Arnold Schwarzenegger
Governor

BIOMASS TO ENERGY:

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

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
USDA Forest Service
Pacific Southwest Research Station

January 2010
CEC-500-2009-080

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Acknowledgements

This report is the result of four years' work of a team with more than 65 participants from more than a dozen institutions. Nearly a third of the total resources required for this complex project were contributed on an in-kind basis, and several scientists and consultants dedicated additional volunteer time. Much credit belongs to the Technical Advisory Committee and the Policy Advisory Committee that were assembled for the project. Without their consultation and guidance, this complex work would have been diminished.

A full list of team members, research cooperators, and technical and policy advisors is available in Appendix 12.

Recommended Citation:

USDA Forest Service, Pacific Southwest Research Station. 2009. *Biomass to Energy: Forest Management for Wildfire Reduction, Energy Production, and Other Benefits.* California Energy Commission, Public Interest Energy Research (PIER) Program. CEC-500-2009-080.

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Abstract

The Biomass to Energy project models the costs and benefits of generating electricity from forest thinnings[1] over a 40-year period beginning in 2006. The study demonstrates that economic valuation is possible for many, but not all, valued assets[2] on the landscape, and that the impacts and costs of forest disturbance (including thinning operations) can be accurately modeled. The study includes a life cycle assessment[3] of forest operations[4] and energy conversion, measuring three biomass conversion technologies. A test of the model structure was developed on a Northern California forest landscape comprising approximately 2.7 million acres spanning the crest of the Sierra Nevada range and encompassing the Feather River basin. A Reference Case and Test Scenario were developed to test the structure and accuracy of the model using real-life data from Mt. Lassen Power (an existing biomass conversion plant), public and private forestry operations, and historic wildfire ignition patterns. Wildlife habitat impacts and cumulative watershed effects were also modeled. Results of the Test Scenario show that thinning reduces wildfire size and severity — therefore reducing fire-generated greenhouse gas emissions — while producing renewable energy. With appropriate caveats about data resolution and model sensitivity, impacts to wildlife habitat and watershed appeared minimal. The Biomass to Energy project benefits California by contributing to the state's capacity to analyze forest biomass utilization opportunities at the landscape scale.

Keywords: Biomass, renewable energy, forest biomass, forest thinnings, biomass energy conversion, wildfire, greenhouse gas, life cycle assessment, Northern California, Mt. Lassen Power

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[1] Forest thinnings are the material that is generated during forest thinning operations. Forest thinning is the selective removal of trees from a forest or portion of a forest.

[2] Examples of valued assets include structures, infrastructure, recreation resources, agricultural production, water quality, air quality, and biological diversity.

[3] A life cycle assessment is an evaluation performed to compare the full range of environmental and social impacts assignable to a product or service.

[4] Forest operations are the physical actions which change the forest, altering structure, composition, condition, or value in order to meet society's needs for clean air and water, forest products, wildlife, recreation, and other benefits.

Executive Summary

Introduction

The Biomass to Energy (B2E) project breaks new ground by offering a framework for deciding whether biomass energy generation is a suitable investment for a given forest. This study offers a credible way to establish the relative values of converting forest thinnings into energy, as well as the costs (especially wildfires and air pollution) of not doing so. Such a framework updates the debate about structuring financial incentives that correspond to avoided costs.

Biomass has been used as a source of renewable energy for approximately 50 years and currently generates about 1 percent of California's total power. From an engineering perspective, the technology is not the most efficient way to make electricity. Yet biomass conversion offers a unique paired benefit: a way to recycle forest waste into renewable energy while simultaneously decreasing potential fuel for wildfires.

Modern management practices designed to protect forests (for example, restricting thinning or excessive harvesting) have produced increasingly dense vegetation. In recent years, wildfires occurring in overstocked forests consumed brush and smaller trees (*ladder fuels*), growing into larger, more intense fires involving hundreds to thousands of acres. Such catastrophic wildfires produce more air-polluting emissions and cause more devastation to forests, including wildlife habitat and watersheds, than less intense fires.

The B2E project integrates existing U.S. Forest Service models of fire planning and forest ecology with life cycle assessment models of energy use, emissions, and cost. The life cycle assessment portion of the project assesses environmental impacts associated with treating, disposing of, and using forest biomass and producing electricity or biofuels.

In the short time between beginning this project and completing this Final Report, energy costs have jumped beyond anyone's expectations. The research team has not attempted to update cost/revenue numbers to their present dollar worth, as energy price volatility makes such computation a moving target. All cost and revenue numbers reported in these pages are in 2006 dollars.

Purpose and Project Objectives

The B2E project demonstrates the capabilities of a robust and complex modeling structure using real-world data to identify and analyze costs and benefits associated with removing biomass (thinnings and other waste) from the forest and using it to generate electrical power. Environmental benefits associated with removing biomass from forest ecosystems are quantified by the model, including decreased size and severity of wildfires and reductions in life cycle greenhouse gases and other air pollutants. In addition, this project demonstrates that it is possible to build a set of interconnected and interdisciplinary models to represent quantifiable relationships between economic investment, forest vegetation, and wildfire, on the one hand, and impacts on air quality, energy production, wildlife habitat, and other ecosystem effects on the other.

At the core of this study is a life cycle assessment, which examined approximately 2.7 million contiguous acres of Northern California forest (referred to in this study as the beta landscape.) This beta landscape contains public and private lands located at the northern end of the Sierra Nevada range straddling both the Central Valley (to the west) and the Great Basin (to the east.) Forestry operations and biomass power facilities have been part of the economic fabric of this rural region — including parts of five counties and the Feather River basin — for nearly 30 years. The beta landscape was selected to represent high infrastructure and other asset values, high fire risk, and a broad range of economic, social, and ecological diversity.

A decade is the shortest meaningful period for modeling forest vegetation growth. This study projects data over four decades, beginning in 2006, and accommodates the typical life of a power plant, which is 35-40 years. In each decade, the model measures existing forest inventory and allows for vegetation growth over time. For modeling and analysis, the beta landscape was divided into units called grid cells, each measuring 100 square meters.

For this project, the life cycle assessment models two possible conditions in the beta landscape. First, the Reference Case models only the interaction of vegetation growth and wildfires to establish an ecosystem baseline. To establish the fire model, the research team used historical data. Historically, approximately 65,000 acres within the beta landscape burn over a typical decade. Modeled fires were also burned on the landscape consistent with historic ignition patterns.

This no-treatment Reference Case is compared to a Test Scenario in which a complete menu of forest management treatments such as thinning, clear-cutting, and selective harvesting are modeled. Sawlog and biomass removal occurs during all of these treatments. In the Test Scenario, an average of 492,863 acres per decade receive treatments across the beta landscape. The energy use, emissions, costs, and revenues related to these treatments are quantified.

This B2E study used actual data from the Mount Lassen Power plant in Westwood, California, built around 1980. Mount Lassen Power, which has a long history of continuous operations, receives most of its feedstocks from forest thinning operations within a 30-50 mile radius. Mount Lassen Power provided empirical data representative of operating and maintaining a typical biomass power plant. In addition, a technical working group collected empirical data about equipment used in forest harvest operations from forestry experts. This was used to model fuel and lubricating oil consumption, machine-specific emissions, and productive machine hours.

Most landscape models lack a time dynamic. Such models make a statement about a single event or condition. The reality of forest management at a landscape level is that neither treatments nor fires take place all at once; impacts are distributed over space and time. Also, forests are dynamic systems that change and recover from impacts over time. For this reason, the team explored the need for building a time dimension into the study and concluded that sequential treatments and disturbances should be accommodated.

Developing such a conceptual framework to model landscape level changes over 40 years required a kind of daisy-chaining of various scientific models. For example, vegetation models feed into fuel models, which feed into fire models. Looking at the forest in this way presented major computational and database management challenges. Forest inventory datasets (called tree lists) often reached tens of gigabytes while calculating time-dynamic changes.

The total biomass available for energy conversion is calculated by measuring the amount of vegetation (small trees, branches, brush and litter) removed during a treatment. The next modeling steps include processing, transportation (assuming an average haul distance of 30 miles), and energy production. It should be noted that many biomass plants operating in forests use additional fuels (such as agricultural and urban waste) to achieve economic efficiencies. For this study, the model assumes that only forest waste was used to generate energy.

After treatments are modeled, a reduced level of wildfires occur over the four decades in the Test Scenario, where they are fed by post-treatment fuels conditions. Post-fire treatments (such as salvage operations) are also modeled, as are the growth of treated and untreated forest stands as well as burned stands. The model finally reports on vegetation conditions at the end of each decade resulting from treatments or fires as well as the interactions of treatments and fires in places where the two events overlapped.

Project Outcomes

An initial scenario was built to test the model. This Test Scenario — modeling thinning, transporting, and converting biomass into electrical power — yielded the following results when compared to the no-treatment Reference Case:

- $1.58 billion in power revenues, assuming an 8.3-cent per kilowatt-hour price on the wholesale power market. A negligible amount of fossil fuels (approximately 1.3 percent of total energy consumed) is required to produce this power.
- Clear life cycle climate change benefits, including a 65 percent net reduction in greenhouse gas emissions (from 17 million tons of carbon dioxide (CO2) equivalents to 5.9 million tons of CO2 equivalents.)
- A 22 percent reduction in the number of acres burned by wildfires. Even greater reductions can be anticipated by strategically locating thinning projects in areas of high fire hazard.
- A significant economic gap between the cost of biomass fuel delivered to power plants, estimated at $68 per bone dry ton, and the 2006 financial analysis of greenfield power plant development under which maximum fuel costs would have to be less than $8.20 per bone-dry ton in order to build the project.
- A dramatic drop in fire severity. Again, strategic location of thinning treatments would likely enhance this result.
- Savings of $246 million in avoided wildfire damage to assets, including timber, buildings, and infrastructure, as well as $18 million savings in avoided fire suppression costs.

- A substantial offset of fossil fuel consumed to generate the same amount of electricity over the same period (estimated at a life cycle savings of approximately 120 terawatt-hours.)
- Impacts on habitat suitability over the 40-year period from treatments and fires could not be accurately determined.
- Minimal cumulative watershed effects over the 40-year period.

This final report contains detailed explanations of these findings. Further information, including highly detailed and specific analyses, model specifications and model run results can be found in the appendices.

Conclusions and Recommendations

This study offers insights into potential economic, energy, and environmental trade-offs associated with managing forest biomass. By modeling the effects of biomass removal at the landscape level, this forest-based life cycle assessment provides a credible method of measuring the relative values of converting forest biomass to energy as well as the costs of not doing so. Such a framework can inform the debate about structuring financial incentives that correspond to avoided costs. In addition, this study invites future examination of biomass to energy applications stretching beyond the forest landscape.

Instead, the study supports development of scenarios to demonstrate the interactions of multiple benefits and impacts associated with treatments from which biomass is used for energy production. When quantifying the economics of converting forest waste into renewable energy, the net benefits to the environment extend far beyond energy production, as this study demonstrates.

The vegetation data used in the model were well-suited for estimating wildfire behavior and emissions, the economic value of harvested wood products, and power plant operation and emissions. However, these data were not as well-suited to the characterization of disturbance impacts on habitat. The study's conclusion that treatments have minimal impacts on habitat quality for the nearly 120 habitat types modeled must be viewed with caution and may change with additional research and improvements in habitat modeling.

Cumulative effects on watershed appear to be minimal. Watershed effects are highly localized depending on severity of wildfire. High severity wildfire impacts watersheds more than the impacts associated with treatments. The Test Scenario shows reduced wildfire severity, and therefore reduced soil erosion, as a result of forest thinning.

Some items cannot be modeled, such as social choices that impute value to forest ecosystems. The costs of quantifying and modeling social preferences were found to be beyond the scope and capacity of the B2E project. For example, quantification of "healthy forest conditions" proved elusive and subjective. Further research on this topic would be needed to meet the stringent quantification requirements of the life cycle assessment and economics models used in this study.

Benefits to California

The Biomass-to-Energy project has contributed to California's capacity to analyze forest biomass usage opportunities at the landscape scale. Even in draft form, the Secretary of the United States Department of Agriculture has identified the project as a "highly influential scientific assessment," with implications for how the USDA Forest Service would use life cycle assessment to evaluate the benefits of biomass power.

California has approximately 40 million acres of forest lands, nearly half of which are managed by private landowners. The economics of private forest land management historically have constrained opportunities for effective and sustainable management. The B2E project's approach is likely to assist policy makers and landowners in evaluating comprehensive and long-term benefits to the environment, as well as enhancing economic opportunities in forest-dependent communities.

Realization of the benefits of thinning forests and using the waste products for energy production are largely a matter of public choice and policy making. Many of the benefits of managing California's forests — such as reducing wildfire effects, saving fire suppression costs, providing clean air and water and other climate benefits — may be better reflected in future markets and public policy as a result of this project. Biomass power is a rare form of renewable energy in that it provides a broad range of benefits at relatively low cost to the consumer and substantial ancillary benefits to the environment. Further quantification and analysis, building on the work presented by the project, will help California's policy makers and legislators evaluate how forest biomass will contribute to larger societal and environmental goals.

1.0 Introduction and Background

California's forests represent a significant potential resource for generating biofuels and bioenergy. More recently, policy makers and land managers have begun considering the potential for forested landscapes to substantially alter carbon cycling as a mitigation strategy for greenhouse gas reduction. In addition, most of the state's developed water resources depend heavily on California's forests being maintained in healthy and resilient conditions, especially in the light of probable climate changes over the coming century. In short, forests represent a complex and critical resource, providing a broad array of public and private goods and services (Nechodom et al. 2008).

Nearly 40 million acres, or 40 percent of the state's land area, are covered by some kind of forest (USDA Forest Service 2007). The rich variety of forest ecosystems is almost unequalled in the world, with vegetation types ranging from dense coastal redwood to foothill oak woodland to mid-elevation mixed conifer to high alpine fir. California's Sierra Nevada Range hosts some of the world's most productive temperate forests, growing an impressive range of species from giant sequoia to ponderosa pine and Douglas fir to high-elevation white bark pine.

These forests are prone to wildfire. In fact, fire has been such an integral part of their evolution that foresters refer to them as *fire adapted* forests. In the absence of fire, most Western temperate forest ecosystems become vulnerable to drought, disease and catastrophic[5] wildfires. A management policy of excluding wildfires from forest ecosystems over the past century has contributed to an increasing risk of large-scale wildfires that leave forests in worse shape than after fires that burn under less intense conditions. In sum, some of the forest must burn to be healthy, but high-severity fires over large land areas can leave landscapes and ecosystems in unhealthy conditions for a very long time.

Managing California's forests toward a more stable relationship with fire has become a major focus of forest policy and management over the last several years. How to do this has been controversial. Some would prefer to "let nature take its course," leaving fires to burn largely unabated, protecting only relatively small buffer areas around valuable assets and communities, eventually "resetting" the equilibrium of forested landscapes. Others contend that only intensive forest management over very large areas will create forest structures that will be resilient to fires, allow fire suppression resources to deploy safely around communities, and ensure the long-term sustainability of forests that have been allowed to grow in unsustainable ways. Yet another perspective holds that strategically thinning patches in a pattern across the landscape reduces the rapid spread of intense wildfires, encourages fires to burn undergrowth and to thin trees naturally, and reduces the amount of resources required to manage wildfires in the future.

5. Catastrophic fire refers to stand replacement or high intensity fires that cause damage to ecological and/or economic assets and values. The B2E project also refers to these types of fires as uncharacteristically severe wildfires.

Each of these options has both ecological and economic consequences. Some of these outcomes are quantifiable, while other impacts are more elusive and difficult to measure. For example, the costs of thinning are easily measured by accounting for the expenses associated with moving machinery into the forests, removing trees and brush, and moving products with any value to their respective processing facilities and markets. However, the "costs" associated with impacts to streams, air quality, wildlife habitat or other non-market values are far more difficult to quantify. The "benefits" associated with safer forests, beauty and amenity values, or the social value of sustainably managed forests can be even more elusive.

Nonetheless, society decides how to manage public and private forests based on more than economics and cost, or on the measurable and tradable goods that flow from forest management actions. The values that inhere in forests and their management are a complex bundle of market and non-market, measurable and immeasurable, quantitative and qualitative goods and services. In an ideal universe, we would be able to hold all of these competing values against the same measuring stick, and we would be able to compare them and make choices based on a single metric. This is, of course, simply not possible. There are goods and services in our forests that are highly valued by some – and are often at the center of extreme contention – which cannot be compared to tangible goods and services, or impacts or damages to those goods and services.

In this context, a team of researchers, engineers, and forestry professionals undertook a study, funded by the California Energy Commission, to quantify where possible the multiple costs, benefits, and impacts associated with thinning forests in order to reduce wildfire risks. In addition, since management nearly always produces a flow of products, co-products and waste, the project focused on the potential to produce energy from the non-commercial portion of the wood produced. This product stream, which the project calls *wildland biomass*, or simply *biomass*, is the focus of a life cycle analysis, in which various environmental impacts associated with removal, transportation, processing and conversion of biomass to electricity are compared to the impacts associated with other ways of generating electricity.

The research team also took on another dimension of the problem that has never been modeled before in quite the same way. Could a life cycle assessment be developed to analyze the flow of biomass, energy and costs associated with the production of a healthy forest? To answer this question, two parallel life cycle assessments were attempted, one focused on the impacts, costs, benefits, and co-products associated with the production of electricity, and the other focused on the impacts, costs, benefits, and co-products associated with the production of healthy and sustainable forests. There was a risk inherent in this strategy. Defining the end-product of "electricity delivered to the grid" is fairly straightforward. However, clearly defining the end-product of a "healthy and sustainable forest" is fraught with difficulty. The former can be measured against a simple metric, i.e., megawatt-hours generated. The team attempted to measure the latter in acres that have reached a quantifiable state of "health" (which may be defined differently, based on the management objectives of different landowners) without substantially diminished capacity to maintain qualitatively measured multiple ecological benefits. While not entirely successful, this attempt rendered some very useful quantification and analytical techniques as well as modeling insights.

The team took on this challenge because of the persistent difficulties that face decision makers and stakeholders in managing public and private forests. The team tried to respond to a fairly consistent call for an honest accounting of trade-offs, costs and benefits in managing forests for multiple benefits and outcomes. At the most simple level, the driving question is: Can forests be managed sustainably to produce energy and other products while meeting objectives for maintaining healthy forest conditions (which include reducing wildfire risk and severity) as well as deriving other important forest benefits and values?

To address this question, the team set two *primary* objectives for the project, with three *secondary* objectives.

1.1. Project Objectives

The first primary objective of the research was to produce the structural framework for a life cycle assessment (LCA) approach to identify a range of environmental trade-offs and impacts involved in removal of wildland biomass to produce electricity. A second primary objective was to create and analyze a test scenario, using the LCA developed by the team. A Test Scenario was designed to test the structure of the model, to ensure that logical relationships among processes and sub-models had been established, and to allow sensitivity analyses of key modeling parameters.

Three secondary objectives were required in order to build the modeling platform. Each involved reviews and syntheses of key literature and science. First, the team synthesized scientific knowledge in key environmental areas potentially affected by wildland biomass removal, and evaluated data sources and quality for model development. This step involved a thorough review of the ecological production functions and critical ecological processes that were key to the model, and synthesis of the science about those functions and processes.

The next secondary objective was to investigate, synthesize and report the status of knowledge in environmental and resource economics pertaining to the market and non-market valuation of key indicators to be developed for the model.

Finally, since the model represents an attempt to bring disparate disciplines in the natural sciences and economics into quantified relationships with each other, a number of gaps in research were expected to become far more evident as the model was developed. Therefore a final objective was to identify critical research gaps that would allow further development of the prototype model after the first phase of the project.

2.0 Project Approach

The B2E Project was proposed to the Energy Commission in the context of a growing need to consider environmental effects across large landscapes, an approach that has been manifest in federal land management planning over the past several years. Several notable federal and state regional planning efforts have received tremendous investment and public attention in recent years, including the Northwest Forest Plan, the Sierra Nevada Framework, the Southern California Conservation Plan, the Natural Communities Conservation Plan, the San Diego County Multi-species Habitat Conservation Plan, and the Western Riverside County Habitat Conservation Plan. While many of these plans started out as a means to address one or more threatened or endangered species, in each case both scientific analysis and public pressure have resulted in an increasing focus on multiple ecological and economic processes at different scales. Challenges and appeals to federal planning processes have often focused on the "failure to analyze" landscape level processes that interact with one another to produce unintended consequences.

Federal and state public agencies have begun to put greater emphasis on complex scalar and landscape interactions. Recent discussions to improve National Environmental Policy Act (NEPA) and National Forest Management Act (NFMA) disclosure requirements have focused on how to integrate multiple processes at different scales so that the public can evaluate the impacts and trade-offs of management actions. None of this is simple, and all of it requires dramatic increases in public agency personnel, public and private analytical processes, stakeholder involvement, and complex modeling of ecological and economic impacts.

Because of this increasing emphasis on complexity and scale, the team recognized a need to "push the envelope" and attempt to meet what appears to be more frequent demand for accounting for complex interactions at landscape scales. The team recognized early in its project scoping efforts that the architecture of the final product needed to reflect the actual complexity of public and private land management decision making, taking into account the kinds of fragmented decision processes that often happen on the same landscape, with synthetic consequences for resources and values beyond the technical scope of a particular management decision. Hence, for example, the team modeled patterns of private commercial forestry harvesting alongside the landscape level thinning operations of the Forest Service on national forest lands. And these management patterns were subsequently analyzed in the context of protected and reserved areas that have an effect on the total quality of habitat and watershed resources at the landscape scale.

The research team and the technical advisory committee generally agreed that, while the effort could prove burdensome and fraught with errors and disconnections, it was nonetheless important to attempt to capture complex and highly interrelated ecological and economic processes at a scale that continues to confound land managers and decision makers. Trade-offs at a small watershed scale may be relatively easy to identify, especially when only one or two landowners are involved. But the public cares more about how the entire landscape responds, including impacts on key terrestrial and aquatic species, water quality, air quality and other public goods and services. In this spirit, the team developed a comprehensive forest biomass to energy (B2E) model to achieve the project's primary objective of identifying a range of environmental trade-offs and impacts as well as key cost and benefit relationships associated with managing forests and using the biomass generated from managing those forests to produce electrical energy.

The comprehensive B2E Model is actually comprised of a series of interconnected sub-models, which together identify and analyze economic and environmental costs and benefits of using forest biomass to generate electrical power while meeting an array of landowner forest management objectives at a landscape scale. The sub-models were built to analyze the environmental effects of different forest management strategies conducted over a specified time period through two arenas: the wildland landscape and the biomass power production plant. The landscape and power plant arenas are linked by the transport of biomass material from the wildlands to power plant. The landscape provides the surface for exploring how forest management treatments (which generate biomass material for electricity production) affect vegetation and fire behavior. Landscape-scale changes in vegetation and fire behavior ultimately determine many of the benefits associated with forest-based biomass power (including 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 these benefits.

Three existing biomass power plant technologies and two emerging biomass conversion technologies were analyzed by the engineering and life cycle assessment teams for this project. The results of these analyses have been published by Nechodom et al. (2008), and include very early results from a next-generation thermochemical conversion technology that produces both electricity and ethanol. For the purposes of the LCA portion of this study, three of the technologies specific to electricity generation were analyzed and compared in the LCA model, per the scope of the original Energy Commission contract. The comparison of three biomass-to-electricity technologies allowed the LCA team to reveal differences in efficiencies of electricity production, energy use, and emissions impacts associated with different conversion technologies.

Data for three types of biomass power plants (a current generation combustion plant, a current generation integrated gasification/ combustion plant, and a next generation thermochemical conversion plant) were provided by the LCA and engineering teams. Nameplate and net capacity, efficiencies, and stack emissions are presented below. The emissions are supplemented to include CH_4 and N_2O emissions as described by the U.S. EPA (2003). The use of supporting equipment used at the power plant (i.e., a bulldozer, two loaders, a bobcat, a tub grinder, and a natural gas emergency generator) and ancillary grid electricity use were also included. Although the fuel use and emissions of the supporting equipment were deteriorated over time, based on the U.S. EPA's NONROAD2004 Model, the stack emissions and efficiency were held constant throughout the plant life cycle.

