Life Cycle Assessment: Using Wildland Biomass to Generate Electrical Power

I. The Problem

California faces significant threats from wildfire due to excessive accumulations of forest and wildland fuels. Much of this fuel loading is in the form of small-diameter woody material, or biomass. Fire suppression over the past century, combined with intensive forest management and a generally warmer and wetter climate, has led to increasingly dense vegetation. When wildfires occur, the heavy accumulation of biomass often makes those fires larger and more severe. The increase in forest biomass threatens public health and safety, watersheds, and wildlife habitat with unacceptable losses to wildfire.

Public land management agencies and private landowners are focusing efforts on treating biomass to reduce wildfire hazards. These treatments typically create a significant volume of biomass wood waste. California law and policy, as well as several studies, assert a range of benefits associated with removing and using biomass from forests, as well as from agricultural and urban settings, for energy production. The National Renewable Energy Laboratory and the California Energy Commission, Integrated Waste Management Board, and Air Resources Board have each contributed substantially to analyses of environmental costs and benefits of generating power from biomass (Kadam et al. 1999, CEC 1992, CIWMB 2001). While many studies have concluded that overall benefits of biomass energy production substantially outweigh costs, researchers face considerable challenges in quantifying the relevant economic values, particularly for non-market environmental and ecosystem benefits.

Researcher Gregory Morris calculates that the value of environmental benefits associated with biomass energy production in the United States is 11.4 cents per kilowatt hour over and above the retail value of the energy generated (Morris 1999). The use of biomass from in-forest treatments is the least developed part of Morris' study, due in large measure to a lack of data and other analytical studies. The benefits specific to forest-based biomass power, such as reductions in wildfire impacts on communities, forests, wildlife habitats, and watersheds; improvements in air quality and water quality; protection of human health and welfare; and renewable energy production – and the costs associated with achieving them – have not been sufficiently well quantified to provide useful guidance on policy development. A more accurate accounting of costs and benefits for forest biomass-to-energy strategies is needed to develop coherent policies that link forest health management, fuel loading reduction and energy production.

Current inventory information indicates that in-forest fuels reduction may provide one of the largest sources of biomass fuel for power production in California. Removal of excess biomass from California's wildland areas to achieve public safety and environmental benefits could theoretically produce more than 30 million bone-dry tons (bdt) of biomass annually, of which approximately 18 million bdt would come from commercial and non-commercial forest management (Kadam et al. 1999; Shelly et al. 1998; CEC 1992). Assuming that this volume of biomass could be environmentally and economically available, it would comprise nearly eight times the biomass volume from all sources currently consumed for biomass power production in California (Morris 2002). The potential for power production would be substantial: 30 million bdt could produce over 3,000 megawatts of power. Current biomass power production in California stands at about 650 megawatts annually, with a total capacity of approximately 750 megawatts. Biomass energy contributes 15 percent of the renewable power currently produced in the state, but has the potential to provide many times more (Morris 2002).

II. The Biomass Life Cycle Assessment Project

Many policy and decision makers agree that the social, economic, and environmental costs and benefits of biomass power need to be better understood. Public policy is hampered by lack of knowledge about the many costs and benefits associated with thinning forests and using the biomass from these treatments to generate electrical power.

One approach that can be used to identify and quantify the costs and benefits of biomass energy production is a life cycle assessment. A life cycle assessment, or LCA, models the environmental impacts and related economic values associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment (Figure 1). Decision makers can use LCA models to evaluate opportunities to reduce negative environmental impacts and achieve economic efficiencies.

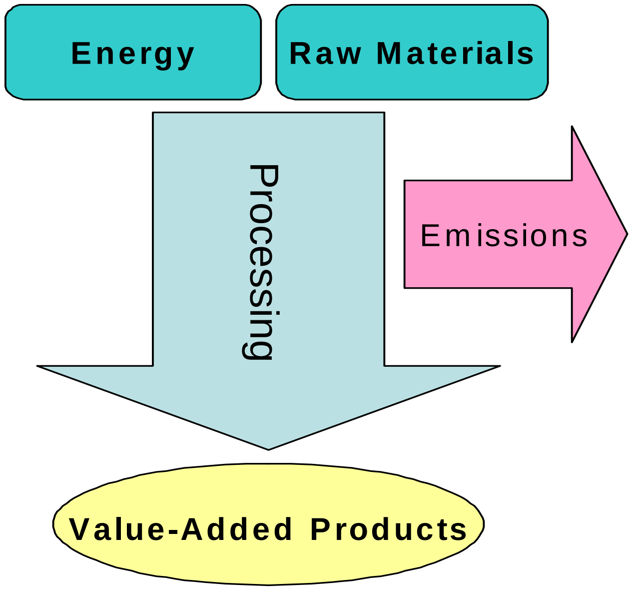

Figure 1. Schematic diagram of an LCA model.

