9806 MJ of natural gas/BDT for electricity generated by the biomass-fired cogeneration facility. Energy benefits would be greater if the fossil fuel energy required to collect, refine, and deliver fossil fuel to market (with added fossil fuel energy penalty on the order of 20%) was considered.[3]

Table 3 shows the emission factors used to calculate project and baseline operations, including NO_x, PM, carbon monoxide (CO), nonmethane volatile organics (NMOCs), methane (CH_4), and carbon dioxide (CO_2). Open pile burning factors considering numerous laboratory-, pilot-, and full-scale studies on conifer biomass are compiled in Table 4.[5–21] The burn pile emission factor was used with a burn pile consumption efficiency rate of 95%. Diesel engine combustion, chipping, and unpaved road travel emission factors are from the California Air Resources Board and the U.S. Environmental Protection Agency (EPA).[24–28] Biomass boiler factors are from annual

Table 3. Emission factors for project and baseline operations.

Process/Reference	Units	NO_x	PM	NMOC	CO	CO_2	CH_4
Open pile burning[5–20]	g/dry kg wood	3	6.5	5	63	1833	3
Chip van engine[24]	g/km traveled	10.6	0.25	0.31	25	1381	0.6
Chip van[25]	g/km unpaved road	–	300	–	–	–	–
Grinder engine[26]	g/kWh	3.1	0.18	0.16	4.0	530[b]	0.32
Excavator engine[26]	g/kWh	5.6	0.17	0.25	5.4	350[b]	0.51
Excavator engine[26]	g/kWh	6.4	0.26	0.31	6.7	370[b]	0.62
Grinder[27]	g/green kg wood	–	0.05	–	–	–	–
Biomass boiler[22]	g/GJ	52	7.7	1.7	73	88,000	4
Natural gas combined cycle[23]	Kg/MWh	0.016	0.011	0.002	0.005	384	–
California in-state electricity production[a28]	Kg/MWh	0.08	0.025	0.01	0.13	250	–

Notes: [a]Shown for comparison purposes; [b]Determined from engine diesel fuel usage, operating hours, and rated power output.

manual method stack sampling test programs and continuous emission monitors that are required by PCAPCD to demonstrate compliance with permit limits.[22] Electricity production factors are from the displacement of marginal power from a local utility natural gas combined cycle 120-MW plant that uses selective catalytic reduction and oxidation catalysts for NO_x and CO control.[23] For comparison, overall California state electricity generation emissions factors are also shown.[28]

Table 5 compares biomass project emissions with baseline (open pile burning) emissions. The project reduced PM emissions by 98% (6 kg PM/BDT biomass), NO_x emissions by 54% (1.6 kg NO_x/BDT), NMOC emissions by 99% (4.7 kg NMOCs/BDT), CO emissions by 97% (58 kg CO/BDT), and CO_2 equivalent (CO_2e; determined as $CO_2 + 21 \times CH_4$) emissions by 17% (0.38 t CO_2e/BDT).

The cost to process and transport the piles to the SPI cogeneration facility averaged $64.40/BDT, including $33/BDT to process and $31/BDT to transport the piles. The competitive market value at the time of the project for biomass sourced from timber harvest residual in the central Sierra Nevada region was approximately $33/BDT. The cost to dispose of the biomass wastes at the site of generation with open pile burning is relatively small. Thus, the demonstration program operated with a cost deficit of $31.30/BDT biomass processed.

For the demonstration project to be economically viable, the cost to process and deliver the biomass must be reduced, the price paid at the cogeneration facility must be increased, and/or emission reduction credits must be sold. To break even, emission reduction credits would need to be valued for CO_2e at $83/t CO_2e, NO_x at

Table 4. Emission factors for open pile burning of woody biomass.

