Placer County AIR POLLUTION CONTROL DISTRICT

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Thomas J. Christofk, Air Pollution Control Officer

June 17, 2013

Garry O'Neill
California Energy Commission
1516 Ninth Street, MS-29
Sacramento, CA 95814-5512

Subject: Comments to Docket Number 13-IEP-1M -- Status of Bioenergy Development in California

Dear Mr. O'Neill:

Bioenergy opponents refer to published studies which conclude that the use of forest biomass (including that derived from fuel treatment thinnings) for energy is not carbon neutral and increases GHG emissions [1].

The Placer County Air Pollution Control District (District) has sponsored an evaluation of the applicability of these studies to forest biomass operations in the Sierra Nevada. The results of that review are provided in the enclosed report prepared by Spatial Informatics Group. The report concludes that none of the published studies that are cited by opponents to bioenergy projects are applicable to Sierra Nevada biomass energy operations. This is because:

- The baseline and bioenergy scenarios described by these studies are very different than the context of Sierra Nevada biomass operations. None of the studies consider (1) the use of forest biomass waste residues for energy from fuel hazard reduction thinning that will taken place regardless of the construction of the biomass facility and are the byproduct of harvesting done solely for forest management objectives, or (2) where the residues would otherwise be piled and burned onsite.

- Many of the studies evaluate the use of biomass in addition to current harvest levels and/or harvesting solely for the use as fuel. In the Sierra Nevada forests, harvests are conducted to meet fuel reduction objectives, while the energy use is secondary. Further, a baseline of an un-thinned forest is not relevant to Sierra Nevada forests because thinning would have occurred whether the facility was present or not.

[1] These include: "Reexamining the Benefits of Forest Bioenergy," Center for Biological Diversity presentation at the California Energy Commissions June 3, 2013 Workshop on the Status of Bioenergy Development in California; and Center for Biological Diversity Comments to the Cabin Creek Biomass Facility Project Draft Environmental Impact Report.

- Some studies analyze waste residues that are disposed of through in-field deposit and left to decay. In the Sierra Nevada, residues are pile burned due to fire hazard reduction requirements.

The attached report and technical paper cites other studies that demonstrate that the practice of the use of biomass waste residues from forest fuel treatment operations in the Sierra Nevada for energy actually reduces GHG emissions.

Thank you for the consideration of our comments.

Sincerely,

Tom Christofk

Tom Christofk
Air Pollution Control Officer
Placer County Air Pollution Control District

Enclosure:

#1: **GHG Emissions from Woody Forest Residue Biomass Energy: Literature Review Relevant to the Sierra Nevada Forest** prepared by Spatial Informatics Group for Placer County Air Pollution Control District, June 13, 2013.

#2: **Emission Reductions from Woody Biomass Waste for Energy as an Alternative to Open Burning** published on Journal of the Air & Waste Management Association, January 2011.

Attachment #1

GHG Emissions from Woody Forest Residue Biomass Energy: Literature Review Relevant to the Sierra Nevada Forest

Prepared For:

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Date: June 13, 2013

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SECTION 1: INTRODUCTION

PURPOSE AND INTENT OF WHITE PAPER

This Woody Forest Residue Biomass Energy Greenhouse Gas White Paper addresses the current scientific understanding of greenhouse gas emissions associated with developing energy facilities using woody biomass versus the use of fossil fuels. The objectives of this paper are to:

1. Summarize key issues from recent relevant literature.
2. Discuss specific relevance of literature to a scenario of distributed biomass electricity generation facilities being planned in the Sierra Nevada region.

WOODY BIOMASS GREENHOUSE GAS ACCOUNTING OVERVIEW

Many studies since 1991 have illustrated that energy generated from woody biomass can be carbon intensive (i.e., greater net GHG emissions) relative to the fossil fuel equivalent energy source for short or long periods of time. Buchholz, Gunn, and Saah conducted a literature review of 39 studies published between 1991 and 2012 that investigate the Greenhouse Gas (GHG) emissions (primarily CO_2) of forest-based bioenergy systems. The studies ranged from global to local scales and varied in temporal and analytical boundary setting. **The majority of literature reviewed concluded that biomass utilization for energy is atmospherically CO_2 ("carbon") neutral over time when compared to fossil fuel equivalent energy sources.** That is, there is an initial carbon debt to the atmosphere that is paid back as forests sequester carbon compared to fossil fuel energy sources that continue to emit greenhouse gases. This was a consistent major finding of studies published over the past 22 years[1].