The Pacific Southwest Research Station of the USDA Forest Service is working with the California Energy Commission's Public Interest Energy Research Program; the University of California at Davis; energy, forestry, and environmental consultants; and several State and Federal agencies to construct a cradle-to-grave forest biomass LCA model. The model will be used to identify and analyze social, economic, and environmental costs and benefits of using forest biomass to generate electrical power.

III. Conceptual Design of the Biomass LCA Model

Development of the Biomass LCA model is currently underway, with the focus on developing overall architecture for the model. Some key concepts and definitions common to life cycle analysis are important in the development of the Biomass LCA model framework.

What defines an LCA?

The Society of Environmental Toxicology and Chemistry defines LCA as:

> an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements (Consoli et al. 1993).

LCA is a systematic analytical method used to quantify the benefits and drawbacks associated with the entire life cycle of a product. In LCA, all stages of a product's life are analyzed, from the extraction of raw materials needed to make the product through final product distribution. An LCA is ideal for comparing new technologies with existing technologies to identify overall costs and benefits in terms of economic, environmental, and energy effects.

An LCA has three key steps: (1) an inventory step, which entails identifying and quantifying the resources used (including energy, raw materials, and capital) and wastes and emissions generated at each phase of production, from cradle to grave; (2) an impact assessment step, which involves assessing the economic, energy, and environmental impacts associated with the resources used and wastes generated; and (3) an interpretation step, whereby LCA results are interpreted and communicated.

Framework for the Biomass LCA Model

The objective for the Biomass LCA Project is to develop a comprehensive economic, environmental, and energy LCA model that can be used to evaluate the potential net public benefits associated with treating and utilizing forest biomass. This computer-based model will be designed to facilitate economic, environmental, energy, and effectiveness assessments for the potential public benefits associated with: (1) various options for treating, disposing, and utilizing forest biomass and (2) electricity production from forest remediation biomass. Ultimately, the model will be used to explore opportunities for converting forest biomass to electricity, based on economic viability, environmental impacts, energy efficiency. It will also allow policy makers to evaluate the effectiveness of alternative forest biomass management policies in meeting public goals, stakeholder needs and government regulations.

The Biomass LCA Model framework is comprised of a set of distinct modules, which include: (1) a core series of linked process and activity modules that follow the removal of wildland biomass and its conversion to electrical power, (2) other process and activity modules to assess alternative uses of wildland biomass and other sources of electrical power (such as natural gas), (3) a wildland fire effects module to translate changed forest conditions into changes in fire behavior, effects, and other ecosystem changes, and (4) a public benefits results module to post-process the core LCA outputs and the forest ecosystem responses. Flows of energy, materials, economic costs, wastes, and environmental impacts, will be traced through all of the modules (Figure 2).