Ultimately, the spatial and temporal analytical methods used in the study required separation of the project's modeling processes into different *domains* in order to conduct discrete modeling and analyses. These domains are listed in Table 1 below and described in detail in subsequent sections of this report. Each of the major domain teams has completed a comprehensive report that describes in detail the modeling approaches and findings within that domain. The domain reports are included here as appendices.

Table 1 - B2E project modeling and analysis domains

Domain	Purpose and Modeling Processes
Vegetation	Determine the amount, area, and structure of vegetation across a landscape over time under different scenarios. Interact with the fire modeling domain to reflect changes in vegetation condition before and after modeled fire events. Use Forest Inventory Analysis (FIA) and other vegetation datasets to establish the initial vegetation condition on the landscape. Then use the Forest Vegetation Simulator (FVS) with the Fire and Fuels Extension (FFE) to model changes in the initial vegetation inventory in each time period (decade) due to forest management treatments and/or fires.
Fire	Use inputs from the vegetation domain for each model decade as the initial inventory and condition. Apply a series of representative ignition points and model representative forest fires and report fire effects (fire size and severity) under treated and untreated scenarios.
Equipment Configuration	Establish forest operation equipment options under each scenario. Design a representative configuration of equipment used for each forest management treatment prescription, and scale the equipment configuration to the size, location and distance of the forest treatment operation, including transportation to the conversion facility (sawmill or biomass power plant).
Life Cycle Assessment	Analyze all energy and material inputs and outputs by unit process, beginning with forest management treatments on the landscape and following all operations to terminate with interconnection with the California power grid. Assess environmental impacts, comparing them with those required to produce an equivalent amount of electricity from natural gas.
Economics	Determine economic values associated with changes in natural resource conditions across the landscape. Analyze costs and revenues of forest management and biomass conversion, and integrate these costs and revenues into market transaction and other measurable costs and benefits at the landscape level over time.
Ecosystem Services	Develop a framework for analyzing the non-market values of ecosystem services associated with forest conditions in the landscape. Specify discrete *ecological endpoints* that could be measured in economic terms to determine total system costs and benefits. (This domain remains incomplete due to cost limitations.)
Wildlife Habitat	Evaluate vegetation conditions and other environmental variables to determine effects of forest management treatments and wildfire on wildlife habitat. Assess impacts of treatments and fire on native biological diversity indicators. Integrate key ecosystem services into the habitat suitability indicators matrix for a comprehensive model of sustainable habitat conditions. Use California Wildlife Habitat Relationships (CWHR) as initial model to determine change; develop improved, empirically driven models for specific species to refine initial modeling assumptions.
Cumulative Watershed	Evaluate effects on soil erosion in aquatic systems due to forest management treatments and fire disturbances. Use the Forest Service's Water Erosion Prediction

Domain	Purpose and Modeling Processes
Effects	Project (WEPP) model, a standardized tool for measuring watershed effects, and integrate the Fuel Management Erosion (FuME) extension to determine specific effects of forest treatments on key watershed indicators. Normalize all impacts to a standardized Equivalent Roaded Acre (ERA), used in the Forest Service's Pacific Southwest Region cumulative watershed effects methodology, to compare projected watershed impacts.

2.1. B2E Modeling Domains and Processes

The following sections describe the analytical processes used in the project domains, with the general sequence of process steps outlined in Table 2 below. While the first four process steps were conducted in a sequential manner, subsequent steps were either iterative, interacting with other process steps, such as vegetation and fire modeling, or initiated separately from other processes once treatment plans were in place (for example, equipment configuration). All of the process steps were connected with other process steps, albeit to varying degrees. For example, the wildlife habitat analysis was inherently connected to the vegetation and fire analyses; however, it was independent of the LCA. Both the LCA and economic analyses relied heavily on pre-processing steps in the other domains to provide input to their respective models. Figure 1 graphically depicts the relationships and data flows between the project's various modeling and analysis domains.

Table 2. Sequence of B2E model analytical processes

Process	Domain	Outputs
Establish landscape analysis area.	General: consultation with team and stakeholders	Geographic area of analysis
Select temporal scope.	General: consultation with team and stakeholders	Time frame of analysis
Determine scenarios to be tested.	General: consultation with team and stakeholders	Hypotheses to test; independent variables; landscape goals and objectives identified
Develop vegetation treatment plans.	Vegetation, in consultation with team and stakeholders	Locations, sizes and types of treatments
Track changes in vegetation resulting from the interactions of treatments, fire, and growth over time.	Vegetation Dynamics	Acres treated by prescription and scenario; amount of vegetation removed by treatment; amount of vegetation removed by fire; amount of vegetation retained on site following treatment, fire, and growth
Analyze wildfire behavior.	Fire Behavior	Representative ignition points (following probability and risk analysis); acres burned by severity class in each decade
Calculate emissions from each	Fire Emissions	Emission factors for each type of

Process	Domain	Outputs
type of burn, i.e. wildfire, underburning, or pile burning.		burning; emission quantities for each decade, scenario and type of burn (severity and type of burn)
Determine equipment used for forest treatment operations.	Equipment Configuration	List of all machinery used, including horsepower ratings, operation hours, distances traveled, personnel required; calculation of *sides*[6] required scaled to treatment areas
Characterize power plants or other biomass conversion technologies.	Life Cycle Assessment	Selected technologies to compare; fossil fuel use and other operational materials; energy use, production and waste heat; emissions
Conduct life cycle assessment of in-forest operations and biomass energy conversion facilities.	Life Cycle Assessment; Equipment Configuration	Energy use; emissions; environmental impacts including contribution to global warming potential (GWP), acidification, and smog production
Assess changes in wildlife habitat over time.	Wildlife Habitat	Impacts to key species (requires selection of species matrix)
Conduct ecosystem services assessment.	Ecosystem Services	Impacts to key ecosystem services and ecological endpoints
Analyze cumulative watershed effects.	Cumulative Watershed Effects	Impacts to soil; soil movement
Analyze economic costs and benefits.	Economics	Damage to assets at risk from wildfire; treatment costs and revenues; power plant costs and revenues; fire suppression and rehabilitation costs (on a per acre basis)

6 Side is a common term used by harvest contractors to denote a separate and distinct blend of harvest equipment conducting harvest activities as a separate operation. This is discussed at length in the Equipment Configuration domain section.

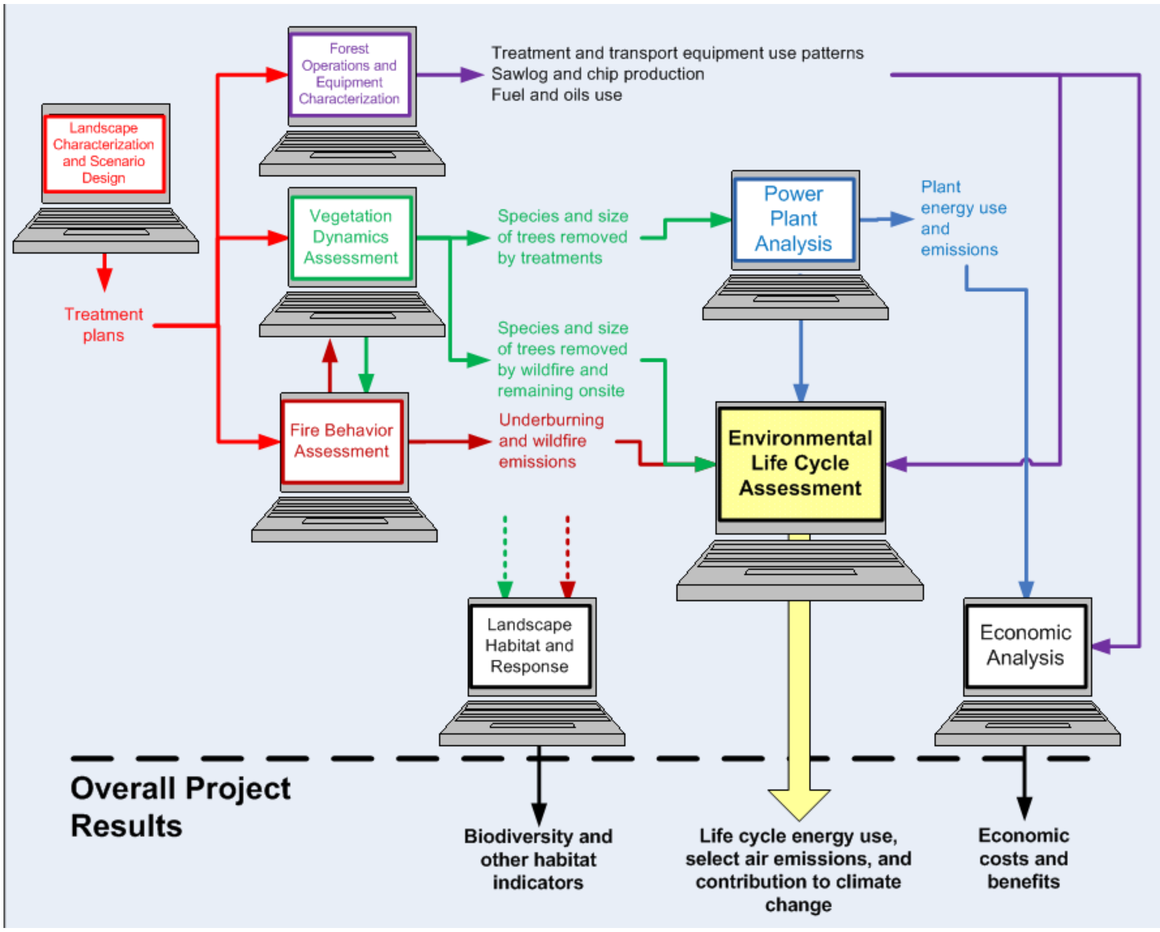

Figure 1. B2E project model

The sections below present the approaches used by each modeling domain. Section 3.0 of this report presents the modeling results in the same logical sequence.

2.2. Selection of Landscape Archetype

In this step, the team worked from an initial Alpha test landscape (1.1 million acres located in the northern Sierra Nevada), expanding to a final landscape archetype, or the Beta landscape, to include more logical regional boundaries. Criteria used to select the Beta landscape archetype included:

- **Hazardous Fuels Conditions:** A significant portion of the landscape has forest conditions that contribute to high risk and hazard for catastrophic wildfire.
- **Ownership Mix:** Given the range of values being measured as a function of changes in resource conditions, the landscape contains multiple ownerships and a range of values.
- **Human Settlement and Capital Assets:** The landscape contains a diversity of infrastructure, structures, and other assets at risk of loss to wildfire.
- **Habitat:** The landscape has a diversity of threatened and endangered species habitats that are at risk of loss from wildfire. (This allows testing the variation in higher-value habitats in the face of disturbance.)

- **Data Quality:** Sufficient data about the attributes to be assessed in each domain exist.
- **Landowner/Agency Interest:** Landowners who have significant data holdings or who are in a position to offer critical review of the data and conclusions regarding the study area are willing to cooperate.
- **Current and Past Management:** The landscape has been actively managed and active management strategies are in place. (This allows testing of the differences between treated and untreated areas. If no management regimes were in place, the project would have to make several broad assumptions about management potential on the landscape.)
- **Geographic Scope and Representative Ecoregion:** The landscape is sufficiently large to capture a diversity of landscape-level ecological processes and to measure changes in ecological endpoints (see ecosystem services model).

2.2.1. The B2E Beta Landscape

The Beta landscape encompasses approximately 2.7 million acres in the northern Sierra Nevada mountain range. The region included parts or all of five counties, a river basin (Feather River) significant for its hydropower resources, as well as other developed water assets, and nearly 180 different vegetation types, ranging from brush and shrub to dense mixed conifer forests. Population in the region was typical of a predominantly rural forested region, and forestry operations and biomass power facilities had been common parts of the economy and landscape for several decades. A growing recreation and amenity industry in the region made it ideal for testing likely changes in value of property, recreation, and other aesthetic changes due to wildfire losses as well as the impacts of fuels treatments.

The study used the following five simplified land ownership categories, stratified in large part by the degree to which lands may be managed to modify wildfire behavior and differences in administrative or policy conditions:

- **Public Multiple Use (PMU):** lands administered and managed by public agencies, specifically the Forest Service (FS) and USDI Bureau of Land Management (BLM). PMU lands do not include areas that are reserved or withdrawn from management (such as wilderness areas, wild and scenic rivers, special management areas, and so forth): such lands are included within the Public Conservation and Recreation category described below.
- **Public Conservation and Recreation (PCR):** lands administered by public agencies that are typically not managed at any significant scale, and therefore assumed to have little or no impacts on wildfire behavior through management.
- **Industrial Private Forests (IPF):** private lands managed primarily for commercial timber production.
- **Non-Industrial Private Forests (NIPF):** private lands managed occasionally for timber values. The project used the California Board of Forestry's definition for NIPF owners:

those who typically own less than 5,000 acres of forest land and do not own a sawmill or other forest products processing facility.

- **Urban and Other (U):** land that is divided into smaller parcels, usually developed with assets, structures or other infrastructure (such as dams, penstocks, landfills, and so forth). These lands are assumed to have little or no management potential in changing wildfire behavior.

Table 3 indicates the distribution of ownerships in the Beta landscape and shows that public lands comprise a significant portion of the landscape.

Table 3. Land ownership categories in the B2E Beta landscape

Land Category	Acres	% of Total
Public Multiple Use	1,374,783	50%
Public Conservation & Recreation	407,776	15%
Industrial Private Forests	457,427	17%
Non Industrial Private Forests	383,008	14%
Urban & Other	112,816	4%
Total	**2,735,809**	**100%**

The 2.7-million acre Beta landscape's location at the northern terminus of the Sierra Nevada Range and its straddling of the Central Valley (to the west) and the Great Basin (to the east) results in representation of a wide range of vegetation types, from hardwood to Jeffrey pine forest types, mixed conifer to pinyon juniper forest types. Table 4 displays the major vegetation types and their respective acreages within the Beta landscape.

Table 4. Major vegetation types in the B2E Beta landscape

Vegetation Type	Acres	% of Total
Alpine	5	nominal
Douglas-fir	4,777	0.2%
Eastside pine	398,401	14.6%
Eastside mixed conifer	579,683	21.2%
Hardwoods (productive)	34,758	1.3%
Hardwoods (non-productive)	67,640	2.5%
Jeffrey pine	10,872	0.4%
Knobcone pine	395	nominal
Lodgepole pine	27,550	1.0%
Westside mixed conifer	519,507	19.0%
Pinion-Juniper	12,209	0.4%
Ponderosa pine	219,552	8.0%
Red fir	101,499	3.7%
Non-forest types	301,392	11.0%
White fir	167,792	6.1%
Shrub types (non-productive)	289,163	10.6%
Total	2,735,195[7]	100%

2.3. Temporal Scope of B2E Modeling Domains

Most landscape models are static. That is, there is no time dynamic in the modeling, which limits the landscape model to statements about a single event or condition. The team explored the need for building a time dimension into the study, and concluded that sequential treatments and disturbances should be accommodated. The reality of forest management at a landscape scale is that neither treatments nor fires take place all at once. Compressing treatments or fire events spatially and temporally onto a landscape renders a distorted view of impacts that are in fact distributed over space and time. This distribution is meaningful in dynamic systems that recover and change over time.

The team analyzed the computational challenges of modeling vegetation changes over time, including the addition of fire and treatment events. In each decade (which is the shortest meaningful time period for modeling forest vegetation growth), the model would need to measure existing forest conditions (forest inventory); apply treatments across the landscape, providing post-treatment fuels conditions for fire modeling; then apply wildfires across the

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7 The slight difference in acreage (614 ac.) between the ownership and vegetation classification, in Tables 3 and 4, is due to the methods used to measure vegetation types. Ownership is drawn from actual polygons while vegetation types are measured in 100 square meter grid cells, and a grid cell is counted under a classification only when a majority of the cell is occupied by the vegetation type.

landscape; apply post-fire treatments, under specified conditions; allow for the growth of treated and untreated forest stands as well as burned stands; and finally report on the vegetation conditions at the end of the decade that resulted from treatments and fires alone as well as the interactions of treatments and fires in places where the two events overlapped. For the Beta landscape, a typical scenario resulted in treating approximately 300,000 acres per decade and burning approximately 65,000 acres per decade, across hundreds of discrete polygons, presenting major computational and data management challenges. Forest inventory datasets (called *tree lists*) often reached tens of gigabytes while calculating time-dynamic changes.

Given these computational challenges, the team determined that a 40-year time frame – or four decadal modeling periods – was an appropriate time scale for the B2E Model to show statistically meaningful variation. In addition, this timeframe fits well with the economics that drive timber harvest (scheduled treatments are typically conducted at 20-year intervals) as well as the life cycle of the technology being evaluated (biomass conversion plants typically have a 30 to 40 year life cycle before replacement).

2.4. B2E Scenario Development

Landscape scenarios were developed to test key parameters, assumptions, and ecosystem effects. The key independent variables that could be manipulated to change outcomes and effects were primarily related to the forest management treatments: their size, spatial distribution, and intensity or type of treatment. Secondary independent variables included power plant technology and location. Dependent variables included the kinds of equipment and their configuration chosen to accomplish the treatments; economic values associated with changes in treatment and fire; and other environmental indicators of habitat, watershed, and carbon storage conditions.

The team developed a Reference Case (which modeled no vegetation treatments) and a Test Scenario (which modeled vegetation management regimes on public multiple use (PMU), industrial private (IPF) and non-industrial private (NIPF) forest lands). Table 5 below shows the basic structure and logic of the scenarios used to test the B2E Model.

Table 5. B2E Beta model scenarios

Scenario	Assumptions related to Wildland Fires and Forest Management Treatments	Average acres per decade treated
Reference Case	Baseline wildland fires burn; No treatments.	IPF/NIPF: 0 PMU: 0 Total: 0
Test Scenario (IPF, NIPF and PMU)	Baseline wildland fires burn; Treatments on IPF, NIPF, and PMU lands.	IPF and NIPF lands: 313,416 PMU lands: 179,447 Total: 492,863

The total number of acres treated does not reflect the variation in types, sizes or locations of treatments. These are described in greater detail in the section below on vegetation treatments. It is also important to emphasize that the Reference Case is technically *not a scenario*, but a hypothetical baseline case that allows comparisons with actual management scenarios.

Scenario development is importantly a collaborative process. The team used wide experience and previous analyses to develop the Test Scenario. The main purpose of the Test Scenario was to test the functioning of the B2E Model, particularly the linkages between the series of the Model's interconnected domains. However, it was clear to the team that scenarios are deeply embedded in social and policy preferences. Additional scenarios would need to engage stakeholders or specific clients in extensive discussions about landscape level goals and objectives before designs for size, type, and location of treatments could be developed.

2.5. Vegetation Treatments

As depicted in Figure 1, all of the B2E Project's models require inputs related to assumptions about vegetation treatments. For the Test Scenario, the team used experience and previous analyses to spatially arrange different types of treatments across the Beta landscape over the 40-year time period. Under future model applications, each scenario must have a clearly-defined set of assumptions relative to treatment area designs for each land ownership category and site condition (for example, slope steepness and proximity to streams). The final treatment plan for each scenario should consist of a map displaying the location of each treatment area and a crosswalk assigning a treatment prescription (a series of discrete treatment activities applied over a specified timeframe to a specific piece of ground) to each treatment area. Hence, the key steps in formulating forest treatment plans include: (a) spatially locating treatment areas across the landscape and (b) applying a series of treatment activities over time (i.e. a treatment prescription) to each treatment area.

2.5.1. Locating Treatment Areas and Assigning Forest Management Regimes

Each treatment area's size, location, and forest management regime in the Beta landscape was determined based on land ownership category. On IPF lands, treatments were designed to meet California Forest Practices Act requirements, and the modeled treatments were developed through a collaborative effort involving scientists, forestry professionals, and the team (see the B2E Project Forest Operations and Equipment Configuration Report, Appendix 3). IPF management regimes were based on a roughly evenly distributed representation of the kinds of commercial operations typically found in California. Of the approximately four million acres of commercial forest lands in California, and among the half-dozen or so major commercial operators in fire-prone forested areas, treatment prescriptions range from clear-cutting to selective harvest. In each commercial forestry operation, throughout the cycle of growing trees to maturity and harvest, thinning operations are typically used to enhance growth and reduce impacts from fire, insects, and disease. These are referred to as pre-commercial thinning and commercial thinning, the former removing smaller stems to reduce competition and enhance the growth, and the latter removing merchantable sawlogs to further enhance the growth of the remaining trees.

Similarly, non-industrial private NIPF lands are modeled under different management objectives than many of the IPF lands. Therefore a set of prescriptions must be developed that reflect the average common practices of smaller, non-industrial land management regimes. For the Test Scenario, the team assumed that these lands would be treated using selective harvests intended to continually maintain trees on site, thereby conserving future options, either for timber production or other purposes.

To locate treatments on national forest lands (which comprised most of the PMU lands in the Beta landscape), the team needed an approach that could be used to validate the modeling assumptions and verify the modeling results. Toward this end, the team relied on existing management direction from the *Sierra Nevada Forest Plan Amendment Record of Decision* (USDA Forest Service 2004), which the national forests in the Beta landscape (Plumas, Lassen, and Tahoe National Forests) are currently following to design fuels treatments. Hence, treatment area locations on national forest lands in the Beta landscape were based on a combination of defensible fuels profile zones (DFPZs), or shaded fuelbreaks, and strategically placed area treatments (SPLATs). While these two specific treatment designs were used for the Beta test, the B2E Model is designed to accommodate and test an endless array of prescriptions for management regimes and different treatment designs.

DFPZs were generally located along ridge tops and roads: these are areas where firefighters would make a stand to contain a wildland fire. A DFPZ's width is determined by potential fire behavior based on available fuels, weather, and topography. DFPZs are not designed to stop an oncoming fire, but rather to provide a safe location to facilitate fire suppression efforts. The DFPZs on the Beta landscape were located as mapped for the *Final Environmental Impact Statement for the Herger-Feinstein Quincy Library Group Forest Recovery Act Pilot Project* (USDA Forest Service 1999).

The SPLATs were located using a conceptual herringbone pattern of area treatments distributed across the Beta landscape, based on the premise that disconnected fuel treatment areas overlapping across the general direction of fire spread are theoretically effective in changing fire spread (Finney 2001). For purposes of modeling, each SPLAT was a 150-acre rectangle, oriented according to the prevailing wind direction in order to intercept a spreading fire. The Beta landscape's highly-stylized herringbone pattern of treatment areas was designed to statistically mimic what is often referred to as "the Finney Effect." The pattern has been used as a starting point for landscape-level fuels reduction planning on national forest lands in California. This pattern of treatments starts with the assumption that forest thinning treatments on approximately 30% of the total land area in a given landscape can have a "speed bump" effect by interrupting and slowing the spread of an oncoming wildland fire, ultimately resulting in smaller wildland fires with less severe effects. As the planning process proceeds, more detailed analyses of actual fuel characteristics and likely wildfire behavior allows planners and stakeholders to work collaboratively to adjust the size, location, shape and treatment prescriptions among SPLATS. The full planning process, which the Forest Service refers to as its *Stewardship and Fireshed Assessment* (SFA) process, involves several hundred person-hours of preparatory work, including a series of planning meetings for agency and public stakeholders, before the final pattern and timing of treatments is ready to be applied. The final step for the

Forest Service involves following National Environmental Policy Act (NEPA) environmental analysis before the SPLAT strategy can be implemented. It is a labor- and data-intensive process, resulting ultimately in a highly-refined, landscape-level plan for modifying the behavior, and hence the effects, of large wildland fires, balanced with other values and concerns.

The B2E project did not engage the complete SFA process as used by the Forest Service, largely due to time and resource constraints, but also because the purpose of this study was a more comprehensive landscape analysis, well beyond the boundaries of a national forest. The research team, working with the SFA cadre, did however use most of the modeling approaches used in the SFA process (described in other parts of this "Approach" section), in which vegetation and fire modeling are used to assess likely fire behaviors and outcomes on a landscape.

Approximately 30% of the PMU lands in the Beta landscape were overlaid by SPLATs; the remaining 70% of PMU lands were not assigned treatments over the 40-year time period. This should be kept in mind as further scenario development is considered in later phases of the study or uses of the model. For example, a slight increase in extent or intensivity of management on PMU lands could result in substantial increases in biomass produced, emissions avoided, electricity produced, etc.