Below is a discussion of some of these key papers with notes on their relevance to small-scale biomass energy generation of the type proposed for the Sierra Nevada region that would use woody feedstocks from piles of thinnings that would have otherwise been burned on site. We refer to this as the "Sierra Nevada Scenario" – where a series of distributed biomass electricity generation facilities (e.g., .5 - 3MW) would be developed to use forest-sourced material (hazardous fuels residuals [i.e., woody biomass material that poses a substantial fire threat to human or environmental health], forest thinning and harvest residuals [i.e., woody biomass generated from forest maintenance and restoration activities], and Wildland Urban Interface activities (WUI; generally areas within ¼-mile of urban centers where materials would otherwise be piled and burned)-sourced waste materials from defensible space clearing activities; materials that would otherwise be piled and burned. Biomass materials (fuel for the plant) would be processed (ground and screened) at the locations from which they are

[1] See Appendix A for a citation list of these studies.

removed (such as U.S. Forest Service USFS fuels reduction sites) and delivered via chip truck to the project site.

The articles discussed below, with the exception of Searchinger et al. (2009), evaluate the atmospheric GHG impacts of switching from fossil fuel energy sources to woody biomass energy in specific ecological contexts and fossil fuel substitution scenarios. Indeed, many analytical studies since 1991 (see further discussion in Section 3) have concluded that biomass energy generation using woody feedstocks from forests can produce initial increases in GHG emissions relative to the fossil fuel equivalent energy source. As described by Walker et al. (2013), a peer-reviewed publication based on the 2010 Manomet findings, the GHG impacts of wood biomass energy will be specific to the forest and technology context of the region or biomass energy projects. Key points and relevance are described for the specific citations below.

SECTION 2: REVIEW OF RELEVANT FOREST BIOMASS ENERGY LITERATURE

ISSUE 1: BIOMASS ELECTRICITY GENERATION CAN BE A GREATER EMITTER OF ATMOSHPERIC GREENHOUSE GASES THAN FOSSIL FUEL SOURCES FOR A VARYING TIME PERIOD (E.G., DECADES TO CENTURIES).

Literature that supports this statement: Mitchell et al. 2012; Schulze et al. 2012; McKechnie et al. 2011; Manomet 2010; Walker et al. 2013; and Searchinger et al. 2009.

MITCHELL, S.R., HARMON, M.E., O'CONNELL, K.E.B. 2012. CARBON DEBT AND CARBON SEQUESTRATION PARITY IN FOREST BIOENERGY PRODUCTION. GCB BIOENERGY 4(6):818-827.

Key Points/Findings: Mitchell et al. (2012) simulated ecosystems in the Pacific Northwest under several initial landscape conditions ranging from afforesting post-agricultural land to old-growth (>200 years) forests. The simulations were used to evaluate the time required to pay back carbon "debt" generated by biomass energy production (i.e., GHG emissions in excess of the fossil fuel baseline). The results showed that initial landscape condition and land-use history are fundamental in determining the amount of time required for forests to repay the carbon debt incurred from bioenergy production. Their baseline is a "do-nothing, no-harvest scenario".

Relevance to the Sierra Nevada Scenario: The simulations conducted by Mitchell et al. capture a range of forest landscape contexts, but **do not specifically evaluate a scenario where residue (i.e., tops, limbs, and small diameter material) is used from ongoing fuel reduction harvests where the baseline fate for the material would be combustion on site in piles.** Therefore, it is not appropriate to apply the results of this simulation study to the Sierra Nevada scenario.

SCHULZE, E.-D., KÖRNER, C., LAW, B. E., HABERL, H., & LUYSSAERT, S. 2012. LARGE-SCALE BIOENERGY FROM ADDITIONAL HARVEST OF FOREST BIOMASS IS NEITHER SUSTAINABLE NOR GREENHOUSE GAS NEUTRAL. GCB BIOENERGY, N/A–N/A. DOI:10.1111/J.1757-1707.2012.01169.X

Key Points/Findings: Schulze et al. (2012), in an invited editorial (i.e., no new analyses were conducted) make the argument that an increase in the appropriation of Net Primary Productivity (NPP[2]) in the form of new biomass harvested for energy, would lead to decreased biomass stocks and consequently more biogenic carbon moving into the atmosphere than is currently the case.

Relevance to the Sierra Nevada Scenario: While Schulze et al. present a valid concern about global primary energy supply targets sourced from biomass, the discussion of "additional" biomass being harvested is **not relevant to the Sierra Nevada Scenario since the residue material used in the facility is already being harvested and burned in piles at the landing areas used for thinning operations.**

MCKECHNIE, J., COLOMBO, S., CHEN, J., MABEE, W., MACLEAN, H.L., 2010. FOREST BIOENERGY OR FOREST CARBON? ASSESSING TRADE-OFFS IN GREENHOUSE GAS MITIGATION WITH WOOD-BASED FUELS. ENVIRON. SCI. TECHNOL. 45: 789–795.