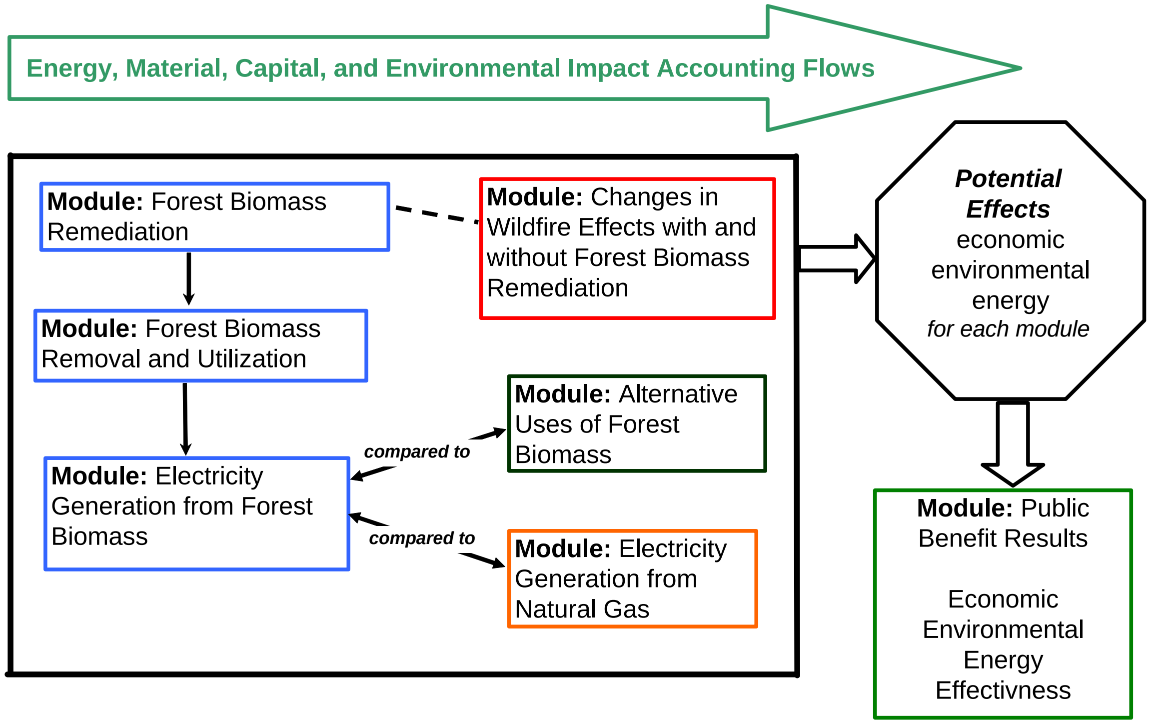

Figure 2. Biomass LCA Model framework.

The model will require synthesis of existing studies and additional research to populate individual modules. A wide range of research and peer-reviewed data will be incorporated into the model, such as wildlife habitat impacts; costs of vegetation management, collection, processing and transport of biomass materials; air and water quality impacts and benefits; changes in wildland fire behavior and impacts; and so forth. Model users will be able to game out different options (or scenarios) within the various modules, and to change modeling assumptions such as forest remediation prescriptions, transportation distances, types of equipment used, biomass generating technologies, and so forth (Figure 3).

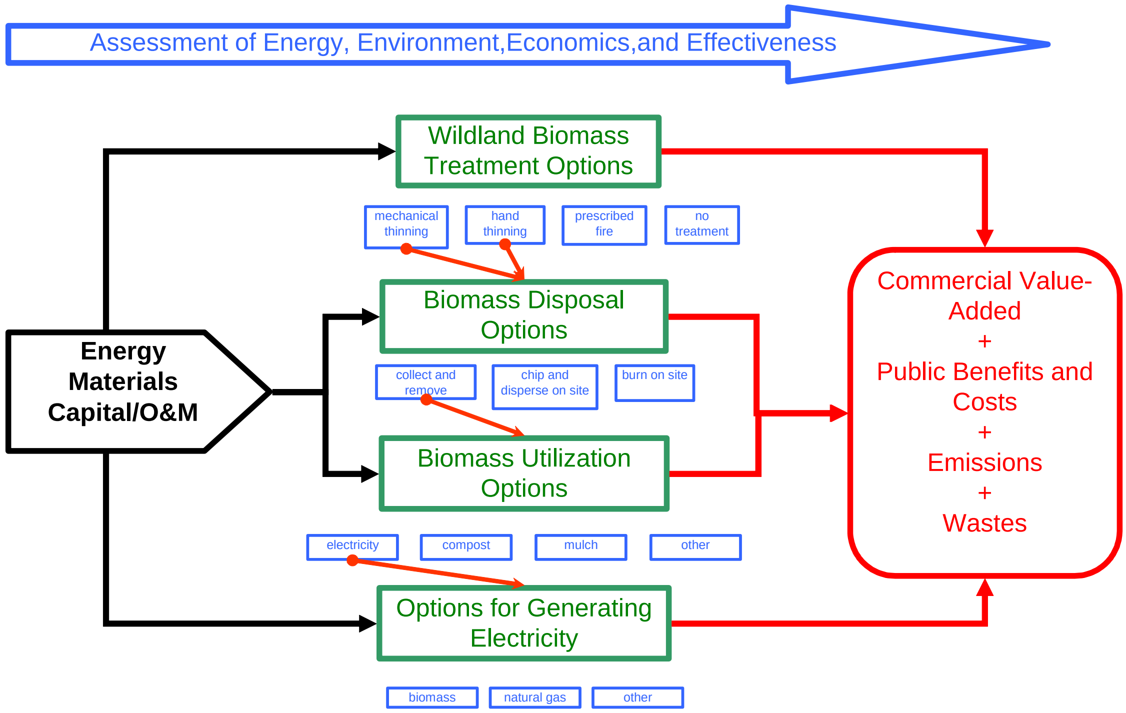

Figure 3. Model options to allow gaming of different scenarios.

IV. Key Questions Related to Model Development

At this early stage of model development, there are a number of outstanding questions that need to be addressed as the model is built. The various teams developing pieces of the model are working in concert to determine the best ways to deal with the following open questions:

Time Dynamics

The LCA model is not a time-dynamic simulation model: it is based on a series of "snapshots." While the LCA model may use outputs from simulation models (for example, fire behavior models), it will be strictly a linear input/output model.

However, an appropriate temporal scale needs to be selected for the model. One possible option is to base the model's temporal scale on the life of a biomass or natural gas plant. Another option is to use fire return intervals for the forest and wildland ecosystems being remediated, accommodating different fire return intervals for different vegetation types (for example, chaparral systems versus mixed conifer forests).