Source, Reference, Test Conditions, Material Type	Material Type	Emission Factor (g/kg dry biomass burned)				
		PM	CO	CH_4	NMOC	NO_x
EPA AP-42,[18] conifer logging slash, piled	Flaming	4	28	1.0	–	–
	Smoldering	7	116	8.5	–	–
	Fire	4	37	1.8	–	–
EPA AP-42,[17] pile burn	Unspecified	14	116	4.7	15	–
	Fir, cedar, hemlock	3.4	75	1	3.4	–
	Ponderosa pine	10	164	2.9	9	–
Ward et al.,[19] Hardy,[10] consume model, 90% consumption efficiency	Dozer piled	6	77	6	4	–
	Crane piled	13	93	11	8	–
	Consume 90% consumption efficiency	9	80	3.8	3.1	–
Jenkins et al.,[12] wind tunnel simulator	Almond	5	53	1.3	10	4
	Douglas fir	7	56	1.5	6	2
	Ponderosa pine	6	43	0.9	4.4	3
	Walnut tree	5	71	2.0	7	5
Lutes and Kariher,[14] pilot, land clearing piles		7–22	19–29	–	4–16[a]	0.2–2
Andreae and Merlet,[5] literature compilation		5–17	81–100	–	–	–
Janhall et al.,[11] literature compilation, forest residues		8	–	–	–	–
Chen et al.,[7] laboratory	Ponderosa pine wood	4	17	–	0.5[a]	0.8
	Ponderosa pine needles	3.3	32	–	3.5[a]	4.1
Freeborn et al.,[8] laboratory, pine, fir, aspen		7	50	–	–	4
McMeeking et al.,[16] laboratory, pine, fir		–	90	3.7	5	2.2
Yokelson et al.,[20] pilot	Broadcast	8	–	–	2[a]	3
	Slash	4	–	–	2[a]	2
	Crowns	–	–	–	4[a]	3

Notes: [a]Total hydrocarbons.

Table 5. Emissions comparison: open pile burning vs. biomass energy.

	Air Emissions (t)						
Operation	NO_x	PM	NMOC	CO	CO_2	CH_4	CO_2e^a
Baseline, open pile burning							
Open pile burning	17.37	37.65	28.96	362	10,618	17.37	10,983
Displaced power from grid	0.47	0.28	0.06	1	2,733		2,733
Total	17.84	37.93	29.02	363	13,352	17.37	13,717
Biomass project							
Boiler	6.58	0.98	0.22	9	11,178	0.55	11,189
Process and transport							
Grinding	0.43	0.52	0.02	1	73	0.04	74
Loading	0.31	0.01	0.01	0	19	0.03	19
Chip van transport	0.91	0.02	0.03	2	118	0.05	119
Total	8.23	1.53	0.28	12	11,388	0.70	11,402
Emissions reductions	9.62	36.39	28.74	350	1,965	16.7	2,315
Percent reduction	54%	96%	99%	97%	15%	96%	17%

Notes: [a]CO_2e determined as $CO_2 + 21 \times CH_4$.

\$19,570/t NO_x, or at a lower price if a combination of pollutant credits is sold. Biomass market fuel prices are trending upward partly because of an increased demand for renewable energy (resulting from the California Renewable Portfolio Standard).

Opportunities were identified to significantly reduce future biomass waste processing costs through maximizing equipment productive work time (minimizing equipment downtime and mobilization) by careful formation of piles, creation of larger piles, and efficient scheduling and coordination of truck transport and grinding equipment. In particular, the grinder (the most expensive cost center) was frequently idle while waiting for the arrival of chip truck transport. Cost reductions can be achieved through operating the grinder closer to full time by using additional chip trucks or grinding into piles that are subsequently loaded into chip trucks at a later time with less expensive equipment such as front-end loaders.