Key Points/Findings: McKechnie et al. (2010) present a life cycle assessment (LCA) and forest carbon analysis to assess total GHG emissions of forest bioenergy over time. The LCA evaluates specific cases in Ontario, Canada where wood pellets would be used to generate electricity instead of coal. The LCA also evaluates ethanol production emissions. The woody feedstocks include both harvest residues and standing trees. McKechnie et al. (2010) found that GHG emissions initially exceed avoided fossil fuel-related emissions, temporarily increasing overall emissions. The length of time for this carbon debt for wood pellet electricity generation ranged from 16-38 years (shorter if using residues only, longer if standing trees were used). Ethanol emissions were greater than fossil fuel emissions for a much longer period of time (>74 years). As others have concluded, McKechnie et al. (2010) found that "forest carbon more significantly affects bioenergy emissions when biomass is sourced from standing trees compared to residues and when less GHG-intensive fuels are displaced." The baseline fate for harvest residues in McKechie et al. (2010) is decomposition on site.

Relevance to the Sierra Nevada Scenario: The baseline fate for thinning residues proposed for use in the Sierra Nevada Scenario is to be burned in piles at the thinning site as opposed to

[2] Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time. (http://daac.ornl.gov/NPP/html_docs/npp_est.html)

decomposition either in piles or distributed back into the forest. Therefore, the conclusions from McKechnie et al. (2010) do not address the specific case described for the Sierra Nevada. In fact, the authors go on to point out: **"In some jurisdictions, residues are burned during site preparation for forest regrowth. Using such residues for bioenergy would not significantly impact forest carbon stocks."** Furthermore, forest carbon stocks are being reduced through thinning even in the absence of the proposed bioenergy project.

WALKER, T., P. CARDELLICHIO, J.S. GUNN, D. SAAH, & J.M. HAGAN. 2013. CARBON ACCOUNTING FOR WOODY BIOMASS FROM MASSACHUSETTS (USA) MANAGED FORESTS: A FRAMEWORK FOR DETERMINING THE TEMPORAL IMPACTS OF WOOD BIOMASS ENERGY ON ATMOSPHERIC GREENHOUSE GAS LEVELS. JOURNAL OF SUSTAINABLE FORESTRY. 32(1-2), 130–158.

Note: Peer-reviewed publication based on the "Manomet Study": Walker, T., P. Cardellichio, J.S. Gunn, D. Saah, J.M. Hagan. 2010. Massachusetts Biomass Sustainability and Carbon Policy Study. Manomet Center for Conservation Sciences NCI-2010-03.

Key Points/Findings: Similar to McKechie et al. (2010), Walker et al. (2010) found that new harvests of standing trees and the utilization of existing harvest residues in Massachusetts forests lead to a temporary carbon debt relative to a fossil fuel equivalent energy source. Walker et al. found that the feedstock matters - and so does the type of energy being produced and energy being replaced compared to projected future baseline. The baseline scenario in Walker et al. was one where typical harvests leave residue (tops/limbs) to decompose either in the forest or at a landing site following de-limbing. Removing this residue and some additional low quality whole trees to supply new bioenergy production results in an initial "carbon debt" to the atmosphere relative to the fossil fuel and forest management baseline. They also concluded that this debt can be recovered over time through forest regrowth. Baseline and bioenergy scenarios did not include natural disturbance risks beyond density-dependent mortality.

Relevance to Sierra Nevada Scenario: The baseline described in the Manomet Study is quite different from the proposed Sierra Nevada Scenario. As with McKechnie et al. (2010), the baseline in the Manomet/Walker et al. (2010) study is to leave harvest residue in the forest to decompose naturally over time. Residues are not burned quickly after the harvest operation as is the case with the proposed scenario. The Manomet/Walker et al. (2010) study also evaluated the impact of the removal of additional whole trees beyond baseline harvest levels. This results in a reduction of forest carbon stocks from the baseline and partly drives the conclusion of excess emissions from bioenergy. **For the Sierra Nevada Scenario, baseline forest carbon stocks are already being reduced in the existing thinning operation followed by relatively immediate combustion in piles. This is a fundamental distinction that prevents the work of Walker et al. (2010) from being applied to this context in the Sierra Nevada.**

SEARCHINGER, T. D., HAMBURG, S. P., MELILLO, J., CHAMEIDES, W., HAVLIK, P., KAMMEN, D. M., LIKENS, G. E., ET AL. 2009. FIXING A CRITICAL CLIMATE ACCOUNTING ERROR. SCIENCE, 326(5952), 527-528.

Key Points/Findings: Searchinger et al. (2009) do not present any new analysis of biomass energy greenhouse gas emissions, but make the important point that "The potential of bioenergy to reduce greenhouse gas emissions inherently depends on the source of the biomass and its net land-use effects." They go on to say: "Bioenergy therefore reduces greenhouse emissions only if the growth and harvesting of the biomass for energy captures carbon above and beyond what would be sequestered anyway and thereby offsets emissions from energy use. This additional carbon may result from land management changes that increase plant uptake or from the use of biomass that would otherwise decompose rapidly." Rapid decomposition results in near term GHG emissions as well as carbon storage in the soil. Searchinger et al. (2009) were speculating about potentially carbon-beneficial scenarios and did not have data to support the statement.