2.5.2 Sequencing Treatment Activities over Time

As described above, types of treatment activities on lands in the Beta landscape ranged from thinning, selective harvest, and clearcut harvest on private lands to thinning on national forest lands. Regardless of ownership or type of treatment activity, all treatments were assumed to be followed by prescribed burning (broadcast burning, understory burning, or slash pile burning) to remove the *slash* (woody residues that are generated in the forest from harvesting activities).

It is important to emphasize the distinction between treatment prescriptions and activities in the modeling. *Treatment activities* are discrete management actions or events, such as thinning or understory burning. A *treatment prescription* is a series of management activities applied over the 40-year timeframe to a specific piece of ground. Hence, each treatment area was assigned a prescription sequence consisting of a series of treatment activities for each 10-year time period. In certain time periods, no treatments were assigned and the growth of the vegetation was simply tracked. For example, a regeneration prescription on IPF land would assign an even-aged harvest (clearcut) on a 20-acre treatment area in the first decade (2006), followed by pre-commercial thinning in the second period (2016), and then a commercial thinning 20 years later (2036). The entire 40-year series of management activities is captured in specific coding in the B2E model databases (see the B2E Project Vegetation Dynamics Domain Report, Appendix 1).

2.6. Vegetation Dynamics Modeling

The vegetation domain tracked changes in vegetation and fuels resulting from modeled growth, vegetation management treatments, and fire across the Beta landscape over the 40-year period. The vegetation domain was closely integrated with the Project's fire domain: the condition of the vegetation and surface fuels (combined with topological and weather variables) was used to model fire behavior (as described in the following section), with the resulting fire effects subsequently fed back and used to modify the vegetation.

The analysis assumed a dynamic landscape where vegetation was constantly undergoing change through the processes of growth, treatment, and wildland fire. The vegetation domain spatially tracked these vegetation changes at multiple scales (from a per-acre scale to an entire landscape scale) over time. The outputs from this domain supplied the raw data used by the B2E Project's other domains, which explored how these landscape-scale vegetation changes ultimately affected wildland fire behavior, electricity production, habitat conditions, emissions, carbon cycling, hydrologic conditions, economics, and ecosystem services.

Geographic Information System (GIS) spatial layers for vegetation, ownership, elevation, and slope in the beta landscape provided the foundation for the vegetation domain. This GIS coverage overlaid the entire landscape with 100-meter grid cells, with each cell assigned to a specific vegetation, ownership, elevation, and slope class.

2.6.1. Initial Vegetation Inventory

The starting point for vegetation modeling was the vegetation inventory, which described the existing condition of the vegetation across the Beta landscape in 2006. Over time, this inventory was modified by modeled growth, treatments, and wildland fire. The initial (2006) vegetation inventory consisted of two components: (1) a vegetation map and (2) Forest Inventory Analysis (FIA) plot data (which describe numbers of trees by species and size class) linked to the vegetation polygons delineated on the vegetation map.

The Forest Service periodically collects vegetation inventory data (known as Forest Inventory Analysis (FIA) data) for national forest lands as well as non-national forest lands. FIA data are gathered over a series of plots located across lands within the Beta landscape. The FIA plot data consist of (a) site reference information (plot location, inventory date, slope, aspect, elevation) and (b) the characteristics of each tree sampled (species, size, canopy position, and so forth, collectively referred to as the tree list for each sample plot). The Forest Service Pacific Southwest Region's Remote Sensing Laboratory provided the FIA data for the Beta landscape.

The vegetation domain team linked the FIA plot data to the vegetation map to provide for statistically valid estimates of vegetation change. Vegetation strata labels served as the bridge between the mapped vegetation polygons and the FIA plot data. A strata label can be thought of as each mapped vegetation polygon's address: the strata label is based on the polygon's vegetation type, tree size, and canopy cover in 2006. Each FIA plot was assigned to a specific vegetation stratum, thereby making it possible to aggregate the tree lists from all the plots assigned to that vegetation stratum. Hence, the vegetation inventory for a particular stratum was represented by an aggregated tree list, which was comprised of the individual tree lists from each of its plots added together. Embedded within each mapped vegetation polygon was a set of 100 square meter grid cells. Every grid cell with that stratum label address started through the vegetation modeling with the same aggregated tree list. Over time, treatment, wildland fire, and growth changed each cell's tree list, depending on the prescription sequence assigned to it.

2.6.2. Modeling the Effects of Forest Treatments on Vegetation

As previously described, management prescriptions were comprised of a series of discrete treatment activities applied over the 40-year beta-test timeframe to a specific grid cell. Hence, each grid cell had a prescription sequence consisting of a series of treatment activities assigned by time period. The strata label served as each grid cell's address while the prescription sequence described the treatment activities that occurred at that address over time (for example, thinning followed-up by underburning in the first decade, no treatment in the second decade, a second thinning in the third decade, and no treatment in the fourth decade).

Sawlog and Biomass Material Removed. For each treatment activity, the vegetation dynamics domain team developed specifications for removing trees from the tree lists. (As previously described, the tree lists were linked to the strata labels (addresses) assigned to each grid cell.) These specifications determined the quantities of sawlogs and biomass material removed from the treated stands.

Residual Stand Conditions following Treatments. The specifications for removing trees from the tree lists had a direct impact on residual stand conditions. For example, specifications for pre-commercial thinning were to remove trees from the tree list such that approximately 225 trees per acre were retained following treatment. The specifications also included favoring retention of commercial conifer species, in other words, targeting non-commercial conifers and other tree species for removal from the tree list. The specifications developed for the Beta test are but a small sample of the possible specifications that could be developed in further scenario testing: the B2E Model was designed to accommodate any possible specifications for removing trees from the tree lists (as well as adding seedlings).

2.6.3. Modeling the Effects of Wildland Fires on Vegetation

The fire domain team modeled wildfire behavior and resulting severity as described in the next section. The vegetation domain team then used the fire severity data for each decade to determine the numbers of trees killed and the amount of biomass consumed by fire. The vegetation team used the First Order Fire Effects Model (FOFEM) (Reinhardt and Keane 2003) to estimate tree mortality (in other words, which trees to remove from the tree lists) based on flame lengths associated with different fire severity classes (described in the fire behavior section below). FOFEM predicts fire-caused tree mortality using bark thickness (based on tree species and diameter) and crown volume scorched (based on scorch height, tree height, and canopy base height).

In addition to estimating trees killed and trees consumed by wildfire, the vegetation team also used the wildfire severity data (combined with ownership classification and management regime) to adjust the prescription sequence for treatment areas that burned in wildfire during any of the four time periods. For example, a cell with an initial prescription sequence of thinnings applied in the first and third decades that intersected with a lethal fire in the third decade would have the following prescription sequence assigned: (1) thinning followed-up by underburning in the first decade, (2) no treatment in the second decade, (3) a lethal fire followed by salvage and tree planting in the third decade, and (4) pre-commercial thinning in the fourth decade).

2.6.4. Modeling Vegetation Growth

Vegetation growth was modeled on all grid cells in each decade. To account for growth, the vegetation domain team used the Forest Vegetation Simulator (FVS) Model (Stage 1973), a computer program used to project the development of forest stands. FVS is an individual-tree, distance-independent growth and yield model. It has its structural roots in the Stand Prognosis Model developed by Albert Stage from the Intermountain Research Station. Staff at the Forest Service's Forest Management Service Center in Fort Collins have calibrated many variants of the model to specific geographic areas throughout the United States. For the Beta landscape, growth equations were derived directly from the Inland California Southern Cascades (ICASCA) variant of FVS.

In any given decade, it was possible for a single grid cell to be assigned a treatment, wildfire disturbance (with effects on the vegetation), and subsequent salvage harvest. In these instances, the following sequence of activities (and effects on the vegetation inventory) was tracked in order: treatment, wildfire, and salvage, all of which were assumed to occur in the first year of the decade. Vegetation growth for the grid cell was then modeled for the remainder of the decade.

2.7. Wildfire Behavior and Severity

This section briefly describes how the team modeled the interaction between wildfire and vegetation under treated and untreated conditions. While Table 2 above separates these steps to clarify the overall project's sequencing of processes, in fact the vegetation dynamics and wildfire behavior domains interacted iteratively to produce the final results for vegetation change for the 40-year span of the study.

Wildfire modeling is a complex process, and models are difficult to calibrate. When scientists model wildfire, they are usually modeling what is called *fire line intensity*. That is, rather than modeling the behavior of an entire fire, with all its complex dynamics and internal weather patterns, most fire models attempt to mimic the behavior of flames at the perimeter of the fire as it moves through vegetation. Two major forms of data are used to model fire line intensity: vegetation and weather. The vegetation data tells the model about the structure and condition of fuels that are being burned. The weather data fundamentally tells the model about the amount of oxygen available by applying models of wind behavior and moisture in the air. Between these two factors, scientists are able to predict how high the flames will get (flame length); whether the flames will reach into the crowns of the trees (active or passive crowning), thereby increasing the speed at which the fire will spread; and the number of trees of a particular size that will be killed by the fire (fire severity).

Locating the places where modeled wildland fires would start (ignition points) presented the team with a fundamental challenge. Since the team determined that the B2E modeling effort would be spatially explicit where possible, the locations of wildfire ignition points had to be specified. The fire domain team ran a randomized ignition experiment across the entire landscape, using risk ratings for ignitions and fuel hazard ratings for vegetation fuel conditions (Figure 2).

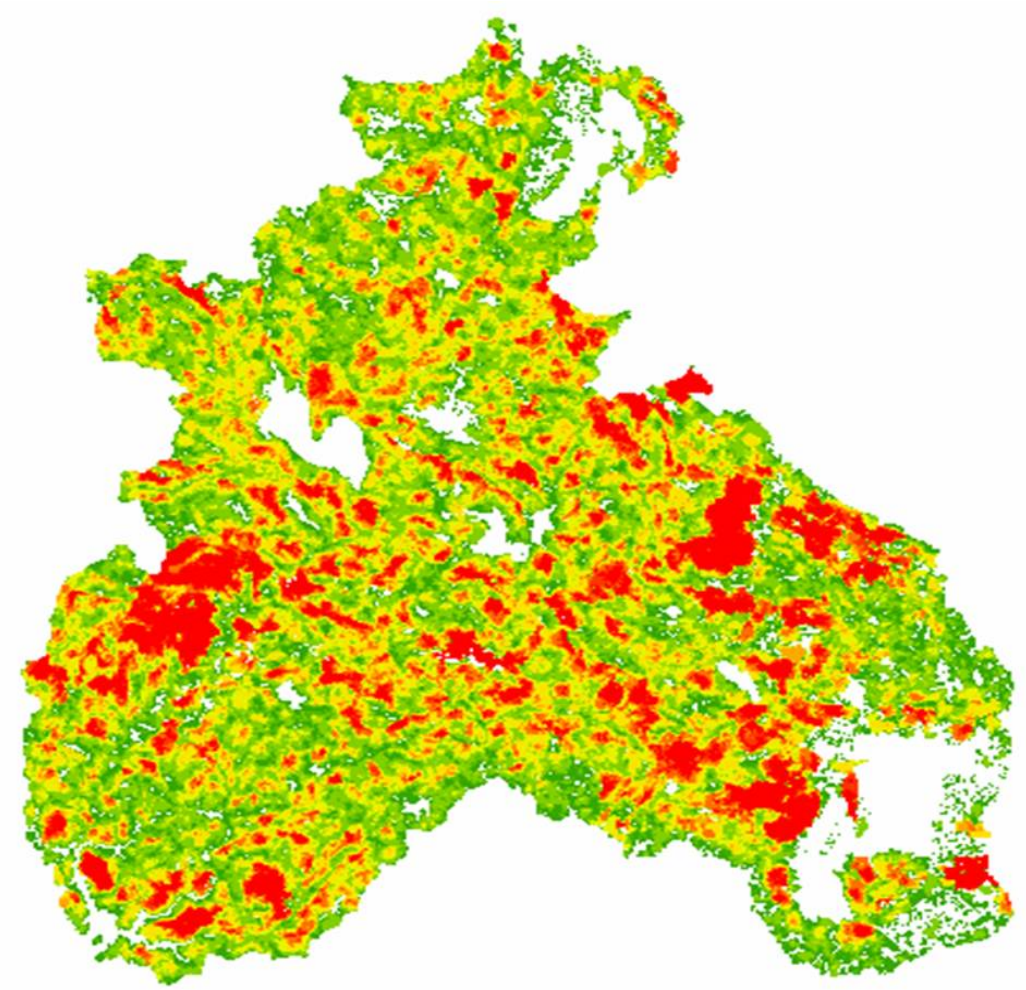

Figure 2. Randomized ignition locations to locate most logical representative ignition points on the B2E Beta landscape.

The randomized ignition map was compared with maps of historical ignition locations from 60 years of fire history. This mapping exercise allowed the team to select discrete ignition points at locations across the Beta landscape, recognizing that demographics, human activities, and climatic conditions would vary with time (Figure 3).

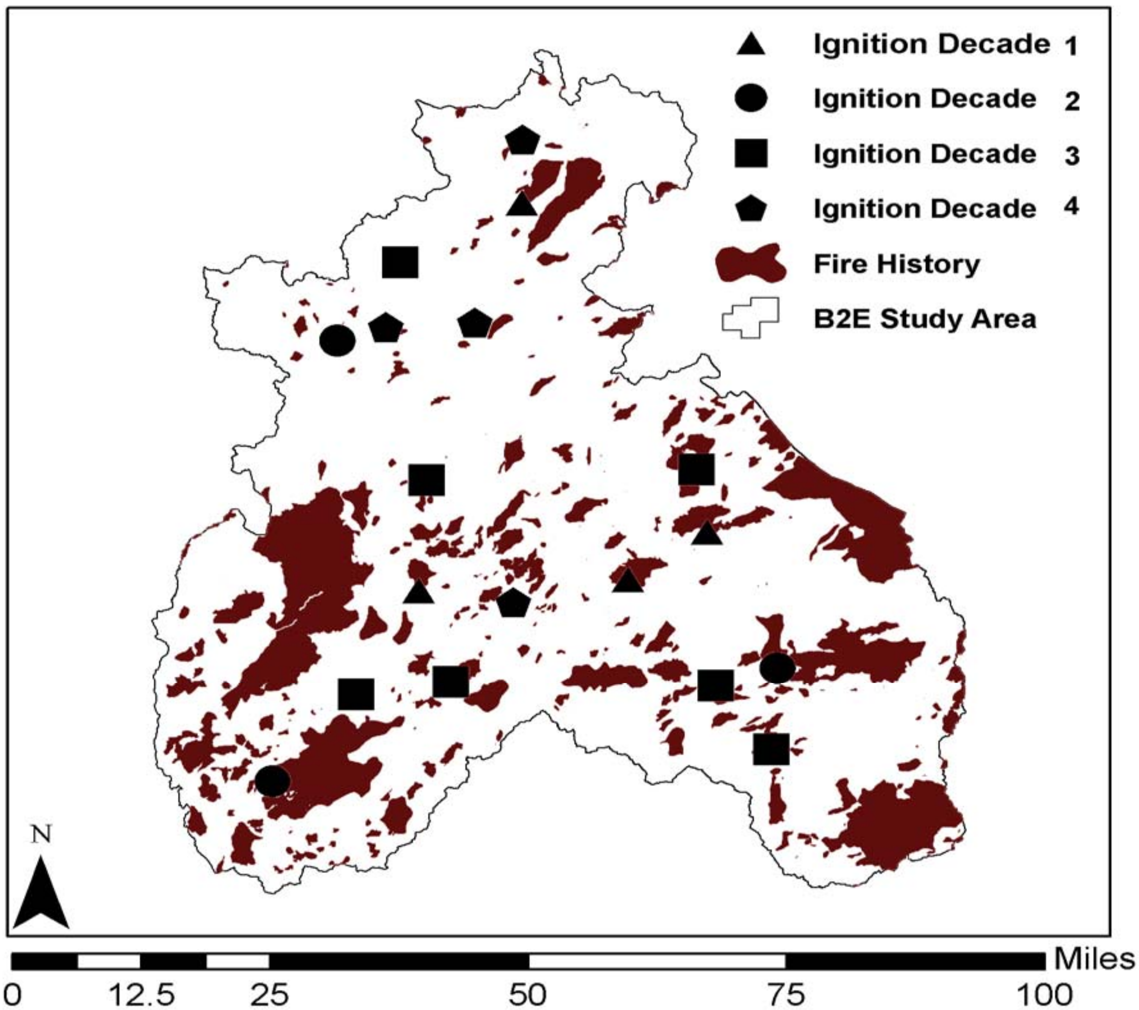

Figure 3. B2E Beta landscape fire history and ignition placement by modeled decade

After the representative ignition points were selected, the wildfire modeling team used the vegetation GIS layers provided by the vegetation dynamics domain team for each decade within the Reference Case and Test Scenario, as inputs to the wildfire model. The wildfire modeling team then tested for change in wildfire severity and the number of acres burned through each decade for the Reference Case and Test Scenario. Modeling outputs included the number of acres burned in three classes of fire severity (lethal, mixed-lethal, and non-lethal fire effects).

Fire behavior was summarized into three classes of severity to distinguish and report changes in wildfire effects across the Beta landscape (Figure 4). Burned areas were classified based on spatially explicit FlamMap Model (Finney, Britten et al. 2006) results of fireline intensity and the crowning behavior of the fires. The severity of wildfire burned on each 100 meter^2 grid cell was assigned to one of three classes (non-lethal, mixed lethal, or lethal effects) depending on its flame length and fire type (ground fire, passive crowning fire, or active crowning fire).

Fire severity was used to determine the numbers of trees killed and the amount of biomass consumed by fire, and these effects were tracked in the vegetation assessment domain. Simulations were performed on a 10-year temporal sequence for 40 years with a series of fires taking place immediately at the beginning of each decade in each management scenario. Note that if a particular grid cell was treated and burned in the same decade, the treatment effects on vegetation were assumed prior to wildfire being modeled on that grid cell. Both treatment and fire (and, in specific instances, salvage) were assumed to occur in the first year of the decade with growth of the modified vegetation modeled for the remaining years of the decade.

Fire Severity Classes		Fire Type (Crown Fire Activity)		
		Ground	Passive Crowning	Active Crowning
Flame Length (feet)	0.00-3.99	N	X	L
	4.00-7.99	X	X	L
	8.00-11.99	X	L	L
	12.00+	L	L	L

Figure 4. Classes of fire severity used in B2E fire modeling: (N) = non-lethal, (X) = mixed lethal, (L) = lethal

The interaction of vegetation and fire is a critical component of any landscape level analysis. In the B2E Project, these two domains constituted the core from which all further modeling domains operated. Once the spatial and temporal scope had been selected and the interaction of vegetation, treatments and wildfire had been modeled, the team was ready to investigate secondary or "downstream" activities. The following sections contribute to analysis of the impacts and effects that follow from the interactions of vegetation and wildfire on a landscape level.

2.8. Fire Emissions Model

After modeling interactions of vegetation and fire on the landscape, the fire emissions domain team was able to characterize emissions from three types of fire: wildfire, underburning, and pile burning. Wildfire burning has been described in detail above. The other two classes of fire are built into the treatment prescriptions analyzed by the vegetation domain team. Under most prescriptions, biomass that is too costly to collect and process is generally piled and burned at the treatment site. Useable biomass was assumed to be removed to the power plant. The vegetation domain report describes each prescription in detail while the equipment configuration domain report describes equipment used to pile slash and burn the piles.

Underburning, the final of the three classes of fire modeled, is used as a treatment follow-up procedure, and was included in the "package" for each treatment prescription, where appropriate. Typically follow-up underburning is conducted within the first one to three years after a treatment is implemented. Since the B2E model has compressed all treatments and fire events to the beginning of each decade for computational efficiency, underburning was assumed to be part of the treatment.

The starting point for calculating fire emissions was determining the amount of woody material the fire (either wildfire or prescribed fire) consumed. Once the amount of material consumed by fire was determined, the corresponding emissions were calculated using vetted relationships between types of forest fuels combustion and corresponding emissions, typically referred to as emission factors.

2.8.1. Fuel Consumption

Wildfire. The vegetation domain team supplied data on amounts of vegetation consumed by wildfire in each decade, based on the CONSUME Model (Ottmar et al. 2001). The CONSUME Model calculates the amount of woody material (in the form of duff, litter, twigs, and foliage) that would be consumed during a low intensity fire (approximating the level of consumption expected in a prescribed underburn). Hence, several adjustments were needed to account for (1) the range of possible wildfire severities, from non-lethal to lethal fires and (2) the full range of vegetation types (including tree stems as well as brush and grass) that could be consumed by modeled wildfires in the Beta landscape.

CONSUME Model vegetation consumption data supplied by the vegetation dynamics domain team was used for all areas affected by modeled non-lethal wildfire. To account for consumption during mixed lethal and lethal fire events, consumption multiplier factors (Table 6) were applied to the vegetation domain consumption data, based on consumption efficiencies measured from actual crown fires in similar forest types (Environment Canada 2007, Taylor and Sherman 1996).

Table 6. CONSUME Multiplier Factors (MFs) for non-lethal, mixed lethal, and lethal fires.

	Fire Severity		
	Non-Lethal	Mixed Lethal	Lethal
Multiplier Factor (MF)	1	1.8285	2.657

The vegetation domain data do not include inventory or consumption values for the grass vegetation type (strata code UGR) or the brush/shrub vegetation type (strata code ZBR) because there are no growth models for these vegetation types in the Forest Vegetation Simulator (FVS). In addition, the vegetation domain's consumption data do not include consumption values for the boles of the trees. The fire emissions domain team applied the following assumptions to first calculate the inventory of grass and shrub types (in bone dry tons, BDTs) (Table 7) and then to calculate wildfire consumption of tree stems and fire events in the grass and brush vegetation types (Table 8).

Table 7. Inventory assumptions for the brush and grass vegetation types

Strata Label	Vegetation Type	Amount of Vegetation (BDT/Acre)
UGR	Grass	4
ZBR	Brush/Shrub	12

Table 8. Combustion efficiencies (combustion factors, CF) for various vegetative components by fire severity class

	Fire Severity		
	Non-lethal	Mixed Lethal	Lethal
Tree Stems	0.02	0.02	0.02
Brush	0.3	0.6	1
Grass	1	1	1

Piling and Burning, Underburning. As previously described, smaller woody material that is left on site following tree removal operations is treated either through piling and burning the material (typically on flat terrain or gentle slopes where mechanized equipment can be used to pile the material) or underburning. The vegetation domain supplied information on the quantities of this material that would be consumed in prescribed fire treatments as follows: small woody material between 0 and 3 inches diameter (reported in cubic feet, converted into BDTs); tops and limbs of all trees removed (BDTs); and brush (BDTs) remaining in treated stands.

2.8.2. Calculating Fire Emissions

Once the quantities of material consumed by fire were determined, the emissions associated with the amount of material burned under specified burning conditions were calculated using emission factors. *Emission factors* (EF) are defined as "the mass of pollutant produced per mass of fuel consumed" (Ottmar 2001). EFs for each of the three fire severities (non-lethal, mixed lethal, and lethal) were provided by the Western Regional Air Partnership (WRAP) Program's Fire Emissions Joint Forum (FEJF) and the Inter-RPO National Wildfire Emission Inventory Project (Air Sciences Inc. 2005; WRAP-FEJF 2006; Randall 2006; Adelman 2004; EPA 2002). The EFs are the result of collaborative research between WRAP and the FEJF, and rely on a point source approach to represent wildland fires, their combustion and emissions within typical western forest types.

Determining the appropriate EF for a particular type of burn first required identification of each burned grid cell's applicable NFDRS (National Fire Danger Rating System) Fuel Model. NFDRS Fuel Models are typically linked to vegetation strata labels. Since the strata labels in the B2E vegetation modeling process served as each grid cell's "permanent address," they did not change from one time period to another. Hence, the emissions domain team used an alternative approach to accommodate changes in the vegetation over time (i.e. succession and growth between time periods). The team constructed a crosswalk based upon expert opinion of both systems (Table 9). This crosswalk links emission factors developed for the NFDRS fuel models (applicable to California vegetation types) to California Wildlife Habitat Relationships (CWHR) types across the Beta landscape. Hence, each CWHR type was linked to a specific NFDRS Fuel Model[8], as shown in Table 9 below.