The largest source of uncertainty in the emissions determinations is from the biomass open pile burning emissions factor. Open pile burn emission factors vary depending on woody biomass chemical composition (moisture, ash), physical characteristics (pile packing size and arrangement, biomass particle size), and atmospheric conditions (temperature, humidity, wind speed). Variability in the biomass open pile burn emissions factor will impact the magnitude of the emission reductions, but it will not alter the conclusion that emissions from the biomass energy project are lower compared with open pile burning. Variability for emissions from the diesel engines, biomass boiler, and displaced electricity grid operations are not significant to the project results because emissions factors from the processes are well established, process operating rates are accurately measured and monitored, the processes are inherently steady, and contributions from these sources are generally much smaller than those from open pile burning.

The demonstration project results are readily applicable to a very broad range of potential forest sourced biomass projects throughout the West and the entire United States. The biomass energy recovery boiler design, operation, and performance used for the demonstration project are representative of existing plants that are in commercial service throughout the United States. Emission contributions from biomass processing and transport are very small in comparison with traditional open pile burning. Thus variations in grinding efficiency, transportation distance, and engine emission characteristics will have very little impact on emission reductions. Transportation distance has a significant impact on the economic viability of biomass energy projects, adding approximately \$0.13/BDT per additional kilometer traveled, but it has very little impact on emission benefits.

CO_2 benefits are strongly dependent on the CO_2 emissions profile from the displaced marginal electricity source. Reductions will be much greater than achieved in the demonstration project for biomass projects in areas where coal firing is prevalent, whereas benefits will be minimal in areas where production is from lower CO_2-emitting sources such as hydroelectric and/or nuclear sources.

NO_x benefits are somewhat dependent on biomass boiler performance. NO_x reductions will be significantly greater than in the demonstration program for low NO_x-emitting systems including emerging energy conversion technologies such as gasification, pyrolysis, and fuel cells and recently constructed or modified biomass boilers that use selective catalytic reduction.

CONCLUSIONS

A framework is developed to quantify air emission reductions for projects that utilize woody biomass waste as fuel for energy production as an alternative to open burning. A demonstration project was conducted involving the grinding and 97-km transport of forest slash in the Sierra Nevada foothills for use in a biomass-fired cogeneration boiler. Significant air emission benefits were obtained: PM emissions were reduced by 98% (6 kg PM/BDT), NO_x emissions by 54% (1.6 kg NO_x/BDT), NMOC emissions by 99% (4.7 kg NMOC/BDT), CO emissions by 97% (58 kg CO/BDT), and CO_2e emissions by 17% (0.38 t CO_2e/BDT).

PM, NO_x, CO, and volatile organic emission reductions result from the utilization of biomass wastes in an energy conversion process that provides efficient combustion and uses add-on control methods for PM and NO_x emissions compared with the inefficient and uncontrolled disposal of biomass wastes using traditional open burning techniques. CO_2e benefits result from the production of renewable energy that displaces marginal supply and elimination of CH_4 emissions from open burning.

Biomass processing (grinding) and transport operations have a significant cost burden on the biomass energy project but a negligible contribution to air emissions. CO_2e benefits are strongly dependent on the CO_2e emission characteristics of the displaced marginal energy generation; benefits will be much greater for projects in regions where coal firing is predominant. Recognition of the value of emission benefits through sale of emission reduction credits will improve the financial performance of biomass power generation facilities and allow them to access more forest- and agricultural-sourced biomass waste fuel.

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About the Authors

Bruce Springsteen is an associate engineer, Tom Christofk is director and an air pollution control officer, and Steve Eubanks is a forest consultant with PCAPCD in Auburn, CA. Tad Mason is chief executive officer and a registered professional forester with TSS Consultants in Rancho Cordova, CA. Chris Clavin is a senior engineer with TSS Consultants. Brett Storey is a senior management analyst and biomass program manager with the Placer County Planning Department. Please address correspondence to: Bruce Springsteen, Placer County Air Pollution Control District, 3091 County Center Drive, Suite 240, Auburn, CA 95603; phone: +1-530-745-2337; fax: +1-530-745-2373; e-mail: bsprings@placer.ca.gov.