Relevance to the Sierra Nevada Scenario: Searchinger et al. (2009) acknowledge that biomass energy use may result in a reduction of overall carbon emissions compared to a *business-as-usual* scenario if the feedstock used is biomass that would otherwise decompose rapidly. The overall GHG balance and length of payback time for a bioenergy system is therefore correlated to the time required to convert biogenic carbon to atmospheric carbon in a baseline scenario. In this context, burning biomass on site results in immediate conversion of biogenic carbon to atmospheric carbon. However, **Searchinger et al. do not make any statements regarding the use of material that would otherwise be burned following removal from the forest.**

ISSUE 2: FUEL REDUCTION THINNING OPERATIONS DESIGNED TO REDUCE FIRE RISK RESULT IN LONG-TERM ATMOSPHERIC GREENHOUSE GAS EMISSIONS INCREASES IF USED FOR BIOENERGY

Literature supporting this statement: Campbell et al. 2011; and Hudiberg et al. 2011

CAMPBELL, J. L., HARMON, M. E., & MITCHELL, S. R. 2012. CAN FUEL-REDUCTION TREATMENTS REALLY INCREASE FOREST CARBON STORAGE IN THE WESTERN US BY REDUCING FUTURE FIRE EMISSIONS? FRONTIERS IN ECOLOGY AND THE ENVIRONMENT, 10(2), 83–90.

Key Points/Findings: Campbell et al. (2012) use modeling results to argue that fuel reduction projects do not usually lead to an atmospheric benefit when the probability that a given area will experience fire is considered. They conclude that thinning results in high forest carbon stock loss relative to what is protected from combustion if a treated area burns. It is important to note that the study does not evaluate the use of fuel reduction thinning material for bioenergy production or wood products, but simply forest carbon stock change. We include a review of studies with findings contrary to Campbell et al. (2012) in Section 3.

Relevance to the Sierra Nevada Scenario: The Campbell et al. (2012) paper is an inappropriate comparison to make in the context of the Sierra Nevada Scenario's emissions relative to a projected future baseline because decisions related to forest management are made separate and distinct from the proposed facilities. The same amount of forest residues will be produced regardless of whether the project will be built, and the fact that some of the waste material will end up as energy instead of being burnt in the open will not change the rate at which thinnings occur. **The baseline of an un-thinned forest is not relevant to the question of the facility's contribution to the atmosphere since the thinning would have occurred whether the facility was present or not.** As the facility would not be a driver of fuel treatments, concerns on GHG implications of forest management decisions are not relevant to the question of GHG accounting.

HUDIBURG, T. W., LAW, B. E., WIRTH, C., & LUYSSAERT, S. (2011). REGIONAL CARBON DIOXIDE IMPLICATIONS OF FOREST BIOENERGY PRODUCTION. NATURE CLIMATE CHANGE, 1(11), 419–423. DOI:10.1038/NCLIMATE1264

Key Points/Findings: Hudiberg et al. (2011) conducted a comprehensive carbon accounting of net biome production (NBP) for the Washington, Oregon, and California forest sector. NBP was defined as "the annual net change of land-based forest carbon after accounting for harvest removals and fire emissions." The baseline defined by Hudiberg et al. (2011) for western US forests is relevant to the Sierra Nevada Scenario and includes current preventative thinning and harvest levels, but the scenarios that were evaluated included removals **in addition** to the current harvest level, and were performed over a 20-year period such that 5% of the landscape is treated each year. They conclude: "…even though forest sector emissions are compensated for by emission savings from bioenergy use, fewer forest fires, and wood product substitution, the end result is an increase in regional CO2 emissions compared to baseline as long as the regional sink persists."

Hudiberg et al.'s (2011) key relevant conclusion is based on a scenario that assumes additional forest thinning operations beyond the current baseline are conducted to support bioenergy production. The results are also presented on a regional basis, and as such it is difficult to downscale the conclusions to specific ecoregions or use to it determine the impact of a single facility.

Relevance to the Sierra Nevada Scenario: The important factor to consider is whether the use of forest thinning residues for bioenergy is additional to what is currently done. The scenarios described in Hudiberg et al. (2011) that result in greater emissions from bioenergy production over the baseline include an increase in thinning activity over current levels to generate feedstocks for bioenergy facilities. The proposed Sierra Nevada Scenario baseline is one where thinning already happens as a common practice and the material is stacked in piles and burned at the forest site. The Sierra Nevada Scenario would convert a feedstock to energy that is currently burned at the forest site. Therefore, the assumption that woody material derived from forest thinning operations, even if intended to reduce fire risk would result in long-term atmospheric CO2 increases if combusted for bioenergy is not supported by Hudiberg et al. (2011) because it does not consider the context where feedstocks are derived from existing management activities and not thinnings that are "additional".