The first step in developing the crosswalk was to disregard NFDRS fuel models not applicable to California vegetation communities. For example, Fuel Model N was eliminated from consideration because it was constructed specifically for the sawgrass prairies of south Florida. Then the expert reviewed the text accounts and available habitat stages for each CWHR habitat type (California Department of Fish and Game 2002). For each possible CWHR habitat and habitat stage, the NFDRS fuel model that most closely portrayed the typical fuels conditions present in the given habitat and stage was identified. This determination was made through information presented in the CWHR habitat text accounts, and expert knowledge of the various habitats. In some cases, assigning a fuel model code to a given CWHR habitat and stage was difficult due to the relatively few number of models, and the inability of any model to accurately describe the vegetative conditions present in the given habitat and stage. In these cases, expert knowledge was used to select the fuel model that most closely approximated the fuel conditions (rather than vegetative conditions) that would be present within the habitat type and stage.

8 http://www.fs.fed.us/fire/planning/nist/nfdr.htm

Table 9. Example Crosswalk between NFRDS Codes and CWHR Types (partial table)

NFDRS Fuel Model[4]	Vegetation Type	CWHR Vegetation Type	CWHR Tree Size and Canopy Cover	CWHR Tree Size and Canopy Cover
L	Ponderosa Pine	P	1S	Seedling, sparse cover
F	Ponderosa pine	P	2D	Sapling, dense cover
L	Ponderosa pine	P	2M	Sapling, moderate cover
L	Ponderosa pine	P	2P	Sapling, open cover
L	Ponderosa pine	P	2S	Sapling, sparse cover
U	Ponderosa pine	P	3D	Pole-sized tree, dense cover
C	Ponderosa pine	P	3M	Pole-sized tree, moderate cover
F	Ponderosa pine	P	3P	Pole-sized tree, open cover
U	Ponderosa pine	P	4D	Small tree, dense cover
C	Ponderosa pine	P	4M	Small tree, moderate cover
C	Ponderosa pine	P	4P	Small tree, open cover
C	Ponderosa pine	P	4S	Small tree, sparse cover
U	Ponderosa pine	P	5D	Med./large tree, dense cover
C	Ponderosa pine	P	5M	Med./large tree, moderate cover
C	Ponderosa pine	P	5P	Med./large tree, open cover
C	Ponderosa pine	P	5S	Med./large tree, sparse cover
U	Ponderosa pine	P	6	Multilayered canopy, dense cover

Using the NFDRS Code (crosswalked from CWHR type) and the moisture condition for lethal, mixed lethal, or non-lethal fire, the WRAP Emissions Factor Table (Table 10) provided the applicable emissions factors. For all wildfires, a moisture condition of dry was assumed. For underburning a moisture condition of moist was assumed and for pile burning, wet conditions were assumed.

Table 10. Example WRAP Emission Factors (abbreviated and partial table)

NFDRS Code	Moisture Condition (MC)	NFDRS Code, MC	Fire Severity	**PM 2.5 EF** (lbs. emitted per ton of material consumed)	**PM 10 EF** (lbs. emitted per ton of material consumed)
U	2 - Dry	U2	lethal	24.5594	28.98
U	4 - Moist	U4	non-lethal	28.6554	33.8133
U	5 - Wet	U5	non-lethal	27.9954	33.0345

For each fire, the tons of emissions for each pollutant (T_P) were calculated using the following formula:

$$T_P = (BDT_{fire} * P_{ef}) \div 2000$$

Where:

T_P = Tons of Pollutant

BDT $_{fire}$ = Bone-Dry Tons of biomass consumed by fire

P_{ef}= emission factor (*ef*) expressed as pounds of pollutant produced per ton consumed by fire

2.9. Forest Operations and Equipment Configuration

From a modeling perspective, forest management treatments are deterministic events. The activities associated with management of vegetation constitute a realm of actions that, collectively, have energy use, emissions, and costs and revenues that can be quantified. In order to quantify these elements, assumptions must be made about the nature of management activities, including the prescriptions applied and the machinery used, that result in movement of products and co-products from the forest to the processing facility (power plant or sawmill).

The equipment configuration team identified the combinations of equipment that would be representative of an "average" forest treatment operation. Equipment configuration modeling was a collaborative effort, involving members of the team, representatives from the logging industry, forestry academics, and biomass power plant fuel procurement officers. Several iterations of the equipment configuration model were developed, beginning with the Alpha model phase and based on actual field data and experience from the Westwood, California, area and the Mt. Lassen Power biomass plant. The types of equipment used, and how it would be deployed on a given site to implement treatment prescriptions, provided the basis for the next step in the B2E modeling sequence, the life cycle assessment.

The equipment configuration domain team's approach used the expert opinion of harvesting contractors and supervisors currently conducting forest management activities in Northern California. Experts were interviewed regarding specific types and quantities of equipment for each harvest treatment prescription and range of slope conditions. Different equipment configurations were developed that were representative of the kinds of side[9] that would be deployed for each modeling condition. Table 11 provides a summary of slope class, treatment prescription, and equipment configuration code.

9. Side is a common term used by harvest contractors to denote a separate and distinct blend of harvest equipment conducting harvest activities as a separate operation. For example, a large thinning operation (several hundred acres in different locations) on national forest land might use two or three sides deployed separately in order to complete the work within the 120 day operating season. Each side is a complete set of all equipment needed to complete harvest, collection, processing and transportation operations.

Table 11 - Equipment configuration code by slope class and treatment prescription

TREATMENT PRESCRIPTION PER OWNERSHIP TYPE	SLOPE CLASS	EQUIPMENT CONFIGURATION CODE
Clearcut (CC) - Even-aged management. Only occurs on industrial forest lands.		
IPF	Less than 35%	CC <35
IPF	35 to 50%	CC 35-50
Pre-Commercial Thinning (**PCT**) **-** No sawlogs removed. Only biomass fuel removed. Typically in plantations.		
IPF	Less than 35%	PCT <35
IPF	35 to 50%	PCT 35-50
Commercial Thinning (**CT**) - Sawlogs and biomass fuel removed. Typically in plantations.		
IPF	Less than 35%	CT <35
IPF	35 to 50%	CT 35-50
Salvage (SAL) - Assumes that no biomass fuel (3.0 to 9.9 inches diameter at breast height (dbh) or limbs/tops) is recovered.		
IPF	Less than 35%	SAL <35
PMU	35 to 50%	SAL <35 Public
IPF	Less than 35%	SAL 35-50
PMU	35 to 50%	SAL 35-50 Public
Select Harvest (SH) - Uneven-aged management harvest removing high-risk trees in mature stands.		
IPF/PMU	Less than 35%	SH <35
IPF/PMU	35 to 50%	SH 35-50
IPF/PMU	Greater than 50%	SH 50+
Restrictive Thinning (RT) - A light thin, but retain 40% canopy. Public lands only.		
PMU	Less than 35%	RT <35 Public
PMU	35 to 50%	RT 35-50 Public

The blend of equipment is labeled with the equipment configuration code as shown in Table 11, based on slope class (topography) and treatment prescription. The equipment configuration team's analysis also synthesized estimates provided by interviewed experts of average production rates for each side. This approach contrasts with those that use empirical or mechanistic models to calculate production rates as a function of site and stand conditions (such as average tree size and skidding distance). The Project's equipment configuration model can easily generate estimates for an almost unlimited number of scenarios. The B2E approach is considered more realistic and provides more precise values for overall costs and production rates because of the level of detail included. However, this approach suggests that further model development must take into account the need to review equipment configurations that comport with regional and local forestry practices.

For each type of equipment, the equipment configuration team selected one or more representative models used in California or currently available equivalents. The team then collected data on purchase prices, fuel consumption rates, and other parameters. The team's equipment choices do not indicate recommendations or preferences for any particular models. It was not practical, nor did the team consider it necessary, to include the full range of equipment model options in the analysis.

Equipment used for prescribed burning was *not included* in this analysis. Prescribed burning equipment configurations would be more appropriately modeled in another iteration of the B2E Model, as they tend to be more similar to the fire suppression equipment configuration. Fire suppression was not modeled as part of the LCA because of the highly diverse configurations of equipment deployed during fire suppression operations on any given fire.

With the equipment configuration analysis completed, the team was able to proceed to build the LCA model. The LCA required detailed analysis of at least two major categories of activities: in-forest (described here) and power plant operations (described in the next section). In-forest operations included all operational steps from harvest to delivery of biomass to the power plant. The modeling did not include any of the resources or impacts associated with scoping, planning or monitoring of in-forest operations. As with fire suppression, these equipment configurations tend to be highly variable for any given operation, and it was deemed impractical by the team to include even a highly-abstracted version of planning and administrative infrastructure.

To summarize clearly the areas of forest management that are not included in the LCA, but which may have measurable impacts on emissions and forest operations:

1. Equipment configurations appropriate to prescribed fire operations (producing the emissions that are generated by underburning, as is seen in the LCA model);

2. Equipment configurations and impacts associated with fire suppression activities;

3. Administrative operations, such as planning, monitoring or research and analysis.

Given the high degree of variability associated with each of these activities, it would not have been realistic to attempt to build representative operational models for them.

2.10. Biomass Energy Conversion Technology Characterization

As mentioned above, two areas of operation affect total system emissions and energy consumption. The first is in-forest operations, captured by the equipment configuration domain, and the second the types of technologies used to convert biomass to energy. At the outset of this research study, the scope of modeling was restricted to electricity production. However, as the research project progressed, it became clear that other forms of energy production would become important to planners and decision makers. The research team therefore developed the conversion facility modules as independent modeling components. This allows future iterations of B2E Model development to include other bioenergy conversion systems, such as thermochemical conversion to ethanol or hydrogen.

In fact, the full analysis undertaken by the LCA team included engineering studies of five existing or emerging biomass conversion technologies. The results of this analysis have been published in a separate publication (Nechodom et al. 2008), and include very early results from next-generation thermochemical conversion technology that produces both electricity and ethanol. For the purposes of this study, the LCA team included three of the technologies specific to electricity generation, per the scope of the original Energy Commission contract. The comparison of three biomass-to-electricity technologies allowed the LCA team to compare differences in electricity production, energy use, and emissions impacts associated with different conversion technologies.

Data for three types of biomass power plants (a current generation combustion plant, a current generation integrated gasification/ combustion plant, and a next generation thermochemical conversion plant) were provided by the LCA team. Nameplate and net capacity, efficiencies, and stack emissions are presented in Table 12 below, as described in Nechodom et al. (2008). The emissions are supplemented to include CH_4 and N_2O emissions as described by the U.S. EPA (2003). The use of supporting equipment (a dozer, two loaders, a bobcat, a tub grinder, and a natural gas emergency generator) and ancillary grid electricity use were also included. Although the fuel use and emissions of the supporting equipment were deteriorated over time, based on the U.S. EPA's NONROAD2004 Model, the stack emissions and efficiency were held constant throughout the plant life cycle. Data were not found to support a time-scaled deterioration rate for the three technologies reviewed.

The LCA Report (Appendix 4) includes the inventory data used for the biomass power plants. These data take into account the proportions of each major species provided by the forest feedstocks and their relative heating values. Since power plant efficiency is a function of Btus per MWh, it is important to note the significant range of heating values per ton among tree species. For example, ponderosa pine contains a total of 17.2 mmBtus per bone dry ton. In contrast, hardwoods have 16.7 mmBtus per bone dry ton. These differences matter, particularly at larger scales of fuel use where biomass plant managers make daily and hourly decisions about *fuel blends* in order to optimize among Btus per ton and moisture content of fuels in the fuel yard. Nearly all biomass power plants seek out a diversified portfolio of wood fuels, and then blend what goes into the power plant on an hourly basis in order to achieve optimal balances between heating values, moisture content, specific fuels behaviors, and so forth.

For this study, analyzing the heating value by species allows estimation of the net electricity generated and delivered to the grid adjustments for each power plant's efficiency.

Table 12. B2E Project power plant characterization

	Current Generation Biomass Combustion Power Plant	Current Generation Integrated Gasification/ Combustion Power Plant	Next Generation Thermochemical Conversion Power Plant
Plant Size (dry tons per day)	500	500	500
Electricity (kWh/dry ton)	1,000	1,200	1,400
Net Energy Efficiency	20%	22%	28%
Plant Emissions (lbs./mmBtu output)			
NOX	0.329	0.067	0.008
SOX	0.125	0.010	0.002
PM	0.269	0.030	0.032
CO	0.897	0.070	0.042
VOC	0.085	0.018	0.003
CO2	972.000	886.000	694.000
CH4	0.329	0.067	0.008
N2O	0.125	0.010	0.002

2.11. Life Cycle Assessment

The environmental life cycle assessment (LCA) was a core element of the B2E study. The LCA tracked energy use, air emissions, and environmental impacts (in terms of climate change, acidification, and smog formation) associated with removing forest biomass to generate electricity. However, this approach accounted only for the energy use, emissions, and impacts associated with producing a megawatt-hour of electricity. The team was also interested to see if an LCA could provide a way to quantify energy use, emissions, and impacts associated with producing a healthy, resilient forest landscape.

The team spent considerable time and effort attempting to develop a landscape system LCA, at the same time realizing the inherent risk in this strategy. Defining the end-product of "electricity to grid" is fairly straightforward, and LCAs are clearly designed to deal with these types of engineered systems, where flows of materials can be tracked and controlled. Clearly defining and quantifying the end-product of a "healthy and sustainable forest" however is fraught with difficulty. Ideally, the end-product of a "healthy and sustainable forest" could be measured in acres that have reached a quantifiable state of "health" (which may be defined differently, based on the management objectives of different landowners) without substantially diminished capacity to maintain qualitatively measured multiple "ecological benefits."

Differing forest management objectives on different ownerships added complexity, particularly since some objectives operate at the stand scale (for example, sawlog production on private lands, which allows a per acre accounting) while others operate at much larger scales (for example, landscape-scale fire behavior modification on national forest lands, which a simple per-acre accounting will not capture). The multitude of management objectives and desired outcomes at a variety of spatial scales made it difficult to develop a specific, single metric that could be used to indicate that the Beta landscape had "arrived" at a "healthy" condition. Extensive work on this problem yielded the following approach: the LCA could track the energy, emissions, and environmental impacts associated with a 2.7 million-acre landscape of differing management outcomes, as measured by extent and severity of wildfire..

The LCA tracked energy use, emissions, and environmental impacts associated with harvesting, chipping, and transporting woody biomass and converting it into electricity. The LCA's environmental impacts were assessed using the outputs of the following B2E Project sub-models: (1) landscape characterization and scenario design, (2) characterization of forest operations and equipment configurations, (3) vegetation dynamics assessment, (4) fire behavior assessment, and (5) power plant analysis. As depicted previously in Figure 2, the outputs from these five sub-models fed data into the LCA. Development of the LCA portion of the B2E study focused the research team on the structural framework of the LCA itself, as well as on the interconnections between the LCA and the sub-models that provided its inputs.

The LCA estimated the life cycle impacts of harvest, biomass chip transport, and electricity generation. The life cycle begins at resource acquisition (in other words, at the well for mobile fuels and grid electricity generation and in the forest for biomass electricity generation) and extends through fuel combustion or point-of-use. Figure 5 presents the main process flows for the LCA.

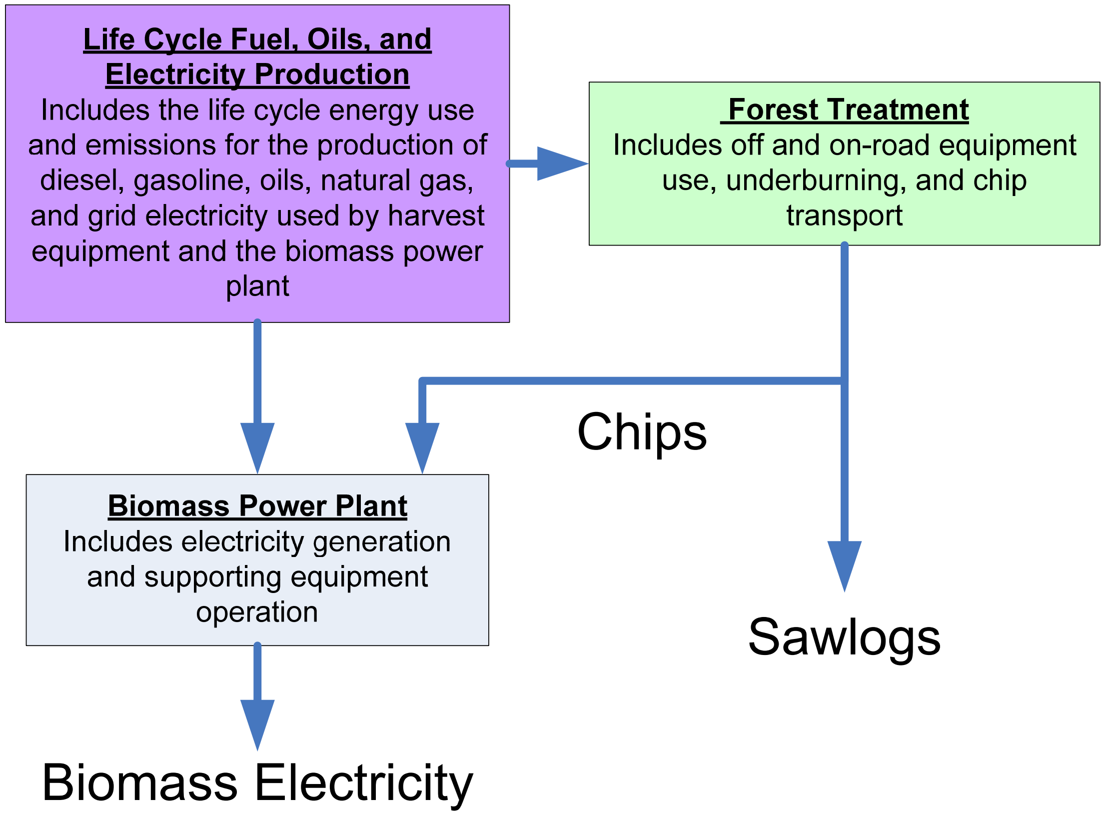

Figure 5. LCA process flows

The LCA included four phases based on the protocol standardized by the International Standards Organization (ISO) [10] and based on the computational structure described in Heijungs and Suh (2002). The four phases, briefly summarized here, are described in detail in the LCA Report for the B2E Project (Appendix 4). The first phase, *goal and scope definition*, described the reasons for carrying out the study, the intended audience, geographic and temporal considerations, system functions and boundaries, impact assessment and interpretation methods[11]. Next, the *inventory assessment* quantified life cycle energy use (total, fossil, and petroleum) and eight air emissions (carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4) nitrous oxide (N_2O), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs), particulate matter less than 10 microns in diameter (PM10), and sulfur oxides (SOx)) for acquisition and processing of residual biomass (harvest and chipping

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10 ISO 14040:2006 and ISO 14044:2006 replace the previous standards (ISO 14040:1997, ISO 14041:1999, ISO 14042:2000 and ISO 14043:2000). The new editions have been updated since the development of the goal and scope (Heijungs and Suh 2002) to improve the readability, while leaving the requirements and technical content unaffected, except for errors and inconsistencies (from http://elsmar.com/Forums/showthread.php?t=17459)

11 An extensive literature review of forest product LCAs formed the basis for the development of the project's goal and scope definition document (Cooper et al. 2006).

operations within the forest); transport of chips to a biomass power plant; and conversion of chips into electricity. Third, the *impact assessment* estimated air emissions contributing to global climate change (from CO_2, N_2O, and CH_4) and acidification (from SOx and NOx), and photochemical smog (from CH_4, NOx, CO, and NMVOCs). The final phase, the *interpretation* step, formulated the results in different ways, including an evaluation of alternative biomass electricity generation technologies.

Model interconnection was tested through the development of an LCA that compared the Reference Case (no treatment in the Beta landscape) with a Test Scenario that included a variety of vegetation and fuels treatments in the Beta landscape, designed to meet objectives emphasizing production of wood products on private lands and strategic fuels treatments to enhance suppression capabilities and modify landscape fire behavior on national forest lands. The LCA results in Section 3.0 are presented **in net form, depending on the selected production function,** allowing comparisons between systems that have different levels of sawlog production and electricity generation. The Test Scenario allows us to present different views of energy use, outputs and impacts by placing the focus on which part of the system the user may care about. For example, if one is mostly interested in the use, outputs and impacts associated with the biomass fuel chip production only, the net analysis allows a full assessment based on that primary interest. Examples of how this works are presented below.

2.11.1. Goal and Scope of LCA

In keeping with international standards for life cycle assessment, a complete discussion of the goal and scope of the B2E Project LCA is provided in the LCA Report (Appendix 4). The goal of the LCA was to analyze utilization of forest biomass to generate electricity. The scope of the LCA was based on selected decision categories as defined by the B2E Project's Technical Advisory Committee in June 2005. Table 13 below displays the decision categories and associated impact categories investigated in the LCA for the B2E Project.

Table 13. B2E Project LCA decision and impact categories

Decision Category	Impact Category	Impact Category Description
Infrastructure and Human Use Impacts	Total energy consumption*	Sum of the total energy consumption for the life cycle (as mmBtu***)
	Fossil energy consumption*	Sum of the fossil energy consumption for the life cycle (as mmBtu)
	Petroleum energy consumption*	Sum of the petroleum energy consumption for the life cycle (as mmBtu)
Air Resources Impacts	Contribution to climate change**	Total carbon dioxide equivalents from life cycle air emissions of CO_2, N_2O, & CH_4 (as tons CO_2 equiv)
	Contribution to acidification**	Total hydrogen ion equivalents from life cycle air emissions of SO_x & NO_x (as tons H^+ equiv)
	Contribution to photochemical smog**	Total nitrogen oxides equivalents from life cycle air emissions of CH_4, NO_x, CO, & NMVOCs (as tons NOX equiv)
	PM10 emissions*	Sum of particulate matter emissions (as tons PM10)

* The contribution of the inventory flows was measured by the amount of the inventory flows

** The contribution of the inventory flows was measured using impact equivalency factors

*** mmBtu is 1 million Btu

The LCA evaluated the Reference Case as well as a Test Scenario. Table 14 summarizes the assumptions regarding treatments for the Reference Case and the Test Scenario. The total biomass loading on the landscape ranged from approximately 4 bone dry tons per acre (BDTs/acre) for grasslands to 60 to 80 BDTs/acre for fully stocked forested areas. Treatments were assumed to occur over a 120-day period each year (during the summer months) on both private and public lands. Biomass removed from the landscape not destined for use as sawlogs was assumed to be chipped in the forest and used to generate electricity.

Table 14. Landscape treatment scenarios

Reference Case – No Treatment	No treatment is performed on public or private lands.
Test Scenario - Treatment of Private and Public Multiple Use (PMU) forest lands	Treatments on private forest lands are designed to meet objectives for producing wood products. On industrial private forest (IPF) lands, treatments include regeneration harvest (clearcutting), precommercial thinning, commercial thinning, and underburning. Treatments on non-industrial private forest (NIPF) lands include selective harvesting. Treatments on public multiple use (PMU) lands are aimed at strategically managing fuels and include thinning to create defensible fuels profile zones (DFPZs) as well as strategically placed area treatments (SPLATs). An average of 20 BDT/acre of forest biomass was assumed to be removed after saw timber was harvested.

2.11.2. Gross vs. Net Inventory and Assessment

The Approach and Results sections for the LCA rely heavily on an understanding of the difference between the "gross inventory assessment" and the "net LCA assessment." In the gross assessment, life cycle energy use and emissions for wildfires and all treatment processes are included, with only the Test Scenario producing sawlogs and electricity. The net assessment gives the Test Scenario "credit" (i.e., a subtraction of mass or energy) for producing sawlogs and electricity, so that the Reference Case, the Test Scenario, and conventional electricity generation can be compared.