Scenarios, Impact Categories, and Conversion Processes

The number of scenarios (pathways along which various treatment, disposal, utilization, and energy production options are combined and run - see Figure 3) in the model directly affect the complexity of the project in terms of data needs, time needed to complete and populate the model, and financial resources to complete the project. The number of conversion process options considered in the model (such as comparing small-scale distributed gasification systems with a number of standard biomass power plant designs) will greatly increase the number of scenarios and model runs, while the number of impact categories will greatly increase the data requirements for each process and scenario.. Selecting the number of scenarios, impact categories, and conversion processes is an important consideration in further developing the model.

Benchmarking

Most LCAs compare a known product or process with an alternative product or process under consideration. This is what is known as benchmarking. The benchmark provides a means of determining whether or not the process being evaluated in the LCA will result in more or less environmental, economic, and energy impacts compared to another set of processes. A critical step in model development is clearly defining and representing the benchmark process for each module (Figure 2) in the forest to electricity process. For example, the LCA team will need to establish a benchmark for comparing alternative forest remediation actions. Similarly, alternative biomass products will need to be defined as the benchmark to compare to the pathway of biomass conversion to electricity.

A comprehensive review of the literature has led the team to conclude that no LCA computer models have yet been developed to assess potential public benefits associated with using forest biomass for electrical power generation. The forest biomass LCA model may itself eventually provide a benchmark for future studies.

While the entire process – from forests to electricity generation – does not have a benchmark, the biomass electricity generation modules do have a solid basis for comparison with natural gas electricity generation. Since natural gas is currently the primary source of electricity in California, it is most likely to be used to meet increasing future energy demands. For this reason, the research team will be able to benchmark some of the key components of the model.

Landscape Archetypes

One important risk in complex environmental modeling concerns the degree of generality one assumes about the impacts of the unit processes within the model. To increase the accuracy of the modeling assumptions and impacts, the LCA project team will select specific geographic locations that correspond to the kinds of forest remediation needs in California. Each location will represent a different landscape archetype. The team will draw data from these selected areas to resolve fuzziness in the model, test assumptions, and provide opportunities to "ground truth" the model. Selection of the number and kinds of landscape archetypes will be a key challenge early on in the project. Possible criteria for selecting areas include the following: (1) vegetation condition, (2) human population density, (3) sensitive ecological systems (habitats), and (4) existing infrastructure-related opportunities (for example, roads to provide access to treatment areas and transport materials from treatment sites).

Model Software and Databases

Critical to Biomass LCA model development is deciding whether to use existing LCA model software or develop a new computer model for the Biomass LCA. Three options are being considered: (1) select an existing computer model(s) and modify the model(s) to meet the requirements of the project, (2) develop a new computer model, or (3) develop a new computer model and integrate it with an existing model(s). Deciding which option to pursue will depend on the degree to which existing models meet the requirements of the Biomass LCA model and how well they incorporate economic, environmental, and energy assessment capabilities. Among existing models and databases, the project team will be looking at each model's ability to allow users to (a) link financial models (such as biomass power plant financials) to energy and environmental impact models, (b) dynamically link datasets to provide real-time updates, (c) perform sensitivity analyses on datasets, (d) construct and report an audit trail, (e) create impact measurements that change progressively (especially for tracking non-market values associated with environmental impacts), and (f) share and publish model and database assumptions, algorithms, and other project information in the public domain.

V. Biomass LCA Project Roles and Responsibilities

Several teams are being assembled to conduct the Biomass LCA project, and all are part of the LCA project team. The modeling team is developing the architecture of the LCA model and will populate the model with several very large datasets. The economics team will identify environmental and social values and conduct studies for quantifying these values. An ecosystem research team will synthesize key areas of ecosystem science, develop a comprehensive research agenda to support model development, and conduct specific ecosystem studies to complete the model.

Two advisory committees will oversee the entire Biomass LCA effort:

- a technical advisory committee (TAC), which will draw upon representatives from the forestry and biomass power industries, environmental community, and State and Federal scientific and technical experts, to advise the LCA project team regarding technical matters, especially where information is weak, and
- a policy advisory committee (PAC), with membership from a broad range of policy and decision makers, to help the team understand sensitive policy issues.

The Biomass LCA project is planned in three phases over a 3- to 5-year period. Phase I of the project will span approximately 2 years, with a prototype version of the LCA model expected by mid-2006. Later phases of the project will focus on key areas of research needed to refine the model. The ultimate product of this project will be a comprehensive model that provides a decision support tool to help policy makers estimate public costs and benefits, as well as identify policy opportunities for pricing public goods, associated with using biomass to generate electrical power.

VI. References

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