ISSUE 3: USING FOREST RESIDUALS REPRESENTS A CHANGE IN MANAGEMENT PRACTICE THAT WILL AFFECT GREENHOUSE GAS EMISSIONS

"… a change in forest management practices, for instance, by decreasing rotation length or increasing the use of forest residues also has a long-term impact on the landscape-level terrestrial stock or the stand-level C[arbon] stock time-averaged over the rotation." Citation for this statement: Pingoud et al. 2011; and related statements in Repo et al. 2010.

PINGOUD, K., EKHOLM, T., & SAVOLAINEN, I. (2011). GLOBAL WARMING POTENTIAL FACTORS AND WARMING PAYBACK TIME AS CLIMATE INDICATORS OF FOREST BIOMASS USE. MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE, ONLINE, 1–18. DOI:10.1007/S11027-011-9331-9

Key Points/Findings: Pingoud et al. (2011) utilize a global warming potential (GWP) factor to evaluate the GHG implications of biological carbon life cycles compared to permanent fossil fuel emissions. The factor accounts for the pulse of GHGs emitted to the atmosphere when biomass is combusted relative to a lower emission per unit energy of a fossil fuel (or from decomposing harvest residues). The GWP is a radiative-forcing based metric and the authors propose that it is a more realistic warming indicator than simply considering net carbon balance.

Relevance to the Sierra Nevada Scenario: The quoted text from Pingoud et al. (2011) is from the paper's introduction and is not a conclusion from the study; and does not provide evidence to support the broad assertion that increased use of forest residuals represents a change in forest management from the baseline in all contexts. **The Sierra Nevada Scenario feedstocks are derived from thinning material that would be generated in the absence of the facility and burned in piles at the forest site. Therefore the particular quote from the Pingoud et al. (2011) paper is not applicable to the Sierra Nevada Scenario.** The paper does discuss a pulse emissions factor that would more accurately reflect the global warming potential of such an emission. However, the pulse of emissions from pile burning would have an equivalent global warming potential to the bioenergy emission (total volume emitted will vary with combustion efficiency of the pile and the facility) and as such would tend to support the conclusion that the facility does not contribute to a net increase in CO2 emissions.

REPO, A., TUOMI, M., LISKI, J., 2011. INDIRECT CARBON DIOXIDE EMISSIONS FROM PRODUCING BIOENERGY FROM FOREST HARVEST RESIDUES. GCB BIOENERGY 3: 107–115.

Key Points/Findings: Repo et al. (2010) evaluates the use of logging (harvest) residue for bioenergy in boreal Norway spruce forest in Finland. The baseline business-as-usual context for the study assumes logging residue left in the forest to decompose (e.g., McKechnie et al., 2011 and Walker et al, 2010). The authors state that "indirect emission of using logging residues for energy production depend critically on the decomposition rate of the residues if they were left at the site." As with similar studies, the authors conclude there is a short term carbon debt to the atmosphere relative to a fossil fuel energy baseline, but over time the bioenergy system achieves net benefits relative to fossil fuels.

Relevance to the Sierra Nevada Scenario: The increased use of forest residuals in the Sierra Nevada Scenario does not represent a change in management practice that may affect overall greenhouse gas emissions. For this statement to be relevant, the presence of the biomass facility would be the (market) driver for additional harvests of residue. **In the Sierra Nevada Scenario, the well-established driver for harvests is to meet fuel reduction objectives, while the energy use is secondary. As such, conclusions from Repo et al. are not applicable to the Sierra Nevada Scenario.**

ISSUE 4: ASSUMPTIONS USED IN CALCULATING ATMOSPHERIC GREENHOUSE GAS EMISSIONS HAVE AN IMPACT ON THE OUTCOME OF THE ANALYSIS

HOLTSMARK, B. 2012. THE OUTCOME IS IN THE ASSUMPTIONS: ANALYZING THE EFFECTS ON ATMOSPHERIC CO2 LEVELS OF INCREASED USE OF BIOENERGY FROM FOREST BIOMASS. GCB BIOENERGY. ONLINE EARLY VIEW.

Key Points/Findings: Holtsmark (2012) modifies assumptions used in five published studies (including the Manomet Study and McKechnie et al., 2011 reviewed above) to evaluate the impacts on the analysis outcomes. Holtsmark (2012) looks at several assumptions, including whether a single or a set of repeated harvests were considered. Indeed, Walker et al. (2013) acknowledge that the outcome in terms of the length of the carbon debt payback period would likely be longer if harvest entries occurred at an interval more frequent than the payback period itself.