A gross inventory assessment was undertaken to estimate the life cycle energy use and emissions for the Reference Case and the Test Scenario, representing the management regime as it would occur, including using a current-generation biomass combustion power plant, following the main process flows for the LCA depicted in Figure 5 above. The function of the gross LCA assessment was simply to track management of the Beta landscape over a 40-year period while producing sawlogs and electricity (from the biomass chips). Note that in the LCA, the term "chips" and "chipped forest biomass" are used. This includes tops, limbs, and waste material from the harvested trees, which are processed through a chipper to create wood chips, which can be converted to electricity at a power plant or used for other purposes, such as mulch.

2.11.3. Forest Treatment and Chip Transport Models and Data

The B2E Project's vegetation dynamics modeling (described in Section 2.1.5 of this Report) provided data on the amount of acres treated and quantities of sawlogs and chips generated from the treatments. The forest operations and equipment characterization model (described in Section 2.1.8) provided the data related to the type and quantities of equipment used in harvesting operations and to transport the harvested material to the processing facility (sawmill or biomass power plant). Forest treatment and chip transport included off-road equipment use for biomass harvest, such as the use of feller bunchers, skidders, and chippers, on-road equipment use for harvest equipment mobilization, the use of a water truck for forest road dust control, crew transport, and chip transport at an average distance of 30 miles from the treatment site. The Test Scenario was assumed to be executed based on combinations of six harvest methods (clearcut, pre-commercial thinning, commercial thinning, salvage, selective harvest, and restrictive thinning) for three slope ranges as displayed in Table 15. For each prescription, per-acre production rates for sawlogs and chips were determined via the forest operations and equipment characterization model.

Table 15. Treatments, equipment configuration, and production Rates

Treatment	Description	Slope %	Equipment Configuration	Chips (dry tons/ acre)	Sawlogs (dry tons/ acre)
Clearcut	Even-aged management. Only occurs on Industrial Forest Lands.	<35%	CC <35	30	47
		35 to 50%	CC 35-50	33	48
Pre-Commercial Thinning	No sawlogs removed. Only biomass fuel removed. Typically in plantations.	<35%	PCT <35	5.0	0
		35 to 50%	PCT 35-50	8.3	0
Commercial Thinning	Sawlogs and biomass fuel removed. Typically in plantations.	<35%	CT <35	14	7.5
		35 to 50%	CT 35-50	21	6.7
Salvage	Assumes that no biomass fuel (3"-9.9" diameter at breast height or limbs/tops) was recovered (burned up in wildfire).	<35%	SAL <35	0	11
		35 to 50%	SAL 35-50	0	13
Select Harvest	Uneven-aged management harvest removing individual or small groups of trees.	<35%	SH <35	12	16
		35 to 50%	SH 35-50	13	16
		>50%	SH 50+ (only on Industrial Forest Lands)	14	17
Restrictive Thinning	Thinning aimed at ladder fuel reduction, constrained canopy thinning, and retaining 40% canopy cover.	<35%	RT <35	6.6	12
		35 to 50%	RT 35-50	6.8	17

Data on equipment power, life, and fuel and oil use were combined with the productive machine hours per dry tons of woody material leaving the forest as chips or sawlogs to estimate fuel and oil use. Given the fuel and oil use on a dry-ton basis, total fuel and oil use for the Test Scenario was estimated based on the chips and sawlogs generated per decade (as derived from the vegetation dynamics assessment).

Based on the equipment fuel use, the equipment emissions were estimated based on the U.S. Environmental Protection Agency's NONROAD2004 and MOBILE6 emission inventory models as listed in Table 16. For the application of these models, estimation began with zero-hour or zero-mile emissions and break-specific fuel consumption (BSFC) and was followed by adjustments (where applicable) to account for transient operation, changes in emission factors over time, and technology distributions (for tiered regulatory compliance). For example, emission factors account for changes in regulations on diesel sulfur content. Beginning June 1, 2007, non-road diesel was required to have maximum of 500 ppm sulfur, and beginning June 1, 2012, the sulfur content must be reduced to 15 ppm (US EPA 2004).

Table 16. Harvest and chip transport emissions models

Off-road equipment except chainsaws	NONROAD2004 emission inventory model (technology distributions, zero hour emissions, deterioration factors, transient adjustment factors) [12]; California Statewide Off-Road Fuel Correction Factors [13]
Chainsaws	NONROAD2004 emission inventory model (zero hour emissions, deterioration factors, transient adjustment factors) [14]; Deterioration rates [15]
On-road equipment	MOBILE6 emission inventory model (zero hour emissions, correction factors) [16, 17]; Native road PM emissions [18]

Equipment was assumed to be dedicated to the project, to be new in the first year of the project, and subsequently replaced at the end of its operating life, thus returning the accounting to zero-hour or zero-mile performance (for example, Figure 6 shows that a Morbark Model 30/36 chipper is used for 8,000 hours and then replaced). Machine hours were estimated per decade for the Test Scenario based on the "productive" machine hours and the amounts of sawlogs and chips generated per decade. In addition, average cumulative operating hours per decade were estimated for each piece of equipment. Although emissions were adjusted for transient operation and degraded until the equipment was replaced, fuel and oils use was assumed to be constant over the life of the equipment (to match assumptions made in the project's economic analysis). Finally, PM emissions for on-road equipment traveling on native roads have been calculated and regulated adjustments in fuel sulfur levels have been considered in appropriate years as described in U.S.EPA (1995). The resulting "effective" emission factors are presented in sub-appendix A of the LCA Report (Appendix 4).

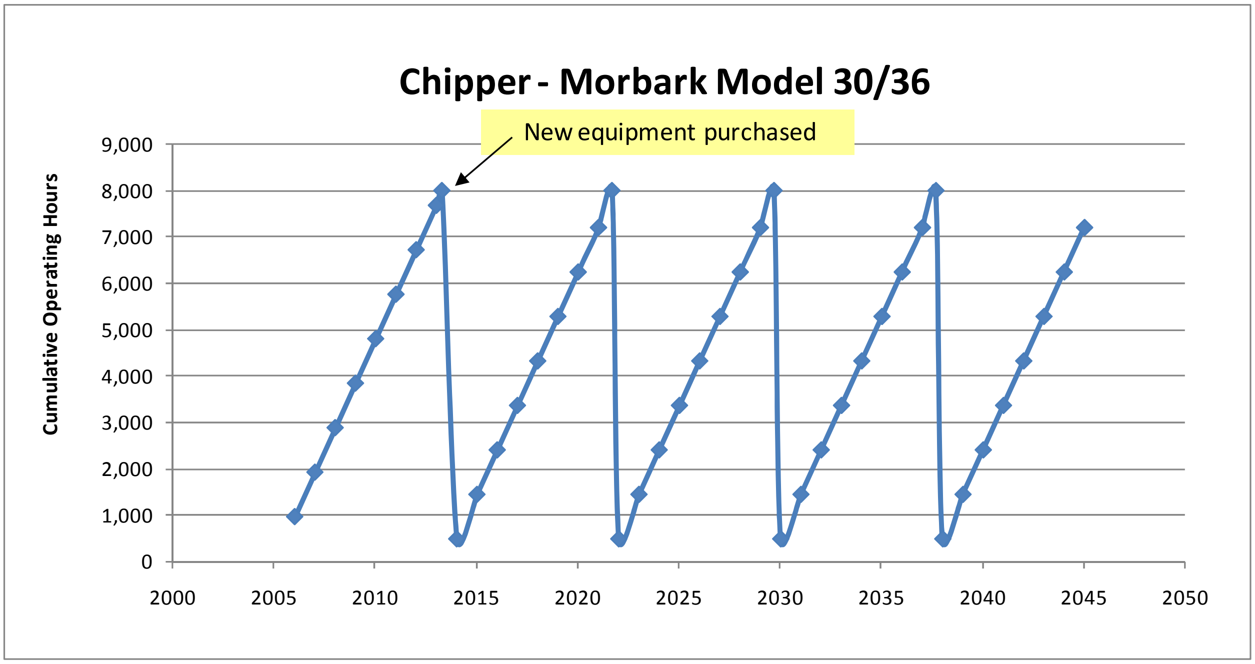

Figure 6. Example of new equipment purchase dates for emissions degradation estimation

2.11.4. Fuel, Oils, and Electricity Production Models and Data

The U.S. Department of Energy (DOE) Argonne National Lab's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model (Version 1.7) was used to estimate the life cycle of diesel and oils production, grid electricity, and natural gas power plants in California. Since GREET Version 1.7 estimates emissions only to the year 2020, energy use and emissions beyond 2020 have been assumed to be at 2020 levels. The data used are presented in sub-appendix B of the LCA Domain Report, essentially representing well-to-point of use values for all fuels, oils, and electricity production processes.

Biomass Power Plant Operation Models and Data

The "Biomass Energy Technology Conversion Characterization" section above describes in detail the biomass power plant operation models and data used in the LCA.

2.11.5. LCA Environmental Impact Assessment

In all assessments, environmental impact was measured in two ways. The first metrics of environmental impacts were based on the amount of inventory flows, such as the amount of energy or the mass of particulate matter emissions, which applied to four of the impact categories specified by the project's Technical Advisory Committee. The second metric used impact equivalency factors (i.e., scoring factors based on fate, transport, and effects models) from the 1996 Intergovernmental Panel on Climate Change values (IPCC 2007) or as compiled in the U.S. Environmental Protection Agency's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts or TRACI model (US EPA 2008). When equivalency factors were used, impacts were measured relative to one of the emissions contributing to the impact. For example, contribution to climate change was measured in "CO_2 equivalents" such that each species of emissions was assumed to have some multiple of the impact of CO_2 (for example, an emission of 1 kg of CH_4 contributes 21 times that of an emission of 1 kg of CO_2). Table 17 lists the equivalency factors used, consistent with the IPCC and the EPA standards.

Table 17. Equivalency factors used (equivalent mass/mass emitted)

Impacts Considered[12]	CH4	CO	CO2	N2O	NMVOC	NOx	PM	SOx
Contribution to Climate Change (CO2 equivalents)	21	0	1	310	0	0	0	0
Contribution to Acidification (H+ equivalents)	0	0	0	0	0	40	0	50.8
Contribution to photochemical smog (NOx equivalents)	0.0030	0.013	0	0	0.78	1	0	0

12 Climate change equivalency factors were for 100-year time horizons and chosen to match the data used in the U.S. EPA's values in the *Draft 2007 Inventory of Greenhouse Gas Emissions and Sinks* (US EPA 2007a). Data were from the most recent version of TRACI (developed in 2006) for the US average condition and available at http://www.epa.gov/nrmrl/std/sab/traci/

Finally, energy consumption, PM10 emissions, and the impact characterization results were normalized by the commensurate California estimates for the 40-year period, presented in Table 18. Energy use projections represented the 40-year sum of annual values forecasted based on linear regressions of 1996-2006 data from the U.S. DOE Annual Energy Review (U.S. Department of Energy 2006) and multiplied by the ratio of the population of California to that of the U.S. from the U.S. Census Bureau (US Census Bureau 2004). Next, and again multiplied by the same population ratio, California PM10 emissions and emissions contributing to acidification and smog formation were estimated from the 40-year sum of 2005 emission estimates from the U.S. Environmental Protection Agency (US EPA 2007b)[13]. Contribution to climate change was estimated as a 40-year sum of the 2004 level for California (CARB 2008). When combined, the normalization factors are intended to allow the life cycle environmental impacts to be placed within the context of their contribution to the overall California condition. Further model development and application would require the same normalization procedure for any given state in which the model was applied. If actual state-level inventory and analysis exist, it is recommended that those data be used for normalization of test landscape contributions.

Table 18. Normalization factors (estimated 40-year California values)

Factor	Result	Units
Total energy consumption	260,000	tera Btu
Fossil fuel consumption	190,000	tera Btu
Petroleum consumption	190,000	tera Btu
Climate change	21,000	million tons CO2 equivalents
Smog formation	150	million tons NOx equivalents
Acidification	6,800	million tons H+ equivalents
PM10 emissions	8.9	million tons

Note that the assessments in this study *did not include* the construction, maintenance, and decommissioning of facilities and capital equipment (in other words, harvest equipment, distribution/ transport equipment, power plant buildings and equipment) and the life cycle of other feedstocks needed to ensure continuous power plant operation.

2.11.6. B2E LCA Interpretation

The B2E Project's approach modeled one Test Scenario; however, the Test Scenario could be compared to other future scenarios, each of which would produce a variation in:

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13 Although the 40-year data could be forecasted from the U.S. Environmental Protection Agency data this method results in negative U.S. emission values as early as 2023. Thus, using the 2005 per capita value was chosen for emissions normalization. Note also that the non-greenhouse gas U.S. emissions data do not include fire and dust.

- the amount of sawlogs produced, and
- the amount of chips used in the production of electricity (and thus the generation of a different amount of electricity).

The B2E Project included developing an LCA framework that would facilitate the comparison of different management scenarios. While the LCA Domain Report (Appendix 4) presents the gross LCA results (which represent the main LCA flows depicted in Figure 5 for a current generation biomass combustion power plant), the gross assessment results do not allow for the comparison between scenarios because they do not account for the variation in sawlogs and chips produced under different scenarios. Hence, the focus of this section is on interpreting the gross LCA results to provide the means for future scenario comparisons. Interpretation of the gross results is done in two steps. First processes, inputs and emissions are allocated to sawlog production and electricity generation. Next variations in the conversion technology (i.e., type of power plant) used to generate electricity are calculated. These steps are described in the Results Section (3.0) to provide context for, and explanation of, the LCA modeling results.

2.12. Landscape Greenhouse Gas Model

The Biomass to Energy project attempted to build an atmospheric carbon flux model based on an interpretation of the data generated by the tree lists and the fire modeling. The Landscape GHG model (LGHG) was developed in order to test assumptions about total fates of carbon dioxide (CO) and methane (CH4) in the atmosphere, and to relate those greenhouse gases to forest growth and biomass removals over the 40 year modeling period.

While the LGHG had promising results, the team determined that the model would need further development in order to fully account for the greenhouse gases associated with post-fire decay and decomposition and the net sequestration from forest growth. The initial version of the model used generalized growth curves for forest mensuration after disturbance, and used assumptions about the sequestration capabilities of broad forest types. Additional assumptions were made about the fate of wood products and biofuels used for energy generation that were consistent with the assumptions used in the life cycle assessment. The LGHG model does not attempt to track all landscape-related carbon flows. Rather, the model is constrained to analyzing the flow of carbon in above-ground live tree biomass into biofuels and sawlogs, and into the atmosphere as a result of wildfire and decomposition.

The LGHG model was tested against a one-year GHG fate model (Morris 1999), developed in order to estimate total CO2 and CH4 burdens and fates in the atmosphere. This original model accommodates a wider variety of biomass fuels (such as sawmill waste, forest treatment residues, agricultural residues, recovered municipal waste and landfill gas). The modules pertaining to in-forest waste and tree growth were compared to the LGHG model in order to test the accuracy of LGHG accounting. The equations used in the B2E application of the original model to account for fire probability and losses, post-fire mortality and decomposition and post-fire growth and sequestration were derived from the tree lists generated through the vegetation and fire analyses presented in Appendices 1 and 2.

2.13. Wildlife Habitat Assessment

Once the analysis of vegetation growth, fire disturbances, and treatments were completed, the habitat domain team subsequently modeled their effects on wildlife habitat and associated values. As most analyses of wildlife habitat depend on data reflecting the structure and condition of vegetation, the habitat domain team used tree list data produced by the vegetation domain team, adapted to allow for habitat quality analysis.

A key reference used for the wildlife habitat analysis was the California Wildlife Habitat Relations (CWHR) model (CDFG 2002). The habitat domain team evaluated vegetation conditions, along with environmental variables (for example, elevation, slope, and precipitation) to evaluate how habitat conditions for wildlife species would be expected to change under different forest management scenarios. The team evaluated the potential effects of the Reference Case and the Test Scenario on biological diversity by evaluating changes in habitat suitability from five perspectives: habitat element specialists, aquatic species, service-providing units, indicator species, and individual species of special interest. Each of the five perspectives addresses concerns regarding the direct and indirect effects of management on biological diversity and the services it provides.

Habitat element specialist guilds represent the effects of forest management on vegetation structure, and in turn, habitat conditions for wildlife species.

Service providing units represent the effects of forest management on ecosystem services by affecting the diversity of service providers and biological diversity as a whole.

Species of special interest are those that are of particular interest or concern based on their current population status or their vulnerability to forest management practices.

Aquatic species use upland habitats to meet a variety of life history needs, including foraging, cover, estivation, and dispersal. Upland conditions and activities can also affect aquatic habitats.

Current vegetation conditions across the Beta landscape were generated from existing Forest Inventory and Analysis (FIA) data. Future vegetation conditions were modeled based on current FIA-based vegetation, Forest Vegetation Simulator (FVS) growth models, and a predetermined array of disturbance events (see vegetation dynamics modeling domain). The Reference Case and Test Scenario each had eight time steps (pre- and post-treatment for each of four decades), with one shared starting condition, providing a total of 17 landscape condition snapshots. Vegetation conditions for each landscape were provided by the vegetation dynamics team.

2.13.1. Habitat Element Specialist Guilds

Species associations with primary habitat features that are likely to change as a result of biomass harvesting were identified to create five habitat specialist element guilds: old forests, early seral conditions, snags, logs, and oaks. Membership in each of the five guilds developed for this analysis was determined based on multiple sources. The old growth associates were derived from Graber's (1996) old growth conifer dependent species for the Sierra Nevada, and included old growth dependent and associated species. Early seral species were those for which early seral stages (open, seedling, or sapling stages) were considered high quality habitat for reproduction, feeding, and cover in the CWHR database. Oak guild membership reflected a combination of species dependent upon oak foothill habitats (Graber 1996), and five additional species for which the CWHR database identified acorns as secondarily essential or essential. Snag and log associates were identified using the CWHR database: species for which snags or logs (large and medium diameter) were considered an essential or secondarily essential were included in these guilds.

Each of the habitat element specialist guilds consisted of representatives from multiple vertebrate classes. The team identified a total of 63 old growth associates, including 2 amphibians, 3 reptiles, 36 birds, and 22 mammals (two of which are currently extirpated). Seventy-nine species were identified as early seral associates, including 9 reptiles, 37 birds, and 33 mammals. Forty-four species were associated with oaks or acorns, including 1 amphibian, 3 reptiles, 30 birds, and 10 mammals. Thirty-four species were associated with snags, including 24 birds and 10 mammals (one extirpated); and 16 species were associated with logs, including 1 amphibian, 3 reptiles, 2 birds, and 10 mammals (one extirpated). Modeling snag and log guilds, particularly the patterns of post-fire mortality and snag and log recruitment, has a degree of uncertainty that should be viewed with caution. The team found that the Test Scenario effects on snag and log dependent species were difficult to quantify, and point to a larger finding that habitat modeling requires more refined vegetation data.

2.13.2. Service Providing Units

Following (Luck et al. 2003), seven service providing units can be identified in similar ecological systems. The habitat domain team identified four categories of service providing units (insect regulators, seed dispersers, decomposition aides, and herbivore regulators) to evaluate the effects of forest management on ecosystem services provided by vertebrate species. Insectivorous animals serve to keep populations of herbivorous insects in check, limiting a variety of undesirable damages associated with outbreaks of these insects, such as stress to native plant species including trees (for example, bark beetles). With an emphasis on aerial insects, the team identified 93 members of the insectivorous service-providing unit, including birds and bats. Seed dispersal is a key service in any ecosystem that is provided by vertebrates, as well as invertebrates (for example, ants). Many species eat and transport seeds; the habitat domain team targeted two groups of species (22 species total): conifer seed dispersers (small mammals), and fruit-bearing plant seed dispersers (frugivorous birds and mammalian omnivores). Snags and logs contribute significantly to soil nutrient availability and nutrient cycling in forested ecosystems. Although other biota, such as bacteria, fungi, and ants, serve the primary role in decomposition, the 13 species of woodpeckers and secondary cavity nesters in the Beta landscape contribute to decomposition in an ecologically significant manner by exposing trees to disease through sapsucker feeding holes, and speeding the breakdown of snags and logs through the creation of cavities for feeding and nesting. Herbivore regulators are carnivores, which serve a regulatory function in ecosystems, keeping populations of lower trophic level species (primarily herbivorous mammals) in check. Finally, the team identified two tiers of herbivore regulators: primary (top carnivores; n = 21) and secondary (n = 9).

2.13.3. Species of Special Interest

The habitat domain team considered species with special status, exotic species, and aquatic species in identifying species of special interest. There were five exotic vertebrate species in the Beta landscape: three birds, one amphibian, and one mammal. The team analyzed the richness of exotic species as a group. The team identified Forest Service Sensitive Species and existing Management Indicator Species for the Plumas and Lassen National Forests as species of special interest, and these included 23 species: 8 aquatic species (4 amphibians, 3 birds, 1 reptile), and 16 terrestrial associates (6 birds, 9 mammals).

To test the sensitivity of the data used, the team evaluated the individual responses of one species, the American marten, as a demonstration of the type of analysis that can be conducted in any landscape where systematic surveys have been conducted. For the American marten, the team developed a predictive model for probability of occurrence based on GIS-based environmental data associated with survey data (detection, non-detection) collected in the study area and adjacent landscapes. In 1999 to 2002, the Forest Service's Pacific Southwest Research Station conducted a survey for mammalian carnivores in the Greater Southern Cascades Region of northeastern California using baited trackplate and camera stations (Barrett 1983; Kirk 2007). The surveyed landscape overlaps the Beta landscape, extending far to the north but not as far east as the Beta landscape. Nonetheless, the surveyed landscape is comprised of vegetation and other environmental conditions typical of the Beta landscape; hence, the predictive models developed for the surveyed landscape could be reliably applied to the Beta landscape.

2.13.4. Aquatic Species

The team then identified 79 non-fish aquatic species that were primarily dependent on aquatic habitats, including 15 amphibians, 58 birds, 4 mammals, and 2 reptiles (Appendix 5). In addition, 38 species of fish were identified as confirmed or likely to occur in the Beta landscape (Appendix 5). Aquatic species were only included in the aquatic guild, and were excluded from the habitat element specialist guilds because of their unique considerations relative to changes in upland conditions. Specific aquatic species were not included in this analysis.

2.14. Ecosystem Services and Ecological Endpoints Analysis

This section describes a framework for analyzing ecosystem services pertinent to the Beta landscape. The habitat team analyzed impacts on key ecosystem functions that were classified as *service-providing units*. However, the B2E research team determined that a broader analysis would be appropriate in a further development of the study beyond Phase 1.

This broader analysis would include quantification of the ecological endpoints identified in this section of the study. Ecological endpoints are characterized as ecological functions that have a directly measurable human welfare function, and that can be quantified in an accounting system that makes them fungible. Forest ecosystems can purify water, reduce flood and fire risks, support recreation, provide beauty, improve nearby agricultural output, sequester carbon, and enhance air quality (Daily 1997). However, the services that connect directly to human welfare functions substantially narrow the field of indicators that needs to be measured to understand changes due to disturbances such as wildfire or management such as fuels treatments.

The methods used in the ecosystem services assessment are innovative in the area of resource economics. While the initial scope of this study had hoped to establish a series of values for non market resources, the team found through its parsing of economic values on the Beta landscape that further analysis would be required before those values could be quantified.

Given that the overall goal of this study was to explore trade-offs among all values associated with disturbance and treatment at the landscape level, the fundamental requirement in meeting that goal would be to quantify or at least normalize values in order to make them comparable. The B2E economic model took into account all values that could be measured with market signals, or at least with reasonable proxies for market signals. However, several other values that in fact drive human choice and behavior on the Beta landscape are clearly importantly affected by treatments and fire. Assigning them fungible values proved frustratingly elusive to the research team.

This section illuminates the problem, and even provides a framework for a potential solution. The longer report (see Appendix 7) on ecological endpoints is an analysis of the historically difficult issues of benefits transfer. And, it offers a recommended strategy for distilling ecological endpoints that can be quantified and measured against other values

The methods employed in the analysis if ecosystems services are still under development. The recommended strategy for development is an additional effort to quantify the values identified in the framework in Appendix 7, and summarized in Table 19.

Table 19. Examples of relationships between benefits and endpoints

Benefits	Endpoints
Scenic, aesthetic enjoyment	Undeveloped landcover, untreated landcover (if visible), burned landcover
Residential water provision	Water quality and availability at intake (wells, POTW sources)
Commercial water provision	Water quality and availability at intake (wells, POTW sources)
Irrigation water provision	Water quality and availability at source
Commercially important soils	Soil availability & quality
Recreational open space, aquatic	Boatable waters area, depth, flow
Recreational open space, terrestrial	Parks and public lands
Active hunting and angling	Target species populations (deer, adult steelhead, ducks)
Passive species observation	Target species (songbirds, elk, deer)
Stewardship	Endangered and threatened species not included in active and passive categories, wilderness
Pollutant reductions – Air	Air quality, particulates
Property damage avoidance – Water	Flood events and flood map
Property damage avoidance – Fire	Fire events and fire map
Property damage avoidance – Pests invasives, pollinator losses	Pest, invasive, and pollinator species populations.

2.14.1. Ecological Production Functions

A production function describes the relationships between inputs and outputs in a system. One of the key limitations of this kind of analysis is the ability to state ecological production functions in ways that can be analytically observed and measured. As Boyd points out in Appendix 7, the production functions on the B2E landscape are well on their way to clear definition, but further analysis and modeling would need to be completed before the ecological economic analysis could be completed.

The current analysis for this study concluded with the following evaluation of the existing and needed tools to support identification and quantification of ecological endpoints:

- Better species models that incorporate the spatial configuration of habitat. Models of reproduction, forage, predation, and migration to better predict the location and timing of populations. Of interest are not just valued populations, but pest and invasive populations as well.
- Better hydrological models to link land cover to aquifer and downstream surface water availability. Forests can prevent 'flashy' runoff and thus protect against flood surges. Dense growth is also thought to reduce groundwater delivery.
- Better water quality modeling to link land cover and land management practices to downstream water quality. Forest-related impacts on nutrient cycling and nutrient loads is an example.

- Better understanding of soil quality effects arising from treatment and hydrological processes.
- Better air quality models to allow for the analysis of human health, ecological, and aesthetic impacts.

2.14.2. Scarcity and Substitution

A common principle of resource economics holds that non-market valuation is fundamentally dependent upon some kind of *stated preference method*[14] being applied at the appropriate scale, surveying an appropriate sample population. However, welfare-significant conclusions can be drawn without knowledge of underlying preferences. This is because economic production obeys certain fundamental properties, or principles. For example, all else equal, the following statements are typical of economic logic, and apply to human evaluation of ecological scarcity and value:

- The scarcer an ecological feature, the greater its value.
- The scarcer are substitutes for an ecological feature, the greater its value.
- The more abundant are complements to an ecological feature, the greater its value.[15]

Note that scarcity can be measured, as well as the abundance of substitutes and complements, without detailed knowledge of underlying preferences. For any of the endpoints found to vary as a result of management, policy, or protection useful things can be said about the social value of the change by exploring the scarcity of what is gained or lost. While stated-preference methods are highly recommended to refine the scarcity analysis approach, for a gross assessment employed at the scale of this study, it is sufficient to detect analytically significant differences among policy scenarios.

For example, a waterbody whose quality is enhanced will – all else equal – be more valuable if it is scarce. Is it the only swimmable lake in the county, or one of many? The same holds true of parks, open space, and wilderness. Are these land uses scarce or plentiful? Knowing the answer to these questions may help decision-makers make more informed choices about impacts and priorities.

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14 Stated preference methods fall into three primary categories: a) contingent valuation, in which the respondent is required to make a comparison of value between the resource value in question and known trade-off values; b) travel-cost analysis, in which travel effort and investment constitutes a proxy for the value of the resource; and c) hedonic pricing, which uses property values as a proxy for the value of the resource as compared with comparable purchase prices. Each has strengths and weaknesses, depending on application. For this study, the team recognized that each method represented fruitful areas of future research to enhance and refine the substitution and "rarity" methods used to determine ranges of values and change due to disturbance and management.

15 Though note that not all ecological inputs require complements to yield a benefit.

Substitutes are also important to analyze. If water flows in a stream are reduced, but there are alternative groundwater sources for irrigation or drinking, the social costs of reduced flows will – all else equal – be lower than if there are no substitutes. The benefits of fire and flood damage are likewise influenced by the availability of averting actions which are a substitute for fire or flood risk reductions. Flood pulse attenuation is less valuable in watersheds where there are built flood controls such as levees, dams, and reservoirs. It is more valuable when those built substitutes are absent.

The scarcity of, substitutes for, and complements to many ecosystem goods and services are relatively easy to assess. In many cases, metrics can be derived from social and biophysical GIS data. (Boyd and Wainger 2002; Boyd and Wainger 2003).

Table 20. Examples of endpoints and relationships to metrics of scarcity and substitution

Endpoint (w/benefit)	Scarcity Metric	Substitute Metric
Undeveloped land in viewshed (Aesthetic enjoyment)	% landcover undeveloped in service zone	% landcover lightly developed land
Water quality (Drinking, Irrigation)	Degree to which consumption constrained by availability	Other water sources Wells, POTWs,
Water availability (Irrigation, Commercial)	Degree to which consumption constrained by availability	Other water sources Wells, POTWs
Boatable waters, depth, flow (Recreation)	Number, size of waters in service zone	n/a
Parks & public lands (Recreation)	Number, size of lands	n/a
Species (Hunting, Subsistence)	Population density	species (bass for trout)
Species (Observation)	Population density in service zone	Substitutable target species
Species (Stewardship)	Global or regional population viability	n/a
Wilderness (Stewardship)	Global or regional wilderness availability	n/a
Fire events (Damage avoidance)	n/a	Protective actions (fire breaks, water)
Flood events (Damage avoidance)	n/a	Protective actions (levees, dams)

Each of the three subsections above are areas for further development. Given the limitations of resources and expertise for this aspect of the project, the B2E team determined that recognition of the issues and a recommendation for further development should be sufficient during this proof-of-concept phase of the project.

2.15. Cumulative Watershed Effects Analysis

Cumulative watershed effects analysis evaluates the impacts of multiple disturbance activities across a landscape over time. The underlying premise for this approach is that watersheds recover over time, and the length and progression of the recovery depends on the type of disturbance involved.

In the northern Sierra Nevada, impacts from vegetation management activities are primarily increased erosion and stream sedimentation resulting from decreased soil infiltration, decreased soil cover, bank and fill failures along roads, and altered runoff patterns. While mass wasting can be a potential problem in localized areas, this process was not analyzed for the Beta landscape.

Watershed impacts are most effectively mitigated using Best Management Practices in designing and locating roads and skid trails, maintaining protective vegetation cover, and limiting the extent and intensity of disturbance (Rice and Berg 1987). MacDonald (1994) states that the effects of present day management activities on water quality are usually transient and rarely severe enough to cause significant damage to fish populations. Exceptions to this conclusion include:

- unstable areas or areas with highly erodible soils,
- the combination of management activities with extreme storm events, and
- downstream deposition areas where there is potential for cumulative effects.

The B2E cumulative effects analysis assumed implementation of Best Management Practices in concert with the modeled treatment prescriptions.

Cumulative watershed effects in the Beta landscape were assessed using the Forest Service Pacific Southwest Region's cumulative watershed effects (CWE) model and verified using WEPP FuME. The CWE model is a disturbance-based model that normalizes all disturbances (treatments, wildfires, and so forth) to an acre of road. WEPP FuME is a web based interface (http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/fume/fume.pl) that predicts soil erosion associated with vegetation and fuels management practices (prescribed fire, thinning, and a road network) and compares the result with erosion from wildfire.

2.15.1. Cumulative Watershed Effects Model

The CWE model is a non-specific model for modeling disturbance and recovery. It can be designed to model disturbance and recovery related to sediment and soil erosion, or can be modified for other disturbance related processes, such as mass wasting. The model uses equivalent roaded acres (ERAs) to equate all disturbances to one acre of road, and estimates the recovery of the disturbed areas over a specified period of time, based on a recovery curve for the disturbance being modeled. The CWE model can be modified for different disturbance processes by changing the model's ERA coefficients and recovery curves.

For the B2E Project, GIS coverages displaying watershed disturbances were analyzed using a CWE model written in visual basic. The program read each disturbance and disturbance year and, based on the ERA coefficient, recovery curve, and years to recover, computed the ERAs by year for each watershed, as described below.

2.15.2. Watershed Disturbances

The Beta landscape was divided into 122 watersheds, ranging from 2,500 to 46,000 acres (averaging 23,000 acres). Disturbances were quantified using Forest Service corporate GIS layers displaying: (1) past vegetation management activities on national forest lands (from the Forest Service's Activity Tracking System), (2) forest roads, (3) fire history, including burn severity, and (4) the Beta landscape treatments and wildfires modeled for the three time periods of 2006, 2016, and 2026. Past and ongoing timber harvest activities on private lands were modeled using the state's Timber Harvest Plan GIS coverages, which covered only two of the four counties (Lassen and Sierra Counties) in the Beta landscape at the time of the analysis.

2.15.3. ERA Coefficients and Recovery Curves

ERA coefficients were based on the likely effects of management activities on erosion and sedimentation, these two processes being the most likely mechanisms that would result in a cumulative watershed effects in the Beta landscape. ERA values recover over time. To run the cumulative watershed effects model, the watershed team defined a recovery period (years) and assigned a recovery curve (Figure 7) for each type of disturbance. At this broad scale of analysis, sensitive areas, such as highly erodible soils or areas adjacent to streams, were not separated out for customized ERA coefficients and recovery curves.

ERA coefficients and recovery curves were based on erosion and sedimentation studies from the American River Study on the Eldorado National Forest. (MacDonald et al. 2004) The study measured erosion rates from wildfire, logging roads, timber harvest, and prescribed fire, using sediment fences on the American, Cosumnes and Yuba River Basins. Sediment delivery was also examined. The study results are presented in Table 21.

Table 21. Mean sediment by treatment (1999-2000) and proportioned ERA coefficient

Disturbance Type	Mean Sediment Rates\2 Tons/ha	Kg/M²	Sample Size (n)	ERA Coef\3	Est % Skid trails/landings
Roads Dirt	8.80	0.798	17-55*	1.000	N/A
Roads Gravel or Paved	0.90	0.082	10	0.102	N/A
OHV Trails	3.90	0.354	7	0.443	N/A
Minimally disturbed sites	0.01	0.001	3	0.001	N/A
High Severity Wild Fire	11.00	0.998	3	1.250	N/A
Holland soil skid trail	8.20	0.744	2	0.932	N/A
Other skid trails	0.40	0.036	34	0.045	N/A
Skid Trails (Mean)	0.83	0.076	36	0.095	N/A
Prescribed Fire	0.01	0.001	15	0.001	N/A
Thin Unit (estimated\1)	0.13	0.012		0.014	15%
Regeneration Harvest (estimated\1)	0.23	0.021		0.026	27%

\1 Harvest Units estimated from skid trail erosion rates and minimally disturbed rates. 15 percent of the area in thinnings was assumed to be in skid trails and landings, while 26 percent of regeneration harvest areas were assumed to be in skid trails and landings.

\2 Mean sediment rates taken from the American River Sediment Fence study.

\3 ERA Coefficients: Dirt roads are set to 1 ERA per acre and all other ERAs are calculated based on the amount of sediment per acre relative to roads. For example, the mean skid trail produces 0.83 Tons/ha or about 1/10 that of dirt roads.

In the American River study, sediment rates were highly concentrated, with a relative few sites producing the majority of the sediment from each land use (Table 22). For roads, a few segments, with inadequate road drainage, and road segments that were recently graded, produced a majority of the road sediment. On skid trails most of the erosion came from 2 of 36 segments on the Holland soil type. These outliers were not excluded from the B2E analysis but averaged into the ERA coefficients.

For this analysis, dirt roads were set to 1 ERA per acre. All other ERA values were calculated based on the average sediment yield relative to dirt roads. For example, the average sediment yield on high severity wildfire areas is 11 tons/ha and dirt roads are 8.8 tons/ha. High severity wildfire therefore received an ERA coefficient of 11/8.8 or 1.25.

All disturbances were assigned an ERA coefficient, a recovery curve, and recovery years based on the American River study, other studies, and local expertise. Sample ERA coefficients used in the analysis are listed in Table 21. The complete ERA coefficient tables are listed in the cumulative watershed effects domain report.

Table 22. Beta landscape Equivalent Roaded Acre (ERA) coefficients, recovery years, and recovery curves for different types of disturbances.

Activity Group	Activity Method	ERA's / Acre	Recovery Years	Recovery Curve
Harvest Activity Fuels	Broadcast Burn	0.001	3	Concave
Harvest Activity Fuels	Machine Pile	0.021	8	Concave
Fuel Treat	Thin From Below, Tractor	0.014	8	Concave
Harvest	Clear Cut Tractor	0.026	10	Concave
Harvest	Thin Tractor	0.014	8	Concave
Road	Gravel	0.22	60	Flat
Road	Dirt	1	60	Flat
Wildfire	High Severity with Salvage	1.4	8	Concave
Wildfire	Moderate Severity	0.3	4	Concave

Recovery curves are used in this kind of damage analysis as a variable that can help set management priorities. For example, a convex recovery curve can give a particular area a higher priority for restoration or rehabilitation because of the risks of long-term damage without immediate intervention. Recovery curves are assigned based on the type and severity of disturbance being modeled. For example, since an active road does not recover over time, a flat recovery curve would be assigned. Most sediment recovery can be plotted as a concave curve. Each recovery curve plots a unique pace at which watershed recovery from a specified disturbance is modeled. For example, a concave curve plots a more rapid recovery during the earlier part of the recovery period compared to a linear recovery curve, which plots a constant rate of recovery over the recovery period, as illustrated in Figure 7 below. Recovery curves used for the Beta landscape analysis are shown in Figure 7. Note that Figure 7 shows a 100-year recovery period; however, this period varies depending on the type of disturbance being modeled, as shown in Table 22 above.

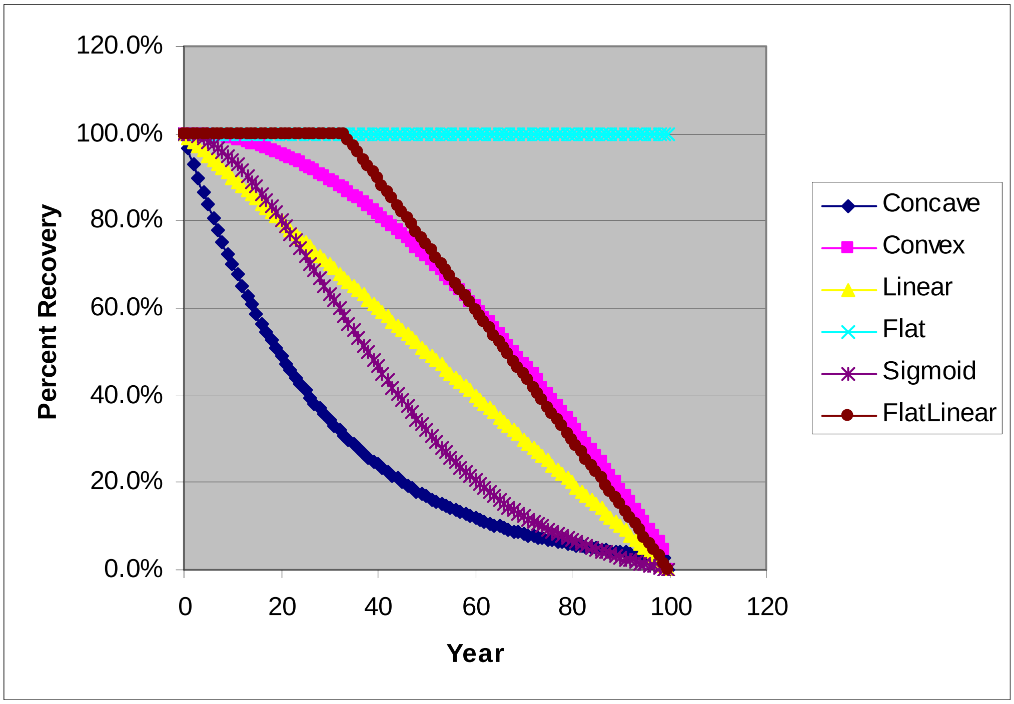

Figure 7. Recovery curves used for B2E Beta landscape cumulative impacts analysis

2.15.4. Watershed Thresholds

The basic area for cumulative watershed effects analysis is a watershed. ERAs are calculated for a watershed over various time periods, and these values are compared to a threshold of concern (TOC) established for the specific watershed. The TOC is expressed as the ERA level that indicates the upper limits of the watershed's tolerance to disturbance. The established TOC is based on the watershed's sensitivity to disturbance and beneficial uses of the water. The TOC does not represent the point at which cumulative watershed effects will occur. Rather, it serves as a "yellow flag" indicator of a particular watershed's increasing susceptibility to potential significant adverse cumulative effects.

The ERA or disturbance threshold for any given watershed is unknown. Thresholds can vary within a watershed based on the intensity and duration of storm events. A very large 100- to 200-year storm event can exceed the threshold of an undisturbed watershed. A relatively small 1 or 2 year storm event may cause debris slides after a wildfire. The amount and severity of disturbances increase the likelihood of a storm event exceeding the watershed threshold.

Thresholds of concern can be estimated based on local knowledge of past events. It is typically a conservative estimate, based on 30- to 100-year storm events. The threshold values used for the B2E analysis were from the Tahoe and Plumas National Forests. Specific thresholds of concern are listed in appendices to the Cumulative Watershed Effects Domain Report (Appendix 6).

2.16. Economic Analysis

The economic analysis focused on determining economic values of changes in resource conditions in the Beta landscape and at the power plant. As such, the analysis necessarily depended on modeling results from most of the Project's other domains, as well as financial data for constructing and operating power plants and the valuation of assets (structures, infrastructure, recreation resources, and agricultural production) at risk to wildfire in the Beta landscape. The analysis, however, was not a comprehensive economic assessment, which would require estimating monetary values for the ecological public goods and services, such as water quality, air quality and biological diversity, supported by the Beta landscape. As discussed in the section on ecosystem services above, prices and quantities were not readily observable for most public goods and services affected by changes in the Beta landscape. (Recreation resources are an exception.) The analysis instead focused on valuating private goods and services (marketable assets, such as timber, structures and power from biomass plants) affected by changes in resource conditions within the Beta landscape and at the power plant. For the most part, data on prices and quantities consumed were available from market transactions to place economic value on these goods.

Different analytical frameworks (Table 23) can be used to present the outputs from economic analyses. Deciding on the appropriate framework often largely depends on the policy questions that need to be answered and the availability of data to conduct the analysis. For example, cost-effectiveness analysis is typically used when a specific project outcome is predetermined and the analytical objective is to determine the least cost way to achieve the objective. Economic costs are derived in terms of the opportunity costs of foregone uses of resources, including any direct costs incurred by implementing agencies. Benefit-cost analysis is a more comprehensive approach to economic analysis, involving equal consideration of economic costs and benefits. Benefits reflect the increased value of market and non-market goods and services (such as recreational, aesthetic, and cultural values).

Table 23. Analytical frameworks for economic analyses

ANALYTICAL FRAMEWORK	PRIMARY OBJECTIVE
Private Investment/Financial Analysis	Identify rate of return on investment
Cost-effectiveness Analysis	Identify least cost program or project
Fiscal Analysis	Identify effect on local government budgets
Local/Regional Economic Impact Analysis	Identify effects on the local economy (jobs, income)
Social/Community Analysis	Identify effects on community well-being
Benefit-Cost Analysis	Identify the net economic value to society

Successfully applying either cost-effectiveness or benefit-cost analysis depends on scientific understanding of the underlying physical and biological processes. The physical changes in environmental and resource conditions are often described by response functions that relate changes in the physical and biological environment to policy actions. The economic analysis attempts to characterize these physical and biological changes in monetary terms. However, if key relationships among the physical and biological processes are not well understood, the economic analysis will mirror (and often compound) the level of uncertainty.

The overarching research question for the B2E Project's economic analysis was as follows: "Do the benefits of removing biomass (both timber and other biomass) from the forest and using it as a fuel source to generate electricity exceed the costs associated with the forest management activities?" The economic analysis focused on estimating the net present value (NPV) of changes in resource conditions associated with the vegetation management treatment scenarios (s1…s3) over a 40-year analysis period (t1…t40). Notationally, the analysis can be expressed as follows:

$$NPV_{s1\ldots 1n} = \sum R_{t1\ldots t40} - C_{t1\ldots t40} + EB_{t1\ldots t40} - EC_{t1\ldots t40} + \Delta MAV_{t1\ldots t40}$$

where:

- **R = Revenues:** discounted annual revenues for power generation, biomass co-products (sawlogs), and salvage logs
- **C = Costs:** discounted annual operations, maintenance, and capital costs for forest fuels management, power plant operations, fire suppression, and forest rehabilitation
- **EB = Environmental Benefits:** discounted annual positive changes in the provision of ecosystem services
- **EC = Environmental Costs:** discounted annual negative changes in the provision of ecosystem services
- **ΔMAC = Change in Market Asset Values:** discounted change in market asset values attributable to wildfires, including structures, infrastructure, agricultural lands production, and recreation resources.
- **s = scenario:** comprehensive array of treatments, vegetation changes and wildfire interactions
- **t = time:** annual time period for each change in value

Although the analytical notation includes consideration of environmental benefits and costs as part of a comprehensive economic analysis, research limitations did not allow for monetizing the environmental effects of the treatment scenarios evaluated for the B2E Project. These limitations and ways to address them are discussed above in the section on ecosystem services.

Consistent with requirements for economic efficiency analysis, the economics domain team used a benefit-cost analytical framework to evaluate changes in resource costs and benefits associated with the Reference Case and the Test Scenario. The analysis also included calibrations against the Private Land scenario, developed to test model sensitivity and to show likely marginal impacts and benefits from private land management. Resource costs were measured in terms of opportunity costs, and benefits were evaluated in terms of willingness-to-pay.

The team developed a spreadsheet model to calculate the annual costs and benefits of the no-treatment Reference Case and the Test Scenario over the 40-year analysis period. As a practical matter, costs and benefits that occur beyond 40 years in the future have little or no present value. Costs and benefits are discounted to present value using a 3 percent real discount rate.

2.16.1. Valuation of Assets at Risk to Fire

A primary focus of the economic analysis was on evaluating changes in the economic value of assets at risk to wildland fire. Based on previous research (California Department of Forestry and Fire Protection 2005 and Baerenklau 2006), key assets with established market values that are at risk to fire include agricultural land resources, timberland resources, recreation resources, structures, infrastructure, and mineral resources.

A geographic information system (GIS)-supported approach that allows for considering spatially-explicit relationships was used to conduct the analysis of assets. GIS was used to develop baseline values of assets at risk and to assess how fire affected these values over time. The geographic mapping levels, units of valuation, and basis of valuation for the assets evaluated in the analysis are shown in Table 24.

Table 24. Geographic specification and valuation parameters for the assets at risk analysis

Applicable Assets	Geographic Mapping/Level of Dis-aggregation	Units for Valuation	Basis of Valuation
Agricultural resources	Region-wide, based on designated rangelands (CDF) and irrigated croplands (ag covertype)	Acres	Average rangeland and irrigated cropland values per acre; crop composite values used for specific areas (e.g., Sierra Valley)
Timberland resources	100 square meter grids used for SFA output, by county	Green and salvage volume (thousand board feet) classifications defined by BOE	Average stumpage values from BOE for harvest, treatment (co-products) and salvage
Recreation resources	Region wide, based on CDF designated recreation areas and other important recreation areas	Visitor days	Average net economic value per visitor day
Structures	Parcels, by county	Improvements to real and personal property, by parcel	Assessment value of improvements and other personal property
Infrastructure	Region wide, based on updated CDF data on powerline and facility siting	Improvements to real property and easements	Replacement value
Mining	Region wide, based on designated mining areas	Not valued	Not valued

GIS layers were created for each of the assets considered in this analysis. Baseline values for each asset were calculated by assigning a known or estimated dollar amount to each cell containing an asset. For example, one mile of transmission line was determined to have an average replacement value of $300,000. This value was converted to cost per meter giving each 100-meter cell containing a transmission line a baseline value for that asset. Layers for recreation, agriculture, structures, and infrastructure (power transmission lines) were then compared to modeled fire location and intensity for each 10-year time period in the Reference Case. Fire intensity (flame length) was translated into a damage function appropriate for each asset type. Burned cells containing assets were assigned a percent loss based on the fire intensity in that cell. Asset damages were aggregated within each asset type to determine total asset loss.