Relevance to Sierra Nevada Scenario: The frequency of harvest has no bearing on the calculations made in the evaluation of Sierra Nevada Scenario facility's emissions relative to the current baseline. In this study, as well as other studies discussed above, the carbon debt payback period partly relies on the regrowth of forests following new biomass harvests. **The important distinction between these studies and the Sierra Nevada Scenario is that fuel treatments will be carried out regardless of the presence of the biomass facility, and the frequency of forest thinning is determined by other parameters.**

ISSUE 5: LIFE CYCLE GREENHOUSE GAS EMISSIONS OF THE PILE BURNING OF THINNING RESIDUE

JONES, G., LOEFFLER, D., CALKIN, D., & CHUNG, W. 2010. FOREST TREATMENT RESIDUES FOR THERMAL ENERGY COMPARED WITH DISPOSAL BY ONSITE BURNING: EMISSIONS AND ENERGY RETURN. BIOMASS AND BIOENERGY, 34(5), 737–746. DOI:10.1016/J.BIOMBIOE.2010.01.016

Key Points/Findings: Jones et al. (2010) represents the sole paper that could be found that evaluates a scenario comparable to the Sierra Nevada Scenario. The study evaluated the life cycle greenhouse gas emissions of pile burning of thinning residue and fossil fuel energy production compared to the use of thinning residue to generate an equivalent amount of bioenergy. The authors concluded:

> "the bioenergy alternative produces substantially less total carbon dioxide emissions than do the pile-burn alternatives. Carbon dioxide emissions from the bioenergy alternative are only 55% of the pile-burn alternative using distillate oil and 62% of the pile-burn alternative using natural gas. The amount of carbon dioxide emissions from burning diesel fuel to collect, grind, and haul the biomass to the boiler facility represents only a very small percentage of the total carbon dioxide emissions in the bioenergy alternative."

Relevance to the Sierra Nevada Scenario: The findings presented in Jones et al. are directly relevant to the Sierra Nevada Scenario. The study's life cycle analysis includes an evaluation of the fossil fuel substitution benefits achieved from bioenergy production. This use of fossil fuel emissions in the baseline is typical of the majority of the citations reviewed above. This study demonstrates there is a bioenergy emissions benefit relative to the baseline when the feedstock is fuel reduction thinning material that would otherwise be burned in piles.

ISSUE 6: GREENHOUSE GAS IMPLICATIONS OF FUEL REDUCTION TREATMENTS RELATIVE TO POTENTIAL FIRE-RELATED EMISSIONS

WINFORD, E.M., GAITHER JR., J.C., 2012. CARBON OUTCOMES FROM FUELS TREATMENT AND BIOENERGY PRODUCTION IN A SIERRA NEVADA FOREST. FOREST ECOLOGY AND MANAGEMENT 282, 1–9.

Key Points/Findings: This study evaluates the carbon implications of fuels treatments in a relevant context for the Sierra Nevada Scenario. Scenarios where there are frequent fires (i.e., < 31 year return interval) lead to carbon benefits from fuel reduction treatments and bioenergy production. Longer fire return intervals had greater carbon benefits in the baseline "no treatment" scenarios. The authors summarize the key drivers as:

> "Net carbon sequestration levels from fuels reduction and bioenergy production must be evaluated over long time periods and are strongly influenced by fire rotation, fire

> severity, starting stand conditions, tree growth (and carbon sequestration) rates, and the efficiency of bioenergy plants. The most critical variable identified as influencing the life-cycle analysis in this study is fire rotation, the length of time that it takes for a given area to burn."

Relevance to Sierra Nevada Scenario: The study uses a baseline forest management scenario of "no treatment" to make the evaluations. This baseline scenario is again different from the Sierra Nevada Scenario where fuel reduction treatments are ongoing even in the absence of the bioenergy facility. While this is a useful study to look at the carbon benefits of thinning activities and bioenergy production as they interact with fire regimes, it is only indirectly relevant to the Sierra Nevada baseline.

CAMPBELL, J. L., HARMON, M. E., & MITCHELL, S. R. 2012. CAN FUEL-REDUCTION TREATMENTS REALLY INCREASE FOREST CARBON STORAGE IN THE WESTERN US BY REDUCING FUTURE FIRE EMISSIONS? FRONTIERS IN ECOLOGY AND THE ENVIRONMENT, 10(2), 83–90.

HURTEAU, M., & NORTH, M. 2009. FUEL TREATMENT EFFECTS ON TREE-BASED FOREST CARBON STORAGE AND EMISSIONS UNDER MODELED WILDFIRE SCENARIOS. FRONTIERS IN ECOLOGY AND THE ENVIRONMENT, 7(8), 409–414. DOI:10.1890/080049

HURTEAU, M. D., & NORTH, M. 2010. CARBON RECOVERY RATES FOLLOWING DIFFERENT WILDFIRE RISK MITIGATION TREATMENTS. FOREST ECOLOGY AND MANAGEMENT, 260(5), 930–937. DOI:10.1016/J.FORECO.2010.06.015