2.16.2. Sawlog Valuation

The economic analysis estimated the net revenues from harvesting of conifer sawtimber by species. The economics domain team reviewed potential sources for objective and consistent valuation data and found that the best available source was the California State Board of Equalization (BOE). The BOE sets timber harvest values as the basis for property taxes paid by California forest landowners and purchasers of public timber, per the California Timber Yield Tax Law of 1976. These values reflect net revenues to operators, thereby accounting for production costs.

The BOE values are derived from market analysis conducted by BOE foresters using actual sawtimber transaction data for each of the 11 timber value areas in California. The market analysis provides approximate stumpage[16] values for the timber before it is harvested, processed and transported to the market (i.e. sawmill, paper mill, composite panel facility). Valuation is expressed in dollars per thousand board feet ($/mbf)[17]. The BOE provides timber harvest values for miscellaneous, green and salvage timber respectively. In addition, BOE timber valuation assumes that value for some conifer species, such as ponderosa pine and Douglas fir, is also a function of size. For these tree species, the BOE assumes that the larger the diameter of the sawlog, the more value it has in the marketplace.

2.16.3. Fuels Treatment Costs

Forest management costs for the Test Scenario were estimated using a spreadsheet model developed by the Project's equipment configuration domain team. Costs were estimated by using the equipment configuration team's characterization of the type and blend of forest harvest and removal equipment used to perform forest management activities in the Beta landscape. Cost estimation was based on information provided by experts (harvesting contractors and supervisors) currently conducting forest management activities in Northern California.

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16 Stumpage values represent the value of timber as it stands prior to harvesting.

17 Thousand board feet (mbf) represents the volume of a log based upon board foot measure. One board foot represents the amount of wood contained in an unfinished board measuring one inch thick, one foot long, and one foot wide.

Total costs were allocated to the two different products, chips and sawlogs, using the following logic: because a primary intent of the operations is to remove fuel and remediate forest stands, the biomass and sawlogs should share equally, on a per-ton basis, the costs of all activities that handle or process both products. Thus, costs were partitioned by weight over the biomass and sawlogs for activities directly associated with each distinct configuration of harvest equipment. The costs of ancillary activities were also shared on the same basis. Costs allocated solely to biomass included chipping and transport of chips to the power plant. (The analysis did not consider loading and hauling activities associated only with sawlogs.) Finally, capital and operations and maintenance costs were calculated separately on a per-ton unit basis for each product (sawlogs and biomass).

2.16.4. Power Plant Costs and Revenues

Power plant cost estimates developed for the B2E Project were primarily comprised of the following three components:

- initial capital and development costs for the permitting and building of the project,
- cost of financing these up-front costs during construction as well as the operating phases of the project, and
- actual operating and maintenance of the project during its operating life.

Initial capital costs were estimated on the basis of similar-sized plants that are being built on the West Coast, with costs based on the assumption that a new facility would be constructed on land that is rural in nature, and built where permitting for a biomass power plant would be a reasonable financial undertaking. Financing cost was based on the assumption that the project will be a stand-alone entity, and that the equity investors and debt lenders would only have recourse to the project itself. Operating and maintenance costs of the project were based strictly on the experience of the Mt. Lassen Power biomass plant in Westwood, California. Mt. Lassen Power has had a long history of continuous operations, sourcing a majority of its feedstocks from thinning operations within a 30 to 50 mile radius of the power plant, providing empirical data representative of the costs associated with the operations of a typical biomass power plant.

Power plant revenue estimates were developed by multiplying the electricity output of the power plants constructed under each scenario by a price per kWh. The prices incorporated into the revenue estimates were based on information provided by the California Renewable Portfolio Standard Program. This program calls for the California Public Utilities Commission to establish a methodology to determine the market price of electricity for terms corresponding to the length of contracts with renewable generators. The market price must reflect the long-term market price of electricity a utility would need to purchase to meet its capacity and energy needs from conventional fossil fuel resources instead of the renewable resources proposed under the RPS bidding process.

2.16.5. Fire Suppression and Rehabilitation Costs

Fire suppression and rehabilitation costs can vary considerably due to differences in location, terrain, fuel type, proximity to populated areas, weather, fire intensity, and so forth. The team's review of literature and data concerning fire costs revealed little fire suppression and rehabilitation information specific to the Beta landscape. Therefore, the team used national data and information available for fires in other areas to develop costs for modeling purposes, implicitly acknowledging that costs may differ for fires in the Beta landscape.

To estimate suppression costs on a per acre basis, the economics domain team relied on cost data from the Forest Service (Strategic Issues Panel on Fire Suppression 2004) as well as a study of Colorado fires (Lynch 2004). The Colorado suppression cost data were generally consistent with the Forest Service cost data, indicating that the national suppression cost of $403 per acre was reasonable for estimating suppression costs in the Beta landscape. This cost was adjusted to 2006 dollars using the Employment Cost Index for state and local government workers, resulting in an average fire suppression cost of $465 per acre.

Expenditures on post-fire rehabilitation vary considerably because this spending is more discretionary than is spending on fire suppression. Additionally, variations in locations of fires can play a larger role in costs. For example, a fire that results in erosion that threatens urban water supplies or that increases the chances for major flooding in urban areas may spur significant emergency and long-term rehabilitation spending, whereas a fire in a remote area that does little damage to major watersheds may generate little or no rehabilitation spending. Activities funded by rehabilitation spending can vary from emergency erosion control to multi-year programs that include watershed seeding and tree plantings. The team used data from a Forest Service study that evaluated emergency rehabilitation treatments following 480 fires, primarily on National Forest System lands, from 1973 through 1998 to develop assumptions for average rehabilitation costs for the Beta landscape.

3.0 Project Results

Project results are presented in the following sections in a sequence following the format in the project approach section. Detailed reports for each domain reported are available in the Appendices, along with complete metadata reports for each model and dataset used. The presentation of results in each domain follows the following format (Table 25):

Table 25 - Format for presentation of B2E model results

Domain	Types of results
Vegetation Dynamics	Types, size and location of treatments; general characteristics of the Beta landscape; removal of sawlogs and biomass under each scenario
Wildfire Behavior	Size, severity and locations of fires under each scenario
Life Cycle Assessment	Smoke emissions from each class of fire; energy use and emissions for each equipment configuration; energy use and emissions for each type of biomass powerplant; comparison of biomass energy with California grid and natural gas power plant; total system emissions; environmental impact analysis for climate change, smog formation, acidification and particulate matter
Landscape Greenhouse Gas	
Habitat	Changes in habitat quality due to fire, treatments or both
Cumulative Watershed Effects	Impacts to soil, soil movement, sedimentation in aquatic systems
Economics	Changes in asset values due to fire and treatment; treatment costs and revenues; power plant costs and revenues; fire suppression costs; rehabilitation costs

Note that the results table above does not address several of the other domains and processes identified in the approach section (2.0). The team considered many of the approach processes and domains to be intermediary steps required only to produce model outputs for the domains reported in the results section (3.0).

It is worth emphasizing that the actual numerical and marginal results presented here are the outcomes of the B2E modeling assumptions. The differences in wildfire severity or size, for example, may not be as dramatic in the Test Scenario as one might have hoped. Or the reduction in wildfire greenhouse emissions may not seem significant, given the effort and expense seen in the equipment deployments or economic returns. This is purely an artifact of the modeled scenario assumptions. Future evolutions or applications of the B2E model would include development of additional scenarios that would test the landscape's ability to produce significant changes, perhaps in greenhouse gases, biomass power produced, or other production functions that might be socially preferable. The Test Scenario assumptions were designed to be as close to current practice and experience as possible so as to allow the modeling teams to calibrate model functions and assumptions. In other words, the team chose to test the models as closely to reality as possible, using actual data where possible, in order to assure proper model functioning.

The Test Scenario applied different types of vegetation treatments to account for different landowner objectives, for example, modeled treatments on private industrial forest lands clearly had a sawlog production management objective. PMU modeled treatments accounted for a variety of objectives. For example, most of the treatments on national forest lands in the first decade were focused on the construction of defensible fuels profile zones (DFPZs), which are designed with the objective of providing a place to deploy firefighters in the event of a wildland fire. Firefighters would use DFPZs to make a stand to hold or contain a fire. Treatments on national forest lands during the second model decade focused more on strategically placed area treatments (SPLATs). SPLATs are designed to interrupt the spread of a wildland fire, thereby slowing its spread. DFPZs are a fire suppression enhancement strategy while the objective of SPLATs is landscape-scale fire behavior modification.

The landscape selected for analysis covers approximately 2.7 million acres of both east and west side forest in the northern Sierra Nevada mountains. Figure 8 shows the location of the Beta landscape. The area spans three national forests, five counties and contains parts of Lassen National Park, several state parks, a state game reserve and several thousand acres of commercial forest lands. Table 26 (duplicated from the Approach section) shows a breakout of the types of land ownerships on the Beta landscape.

Table 26. Land ownership categories in the B2E Beta landscape

Land Category	Acres	% of Total
Public Multiple Use	1,374,783	50%
Public Conservation & Recreation	407,776	15%
Industrial Private Forests	457,427	17%
Non Industrial Private Forests	383,008	14%
Urban & Other	112,816	4%
Total	**2,735,809**	**100%**

Figure 8 - Location of B2E Beta landscape

The B2E model tracks the changes in vegetation type and condition through four modeling decades for both a Reference Case and Test Scenario. The Beta test of the model assumes a beginning year of 2006, and ends with final conditions stated for 2046. Therefore, changes from fire and treatment are displayed for the years 2006, 2016, 2026 and 2036.

3.1. Vegetation dynamics and change

Vegetation conditions are reported in this section under both the Reference Case and the Test Scenario. Treatments are reported by ownership class and slope condition, so that the reader can appreciate the extent of treatments under each scenario. Scenarios will be compared at the end of the section.

3.1.1. Reference Case and Test Scenario

A Reference Case was developed to compare changes under other scenarios, and is typically characterized as the “no treatment” scenario, in which the model grows and burns trees without any treatments being applied. The primary purpose of this scenario is to establish both the extent of growth on the landscape without intervention and the extent and severity of fires without treatment. It is a totally hypothetical case for reference purposes only.

Vegetation changes in the Reference Case are due exclusively to growth and wildfire, and are reported in the next section on wildfire behavior.

Table 27 - Acres and products from the Beta landscape under the Test Scenario

Acres Treated	1,971,451
Biomass Chips Produced (BDT)	20,804,604
Sawlogs Produced (mbf)	15,682,776

Table 28 - Acres treated by decade per scenario under the Test Scenario

	2006	2016	2026	2036
Test Scenario	525,825	447,478	538,485	459,663

3.2. Wildfire Behavior

Wildfire is one of the most critical variables being tested through the use of the B2E model. Since the key objective of the model was to test the effect of thinning on fire extent and severity, the model needed to show sensitivity to the effects of thinning operations. Table 27 above shows the average BDTs removed per acre during the entire 40-year modeling period. This shows a gross level of change in the fine fuels present, available for burning in wildfire.

The fire behavior domain team modeled wildfire behavior under the Reference Case (no treatment) and the Test Scenario. Under the Reference Case, weighted average biomass levels were 79 bone-dry tons (BDTs) per acre; under the Test Scenario, private land treatments removed an average of 31 BDTs/acre, while SPLATs and DFPZs removed an average of 24 BDTs/acre (Appendix 8, Table 1).

While the ownerships, forest type, density and slope dictated the type of treatment prescriptions, the wildfire modeling found that the spatial arrangement of treatments has a greater impact on their ability to change fire intensity and extent than the prescription applied (see Appendix 8). The Test Scenario fires were modeled with spatial adjustments of treatments to protect sensitive wildlife habitat, reduce negative watershed effects, shape recreational opportunities, and capture timber volume under industrial private forest ownerships. The assumptions used in the spatial distribution of treatments are shown in the treatment allocation rule sets and logic described in the vegetation domain appendix.

The wildfire behavior modeling showed a 22% reduction in extent of wildfire compared to the Reference Case (Table 29). The second decade shows the greatest impact on reducing overall wildfire perimeters (Table 29). One might expect to see a similar trend for reducing fire perimeters across all four decades. However, differences due to modeling assumptions and fire ignition locations may explain the variance from the downward trend in the third and fourth decades under the Test Scenario. The substantial changes in decade two are most likely attributable to the location of the ignitions, higher proportion of private industrial ownership, and the topography within the fire perimeters.

Table 29 - B2E burned areas by scenario and by year

Year	Reference Case	Test Scenario
2006	92,684	80,487
2016	60,153	39,846
2026	69,953	44,385
2036	76,543	67,796
Total Acreage	299,334	232,514
% Change from Reference Case	0%	-22%

As would be expected, the Reference Case generated more acres burned compared to the Test Scenario, with an average of 74,833 acres burned per decade. Ignoring the small fires, the B2E Beta landscape's fire history on record (last 80 years) averaged approximately 65,000 burned acres per decade. Wildfire behavior modeling for the B2E Beta test attempted to mimic the fire history on record, burning 65,000 acres in a variety of fire sizes and intensities.

Evaluations of fire hazard mitigation programs tend to focus primarily on changes in the number of acres burned (since those are easiest to monitor). However, the B2E fire modeling also captured changes in the severity of fires. Across the Reference Case and the Test Scenario, approximately 32 % of the acres burned were characterized as non-lethal, that is, surface fires with flame lengths between one and four feet (Table 30). This acreage corresponds well with the Forest Service's wildfire severity monitoring for the Sierra Nevada (Miller and Fites 2006), in which the authors found that approximately one third of the area of large fires burns in the "non-lethal" severity class.

Table 30 - Fire Severity for Modeled Wildfires Under the Reference Case and Test Scenario

Fire Severity Class	Reference Case	% of acres burned	Test Scenario	% of acres burned
N - nonlethal	81,471	27%	86,586	37%
X - mixed lethal	136,887	46%	98,560	42%
L - lethal	80,976	27%	47,368	20%
Grand Total	299,334	100%	232,514	100%

Fire severity classes are important to the B2E modeling because many of the downstream models evaluate the effects of fuel treatment scenarios based upon the three severity classes. For instance, consumption rates for canopy fuels and resultant wildfire emissions for green house gases are all modeled and calibrated based on fire severity classes.

The percentages of acres with lethal and mixed-lethal fire severity classes were highest in decade two (Table 31). Only decade three showed a decrease in the number of acres in the non-lethal severity class (3,880 acres) but that is due to the dramatic drop in total acres burned from implementing both public and private treatments in this particular decade with a combined reduction of 25,568 acres or a 36.5% reduction from the Reference Case (Table 32).

Table 31. Fire severity results comparing reference to test

		Fire Severity Classes		
	Year	Non-Lethal	Mixed Lethal	Lethal
Reference Case	2006	36,579	33,176	22,929
	2016	19,447	20,947	19,759
	2026	19,296	31,691	18,965
	2036	6,148	51,072	19,324
Test Case	2006	37,889	24,740	17,858
	2016	19,914	15,452	4,480
	2026	15,417	18,496	10,472
	2036	13,366	39,873	14,557

Overall, the results of the vegetation and fire modeling show a reduction in acres burned and the severity with which those acres burned. This demonstrates successful implementation of the interactive vegetation and fire modeling. In terms of treatment efficacy, the modeling confirms increasing experience in the management community as well as empirical measurements in the literature: treatments can have a positive effect on reducing the extent and severity of wildfire at the landscape scale.

3.3. Life Cycle Assessment Results

3.3.1. Gross Inventory Results

The gross inventory assessment estimated the life cycle energy use and emissions for the Reference Case and the Test Scenario assuming use of the current generation biomass combustion power plant and as the treatments would be performed (as described in Section 2.0). The Test Scenario in the gross assessment was assumed to produce different amounts of sawlogs and biomass electricity over the 40 study years (Table 32).

Table 32. Gross assessment system products

	Reference Case: No treatment	Test Scenario: Treatments on IPF , NIPF, and PMU lands
Landscape managed (acres)	2,700,000	2,700,000
Area treated (acres)	0	1,971,451
Sawlogs produced (dry tons)	0	31,000,000
Biomass electricity generation: current generation biomass combustion power plant (MWh)	0	19,000,000
Installed biomass electricity generation capacity (MW)	0	61

Table 33 presents the gross inventory analysis results for the Test Scenario, including the life cycle energy use and emissions for harvest equipment operation (including forest treatment and chip transport), underburning, and power plant operations. Total life cycle energy includes the life cycle for fuels used by harvest equipment and during chip transport and for energy use by the power plant (for example, diesel use for forklifts and use of propane for building heat and plant start up), as well as the energy contained in the chips, minus the energy *generated* by the power plant. Because the power plant was assumed to operate at a20 percent conversion efficiency the energy in the chips dominates total energy consumption.

Table 33 - Gross life cycle inventory results for Test Scenario

		Life Cycle for Harvest Equipment Operation and Chip Transport	In-Forest Underburning	Life Cycle of Power Plant Operation	Total Test Scenario
Total energy consumed	mmBtu	2,924,894	-	291,970,023	294,894,918
Fossil energy consumed	mmBtu	2,861,358	-	809,596	3,670,954
Petroleum energy consumed	mmBtu	1,354,024	-	154,141	1,508,165
NMVOC emissions to air	tons	884	27,789	3,601	32,275
CO emissions to air	tons	3,112	120,892	33,153	157,157
NOx emissions to air	tons	1,750	1,125	14,322	17,197
PM10 emissions to air	tons	356	11,599	9,765	21,719
SOx emissions to air	tons	248	736	1,660	2,644
CH4 emissions to air	tons	1,649	5,690	1,689	9,027
N2O emissions to air	tons	29	150	4,377	4,556
CO2 emissions to air	tons	1,182,172	1,576,269	40,834,701	43,593,142

Beyond the total life cycle energy, life cycle fossil and petroleum consumption for the gross assessment was dominated by fuel use for harvest and chip transport (as expected). For emissions, in-forest underburning becomes important in the Test Scenario for NMVOC and CO emissions. Finally, power plant operations account for approximately 94% to total system emissions in raw tons.

3.3.2. Gross Impact Characterization

Table 34 presents the estimated life cycle contribution to climate change, acidification, and smog formation for the gross assessment of the Test Scenario. These results were based on the inventory results presented in Table 33 above and the equivalency factors described in Section 2.0.

Table 34. Gross assessment of climate impact categories from LCA

Impact Category	Units	Life Cycle for Harvest Equipment Operation and Chip Transport	In-Forest Underburning	Life Cycle of Power Plant Operation
Climate Change	tCO2e	1,200,000	1,700,000	42,000,000
Acidification	tH+e	83,000	82,000	660,000
Smog formation	tNOxe	2,500	2,040,000	18,000

Finally, Table 35 presents the gross assessment energy consumption, PM_{10} emissions, and impact characterization results normalized by the 40-year California contribution to each flow or impact using the normalization factors presented in Section 2.0. As shown, the life cycle total energy is estimated to approach a 0.1 percent increase in the California total for the Test Scenario. Normalized values are less than 0.1 percent of the California totals for fossil and petroleum consumption and contribution to acidification.

Table 35. Gross assessment impact normalization (as percent of California impact)

	Total energy	Fossil energy	Petroleum energy	Climate change	Acidification	Smog formation	PM_{10} emissions
Test Scenario	0.12%	0.0019%	0.00080%	-0.18%	0.023%	0.18%	1.4%

3.3.3. LCA Interpretation

The gross assessment results for the Test Scenario above are not technically comparable to any other possible scenarios for three reasons: (1) different scenarios would produce different amounts of sawlogs, (2) different scenarios would produce different amounts of electricity, and (3) different scenarios result in a 2.7 million-acre landscape characterized by differing management outcomes, as measured by extent and severity of wildfire. In LCA terminology, the systems represented by different scenarios would be multifunctional, and the LCA standards followed in this study provide computational remedies for managing multifunctional systems. In LCA terms, co-products are products produced but not used within the system boundaries. (In the Test Scenario, sawlogs are a co-product.) There are three computational options for the management of co-products in life cycle assessments:

1. system expansion (subtracting from the inventory analysis the life cycle energy use and emissions for an alternative means to produce the co-product),

2. allocation (dividing the energy use and emissions among process products and co-products on the basis of the equipment applied, stoichiometry, or co-product mass, energy, or economic value), or

3. ignoring the co-products (which is essentially what has been done in the gross assessment described in this Section).

System expansion is the preferred method when an alternative means to produce the co-product exists (such as another way to produce electricity or sawlogs), with most LCA practitioners using allocation when system expansion is not feasible.

The importance of these computational remedies cannot be overstated. In order to facilitate a net or comparative assessment (for example, the comparison of ways to produce electricity), credit (or subtraction) must be used for system co-products as needed to model systems that produce only one product. For example, consider the net assessment defined in Table 36, in which the electricity generation system was designed to produce only electricity.

Table 36. Net assessment system characteristics (electricity only)

	Electricity generation systems
Final product	Electricity
Magnitude of service	per MWh
Duration of service	40 years
Expected level of performance	Continuous electricity generation
For comparison to	Electricity generation by conventional means such as using the California grid or a natural gas power plant
What needs to be done computationally	Remove energy use, emissions, and impacts for sawlog production

The assessment of the electricity generation system defined in Table 36 follows below for the comparison of different electricity generation systems. In this net assessment, energy use, emissions, and impacts for sawlog production were removed from the gross assessment results using allocation, because system expansion was deemed infeasible in the absence of a viable process to generate sawlogs only. To remove sawlogs from the assessment, the harvest and chip transport equipment were first grouped as that dedicated to chip production, to sawlog production, or to both. Next, fuel and oil use and emissions for chips were estimated to include that for equipment dedicated to chips and that for equipment dedicated to both chips and sawlogs, with the latter mass allocated to the amount of sawlogs produced. Thus, a combination of process-based and mass allocation was used in the net assessment.

3.3.4. Comparison of biomass electricity generation systems

A comparison of different electricity generation systems follows, using the assessment of the electricity generation system defined in Table 36. In this net assessment, energy use, emissions, and impacts for sawlog production were removed from the gross inventory assessment using an allocation method. A system-expansion method was deemed infeasible in the absence of a viable process model that would show the inputs, processes and emissions for sawlog production only. To remove sawlog-related processes from the assessment, the harvest and chip transport equipment were first grouped as those processes dedicated to chip production, those processes dedicated to sawlog production, or those processes dedicated to both. Next, fuel consumption, oil use and emissions for chip production were estimated for equipment dedicated to chip production and for equipment dedicated to both chips and sawlogs. The latter were mass-allocated to the amount of sawlogs produced. Thus, a combination of process-based and mass-based allocation methods were used in the net assessment.

The comparison of electricity generation systems, detailed in the LCA Domain Report (Appendix 4), offers at least two important insights into the system. First, the effect of the low B2E power plant efficiency on the total life cycle energy consumption is revealed, reflecting the differences in the source-to-point-of-use efficiency of conversion of fuel type to energy output for each system: 35 percent efficiency for the natural gas power plant; 45 percent efficiency for the California grid; and 18 percent efficiency for the Test Scenario. Second, the life cycle consumption of fossil and petroleum fuel and the contribution to acidification for the Test Scenario are estimated to be less than that needed to produce equivalent amounts of electricity using conventional means (i.e., NGPP or the California grid).

Alternative Power Plant Technologies

In Figure 9, life cycle energy is dominated by the difference between the energy embodied in the chips and the biomass electricity generated, again ultimately reflecting the power plant efficiency. Table 37 provides characterizations of a current generation integrated gasification/ combustion power plant and a next generation thermochemical conversion power plant as described in Nechodom et al. (2008). In all cases, the supporting equipment energy use and emissions were assumed to be consistent with that of the current generation combustion plant characterized in Section 2.0 , with the exception of the use of grate grease, which was assumed only to be applicable in operations at the current-generation combustion power plant. The LCA Domain Report in Appendix 4 presents the inventory data used for the biomass power plant, considering the species of trees used and the heating values described in Section 2.0. An 8 percent transmission loss is also assumed when calculating total power plant efficiencies.