HUDIBURG, T. W., LAW, B. E., WIRTH, C., & LUYSSAERT, S. (2011). REGIONAL CARBON DIOXIDE IMPLICATIONS OF FOREST BIOENERGY PRODUCTION. NATURE CLIMATE CHANGE, 1(11), 419–423. DOI:10.1038/NCLIMATE1264

SAFFORD, H. D., SCHMIDT, D. A., & CARLSON, C. H. 2009. EFFECTS OF FUEL TREATMENTS ON FIRE SEVERITY IN AN AREA OF WILDLAND–URBAN INTERFACE, ANGORA FIRE, LAKE TAHOE BASIN, CALIFORNIA. FOREST ECOLOGY AND MANAGEMENT, 258(5), 773–787. DOI:10.1016/J.FORECO.2009.05.024

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There is a lack of scientific consensus on the impacts of forest thinning operations on long-term atmospheric CO2. In addition to Campbell et al. (2012), there have been at least four recent papers that evaluate the impacts of fuel treatment (i.e., thinning and prescribed fire) on carbon storage and greenhouse gas emissions in the Sierra Nevada region in particular. Hurteau and

North (2009 and 2010), Safford et al. (2009), and Stephens et al. (2009) do not explicitly evaluate biomass energy emissions but look at forest carbon stock changes under fuel treatment scenarios designed to mitigate wildfire risk and severity.

Hurteau and North (2009 and 2010) used data from stand-scale experimental treatments in Sierran mixed conifer forests to measure changes in forest carbon stocks under various thinning and prescribed fire fuel treatments. In general, thinning trees from small size classes had little impact on tree-based C storage over a 100 year period, but did raise the average height from the ground to the base of the live crown, a key factor in reducing fire intensity[3]. Hurteau and North (2009) concluded that thinning treatments which included prescribed fire had lower wildfire emissions than did treatments that only involved thinning. They found that there is an initial carbon stock loss that results from fuel treatments, but these forests can recover carbon stocks quickly if the treatments do not remove large and fire-resistant over story trees. Based on their work, Hurteau and North conclude that "forests with "high stand-replacing wildfire potential, reducing stem density and aggregating carbon in larger, fire-resistant trees can allow for the restoration of fire as a disturbance process that maintains carbon stocks at levels within the carbon carrying capacity of the forest."

Stephens et al. (2009) provide another recent quantitative study of fuel treatments and carbon storage in the Sierran mixed conifer Blodgett Forest. As with Hurteau and North, Stephens et al. (2009) conclude that when fire frequency is high, short-term carbon loss through treatments such as thinning and prescribed burning can lead to long-term carbon benefits relative to a management regime that does not include these fuel treatments.

These studies highlight the potential for fuel treatments to have long-term carbon benefits in addition to the well-documented fire severity reduction that they are designed to achieve. Understanding the current and future fire regime for a given region is important for evaluating the potential carbon benefits. Forest ecosystems with long fire return intervals may not produce the same carbon benefits as shown for systems with high fire frequency.

SECTION 4: SUMMARY CONCLUSIONS

WOODY BIOMASS ENERGY PROJECTS AND CARBON NEUTRALITY

There is a growing understanding that biomass energy projects are not inherently "carbon neutral". However, there are contexts and scenarios where the carbon "debt" can be quite short (e.g., less than 10 years) or non-existent. Calculating the potential atmospheric GHG

[3] In support of the importance of fuel treatments reducing fire intensity, Safford et al. (2009) found fuel treatments substantially moderated fire severity and reduced tree mortality during the Angora Fire in the Lake Tahoe Basin.

impacts of switching from fossil fuel energy sources to woody biomass energy is complex and context specific. The framework described in Walker et al. (2013) documents the inputs required to evaluate the GHG impacts of a woody biomass energy project. The framework is as follows (from Walker et al. (2013)):

> "Four key inputs are required to calculate the specific shape of the debt-then-dividend curve for a given region or individual biomass facility. *First, the biomass feedstock source*: the GHG implications of feedstocks differ depending on what would have happened to the material in the absence of biomass energy generation. *Second, the form of energy generated*: energy technologies have different generation efficiencies and thus different life cycle GHG emissions profiles. *Third, the fossil fuel displaced*: coal, oil, and natural gas each have different emissions per unit of energy produced. *Fourth, the management of the forest*: forest management decisions affect recovery rates of carbon from the atmosphere. This framework has broad application for informing the development of renewable energy and climate policies. Most importantly, this debt-then-dividend framework explicitly recognizes that **GHG benefits of wood biomass energy will be specific to the forest and technology context of the region or biomass energy projects**."

The literature citations discussed above generally illustrate the impacts to atmospheric GHG emissions if **additional** material (i.e., beyond baseline removal rates) is harvested (or thinned) to support bioenergy production. The studies conclude that this results in a temporary (and sometimes permanent) reduction of forest carbon stocks and generally results in higher emissions from bioenergy relative to an equivalent fossil fuel energy source. The baseline and bioenergy scenarios described by these studies are very different than the context described in the Sierra Nevada Scenario. Use of existing fuel reduction thinning material from piles otherwise destined to be burned does not result in a decrease in forest carbon stocks from the baseline scenario because the fate of the waste materials has already been determined by others. This is a fundamental distinction between the proposed scenario and many of the studies cited by above.

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KEY CONTRIBUTORS

DR. DAVID SAAH, MANAGING PRINCIPAL

Dr. Saah has been broadly trained as an environmental scientist with expertise in a number of areas including: landscape ecology, ecosystem ecology, hydrology, geomorphology, ecosystem modeling, natural hazard modeling, remote sensing, geographic information systems (GIS) and geospatial analysis. He has used these skills to conduct research primarily at the landscape level in a variety of systems. Dr. Saah has participated in research projects throughout the United States and Internationally. His academic research uses integrated geospatial science for multi-scale mapping, monitoring and modeling of environmental spatial heterogeneity, particularly in riparian, savanna, and forest ecosystems. These efforts include quantification of change in landscape pattern, investigating the linkages between pattern and processes, and understanding the pattern-process dynamic within different environmental management regimes. To complement this, Dr. Saah's consulting research interest and experience include: developing holistic decision support systems for resource management, assessing natural hazards, and quantifying ecosystem service valuation. In addition, all of his research addresses access, availability, and accuracy of geospatial and environmental datasets, and scale in natural resource and environmental research. Dr. Saah is committed to producing high quality research projects that integrate the most current science and technology. He is dedicated to the accurate dissemination of results from these endeavors through innovative presentations, publications, and workshops.

DR. JOHN GUNN, SENIOR SCIENTIST AND EXECUTIVE DIRECTOR, SIG-NAL

Dr. Gunn became the Executive Director of the newly-launched Spatial Informatics Group – Natural Assets Laboratory (SIG-NAL) on November 1st, 2012. Prior to SIG-NAL, John was a Senior Program Leader within the Natural Capital Initiative at the Manomet Center for Conservation Sciences. John has a B.S. in wildlife management from the University of Maine, an M.F.S. from the Yale School of Forestry and Environmental Studies, and a Ph.D. in biology from the University of New Brunswick studying the landscape ecology of forest songbirds. He has a broad background in sustainable forestry, including a position developing FSC-certified forest management systems for a large private landowner in Maine and extensive work on family forest and group certification issues throughout North America. John's recent work has focused on developing the tools and science necessary to implement payments for ecosystem services programs (such as carbon sequestration and drinking water quality) involving forest landowners. John has been elected to serve as an Environmental Chamber representative on the Forest Stewardship Council (FSC) US Board of Directors through 2013.

DR. THOMAS BUCHHOLZ, SENIOR SCIENTIST

Dr. Buchholz has research and work experience in the management and economics of natural forests, timber plantations, and short rotation energy crops (e.g. willow shrub plantations) for biomass production. He earned his Ph.D. from SUNY-ESF in bioenergy sustainability assessments and his M.Sc. in sustainable forestry in Germany; he is especially knowledgeable of the US and European bioenergy research and policy communities, and industry. In the course of his doctoral and post-doctoral research and his work with the Carbon Dynamics Lab at UVM, he has developed sustainability frameworks for bioenergy systems with substantive stakeholder inputs, and tested them on case studies in the US and abroad. In 2007, Dr. Buchholz worked at forestry program of the International Institute of Applied Systems Analysis (IIASA) in Austria, investigating the application of Multi-Criteria Analysis tools for participatory sustainability assessments of bioenergy systems. Being an affiliate at the Gund Institute for Ecological Economics as well as a member of the Carbon Dynamics Laboratory at the University of Vermont, he has been the lead author of several reports on forest bioenergy and energy plantation economics across the globe. Recent work includes micro- and macroeconomic analysis of forest based bioenergy use in the Northeastern US. Dr. Buchholz's main interest is applied research working on the interface of policy and science. The motivation for his work is to directly assist stakeholders and decision makers in the natural resource field in identifying lasting forest management and bioenergy solutions.

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Attachment #2

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

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

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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

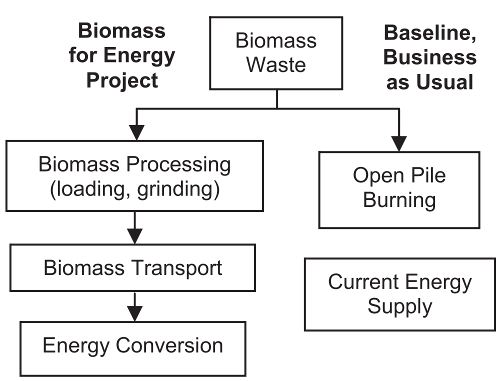

Figure 2. Biomass-for-energy project emission reduction procedure.

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.

Operation	Air Emissions (t)						
	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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