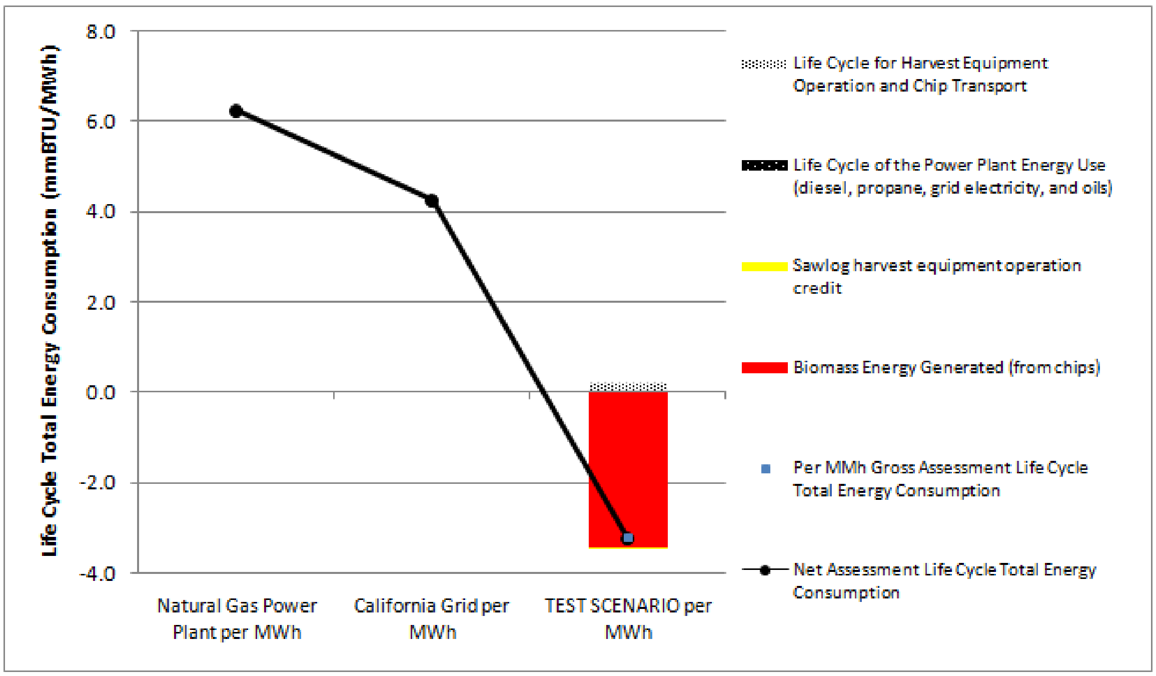

Figure 9 - Life cycle energy consumption net assessment

In order to show the effects of power plant efficiencies, Table 37 presents the two other biomass conversion systems modeled for the final report of the B2E project. These characterizations are important to understand in the context of the net assessment, which compares the assessment impacts depending on which technology is selected. Power plant efficiencies range from 18% for the current generation combustion plant used in the gross assessment to 28% for the thermochemical conversion technology. A complete characterization of all technologies used in the B2E project is available in the LCA Domain Report (Appendix 4) and in Nechodom, et al. (2008).

Table 37. Power plant characterizations for net assessment comparison

	Current Generation Integrated Gasification/ Combustion Power Plant	Next Generation Thermochemical Conversion Power Plant
Electricity (kWh/dry ton)	1,200	1,400
Plant Energy Efficiency	22%	28%
Plant Emissions (lbs/mmBtu output)		
NOX	0.067	0.0084
SOX	0.010	0.0016
PM	0.030	0.032
CO	0.070	0.042
NMVOC	0.018	0.0031
CO_2	890	690
CH_4	19	19
N_2O	0.065	0.065

Table 38 presents the LCA results for all three power plant technologies based on the forest management net assessment, in which the managed acres are held constant in order to compare life cycle impacts from electricity generation.

Table 38. Life cycle impacts of the three modeled B2E power plant technologies

		Current Generation Biomass Combustion Power Plant	Current Generation Integrated Gasification/ Combustion Power Plant	Next Generation Thermochemical Conversion Power Plant
Landscape managed	Acres	2,700,000	2,700,000	2,700,000
Area treated	Acres	1,971,451	1,971,451	1,971,451
Total energy consumed	tera Btu	170	150	99
Fossil energy consumed	tera Btu	(120)	(130)	(160)
Petroleum energy consumed	tera Btu	(0.78)	(0.96)	(1.50)
Climate Change	million tons CO2 equiv	5.90	4.60	0.37
Acidification	million tons H+ equiv	0.47	(0.02)	(0.43)
Smog formation	million tons NOx equiv	0.24	0.23	0.22
PM10 emissions to air	million tons	0.12	0.11	0.11

3.4. Landscape Greenhouse Gas Model

The results from the LGHG model were found to be divergent from the results of the LCA model. However, as a generalized model of GHG fluxes between above ground biomass and the atmosphere, it provides some useful insights. According to the LGHG model, both the Reference Case and the Test Scenario show net increases in carbon in above-ground live biomass. Over the 40-year timeframe of the B2E model, the Reference Case sequesters approximately 100,000 tons of CO2 from the atmosphere, while the Test Scenario removes more than 125,000 tons. Even calculating the release of CO2 from powerplant operations, the net CO2 sequestered in the forest remains positive when compared to the amount of CO2 released by fossil-fuel generation.

The consultant report in Appendix 9 shows a positive relationship between thinning and reduction of CO_2 and CH_4 emissions. When projected over a 100-year timeframe (the commonly accepted time period during which CO_2 "clears" from the atmosphere), Morris shows that the "net biogenic greenhouse gas reduction associated with treatments remains greater than 1 ton of CO_2 equivalents per bdt of treatment removal…".

3.5. Wildlife Habitat Effects

Wildlife habitat effects are measured through changes in vegetative structure. The underlying data for analyzing habitat effects associated with any kind of disturbance, whether wildfire or treatments, are derived from the vegetation dynamics analysis. Data extraction and assumptions are described above in the Approach section, and results are reported here in the following three categories: (1) changes in forest structure; (2) impacts on forest-structure associated species; and (3) changes in service providing units (SPUs). A case study focused on American marten habitat was developed as a complement to the B2E project to test the sensitivity of the B2E habitat modeling against observed marten occupancy data in the Sierra Nevada. Detailed results of effects on American marten habitat from disturbance regimes modeled in the B2E project are reported in Appendix 5.

3.5.1. Forest Structure

Changes in forest structure are measured by two variables: canopy closure and average tree diameter. Prior to treatment, the B2E landscape was predominantly in a high canopy closure condition, with approximately 45% of the landscape characterized by dense canopy closure (greater than 60% or D closure class), and 25% of the landscape characterized by moderate canopy closure (40 to 60% or M closure class). The Reference Case, without treatment, resulted in an increase in the proportion of the landscape with dense canopy closure (D) from 45% to nearly 70% and a decrease in moderate canopy closure (M) to approximately 5%. In contrast, the Test Scenario remained largely unchanged over the duration of the 40 year treatment period. There was a significant difference in the three higher canopy closure classes in the Reference Case, with open (25-40% orP) and moderate (M) canopy closure classes declining and the dense (D) canopy cover class increasing relative to the Reference Case.

Prior to treatment, approximately 50% of the landscape (over 60% of the forested area) was occupied by small diameter forests (average diameter of 12 to 24 inches dbh; diameter class 4), with an additional 20% of the landscape (approximately 35% of the forested area) occupied by medium/large diameter forests (mature forest; average diameter >24 inch dbh; CWHR diameter classes 5 and 6). Pole stands (diameter class 3) occupied less than 3% of the landscape, with the remaining landscape occupied by non-forested habitat conditions.

The Reference Case and Test Scenario differed greatly in the amount of the landscape in small diameter (class 4) and medium/large diameter (class 5/6) forests. In the Reference Case, the proportion of the landscape in small and medium/large diameter forests switched in dominance over the 40-year period, such that at the end of the treatment period, 60% of the forested area was occupied by medium/large diameter trees and 30% occupied by small diameter forest (Figure 10). In the Test Scenario, the proportion of the landscape in small diameter and medium/large diameter forests converged over the course of the modeling period to where each diameter class occupied approximately 35% of the landscape (Figure 11). No change occurred in the number of acres of pole forests (diameter class 3) in the Reference Case or Test Scenario.

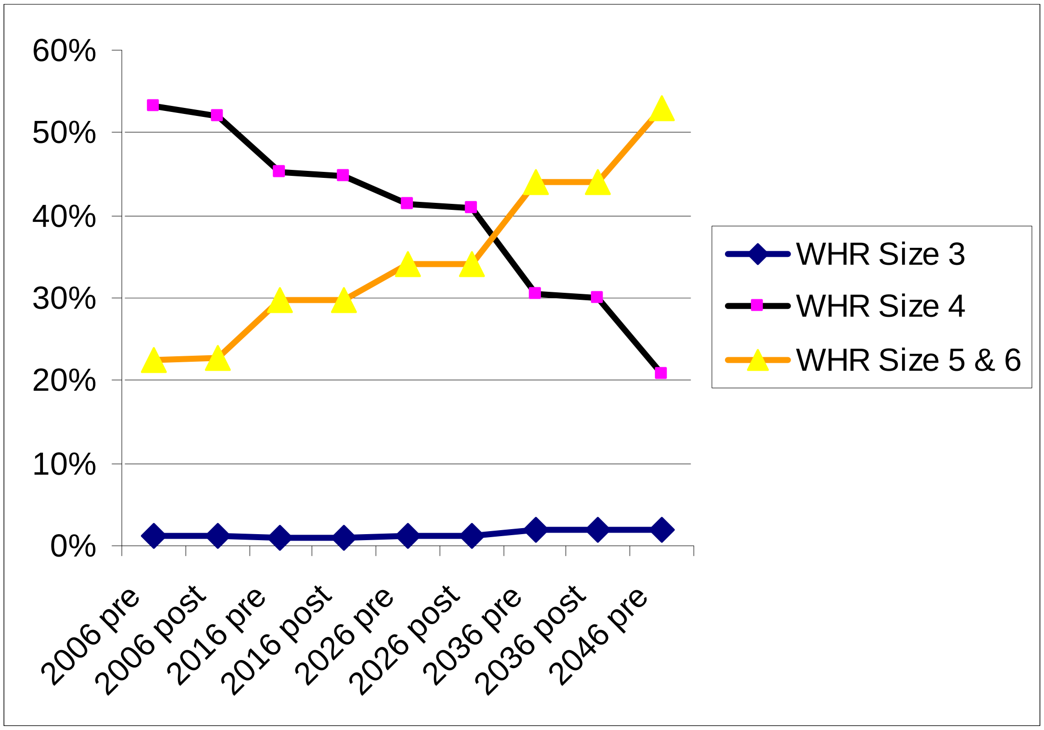

Figure 10 - Changes in Diameter Class, Reference Case Define key.

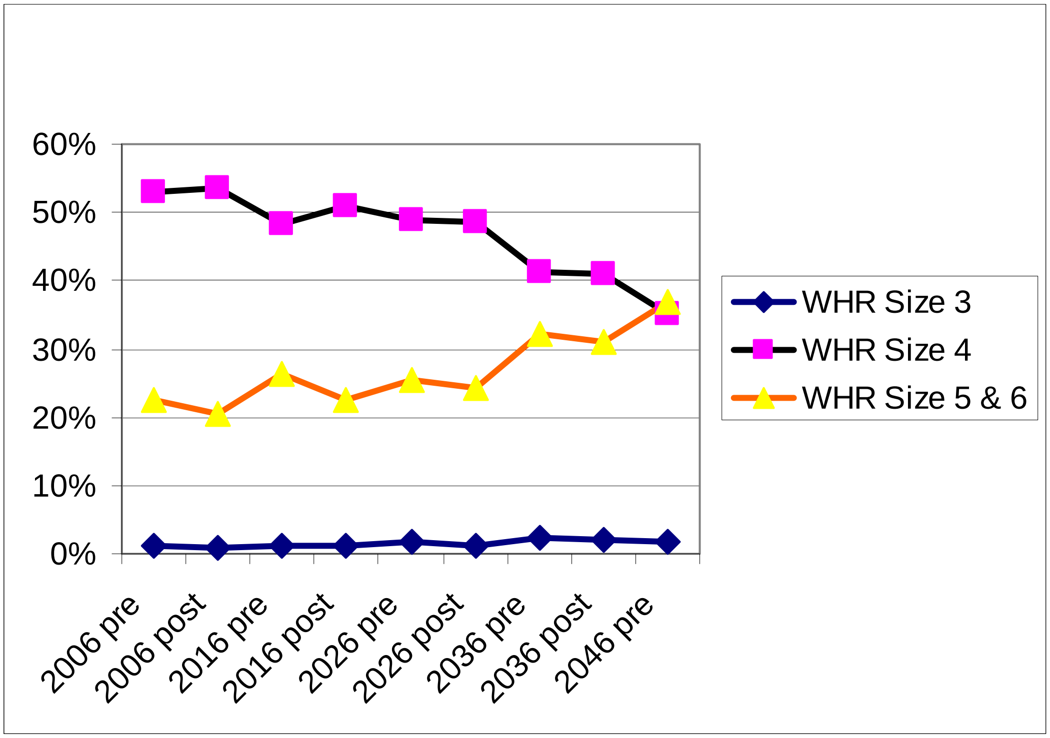

Figure 11 - Changes in Diameter Class, Test Scenario Define Key

CWHR forested habitat types are defined by a combination of vegetation type, canopy closure and average diameter. Prior to treatment, nearly 50% of the landscape was occupied by small diameter forest with higher canopy closure (4MD), typically considered mid-seral conditions, and most of the remaining forested area (20% of the landscape) was medium/large diameter with higher canopy closure (5/6MD), typically considered mature or old forest conditions (Figure 12). Changes in average tree diameter made the greatest difference between the Reference Case and the Test Scenario. In the Reference Case, the landscape was dominated by mid-seral forests (4MD) in the first decades, and changed to an old forest dominated landscape (5/6MD) toward the end of the modeling period (Figure 12). Old forests increased from about 25% of the landscape to about 50% of the landscape, whereas mid-seral forests declined from nearly 50% of the landscape to 20% of the landscape by the end of the 40-year cycle. In the Test Scenario, mid-seral and old forests equalized by the end of the treatment period, indicating that both treatment and fire resulted in a decline in old forest conditions. In addition, open-canopied small diameter forest (4SP) increased slightly to 5 to 10% in the Test scenario.

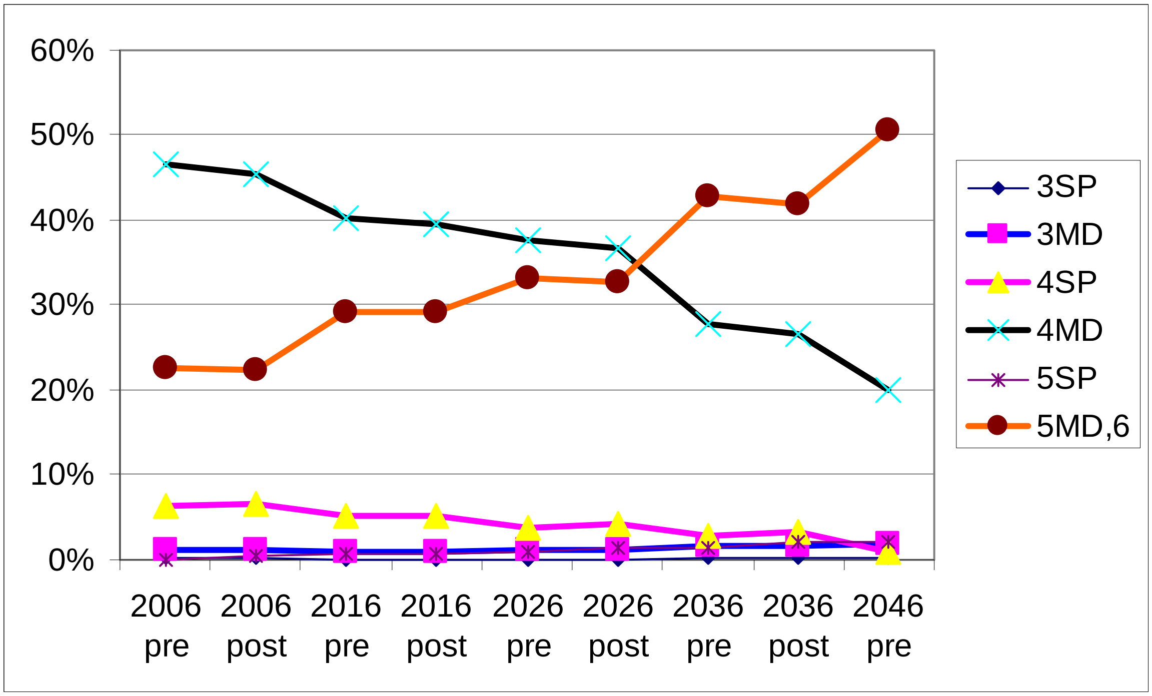

Figure 12 - CWHR Types, Reference Case Define Key

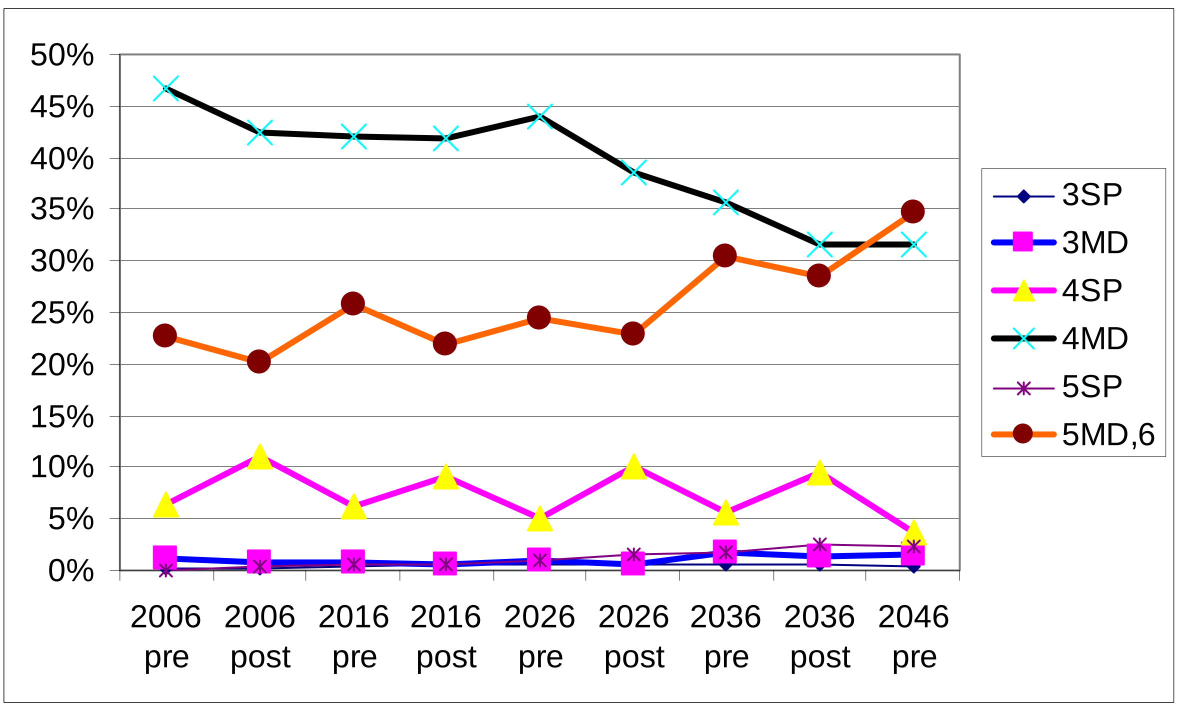

Figure 13 – California Wildlife Habitat Relationships habitat types, Test Scenario

Patterns of change within old forest conditions (5MD,6), revealed that mid-seral forests had approximately half moderate (M) and half dense (D) canopy closure, whereas almost all of old forests had dense (D) canopy closure (Figure 14). Thus, prior to treatment, the landscape was two-thirds mid-seral and one-third old forest conditions (one-third each of 4M, 4D, and 5/6D). In the Reference Case, these three conditions diverged over the course of the modeling period, resulting in old forests with dense canopy closure increasing from 25% to 50% of the landscape, mid-seral with dense closure declining slightly, and mid-seral with a moderate closure nearly declining to zero. In the Test Scenario, the three conditions diverged only slightly, with a slight increase in old forest characteristics with moderate closure.

Within old forests alone, prior to treatment, none of the landscape fell into the medium to large diameter forest classification (diameter class 5) and only a limited amount of medium to large diameter forest remained on the landscape in both the Reference Case and Test Scenario by the end of the modeling period (Figure 15). This reflects the modeling assumption that, as small diameter forests grow, they become multi-layered old forests. In the Test Scenario, it appears treatments in old forests on private lands result in mid-seral conditions, whereas on public lands some remain old forests. This pattern reflects the differences in the types of treatments modeled on public and private lands.

Stand diameter was based on the quadratic mean diameter of the largest 75% of all trees. The use of this approach to determine average diameter is the reason so little of the landscape was classified as pole forests (diameter class 3). It is also likely that this diameter calculation reduced the magnitude of changes observed as a result of biomass removal, which primarily consists of removing smaller diameter understory trees. For example, if primarily smaller diameter trees are removed, then 75% of the remaining trees will consist of fewer small trees with a larger average diameter. Since canopy closure, or the density of tree crowns relative to openings in the forest canopy, is a strong proxy for old-growth forest habitat quality, this method is considered a legitimate means to measure habitat condition. However, it is relatively insensitive to changes in the understory, that is, the conditions created by the smaller trees growing beneath the canopy. Calculation of the quadratic mean diameter of all trees (not just 75% of trees) would likely render a more accurate picture of the effects of fuels treatments on both forest structure and wildfire behavior.

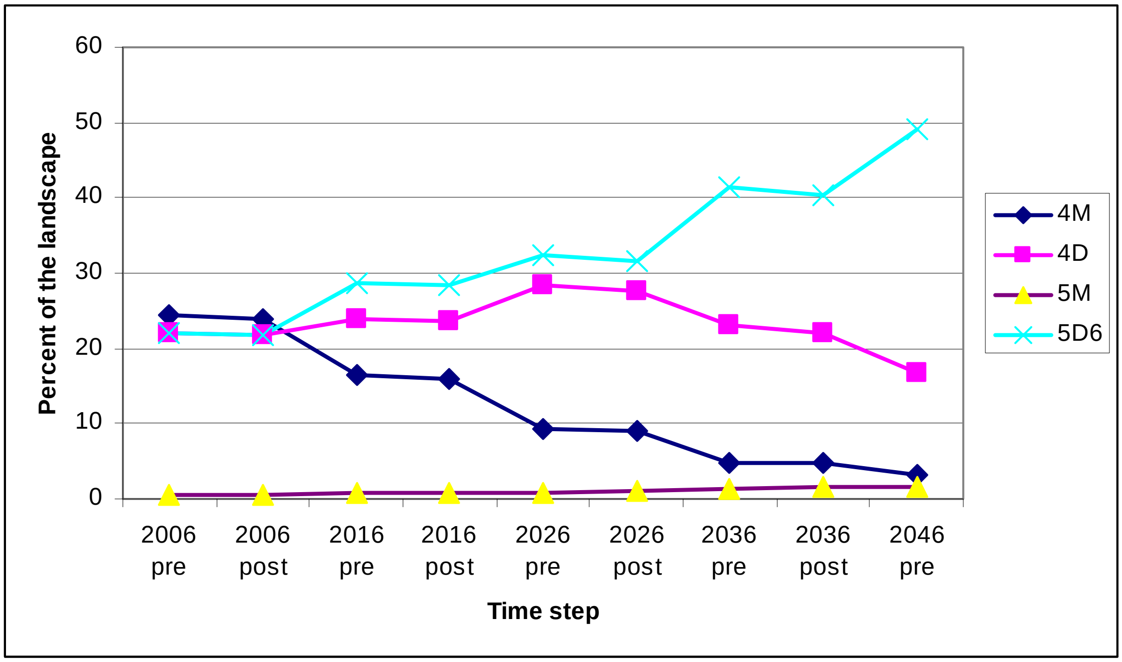

Figure 14 - Mid-seral (diameter class 4) and old forests (diameter class 5/6) with moderate (M; 40-60%) to dense (D, >60%) canopy closure, Reference Case

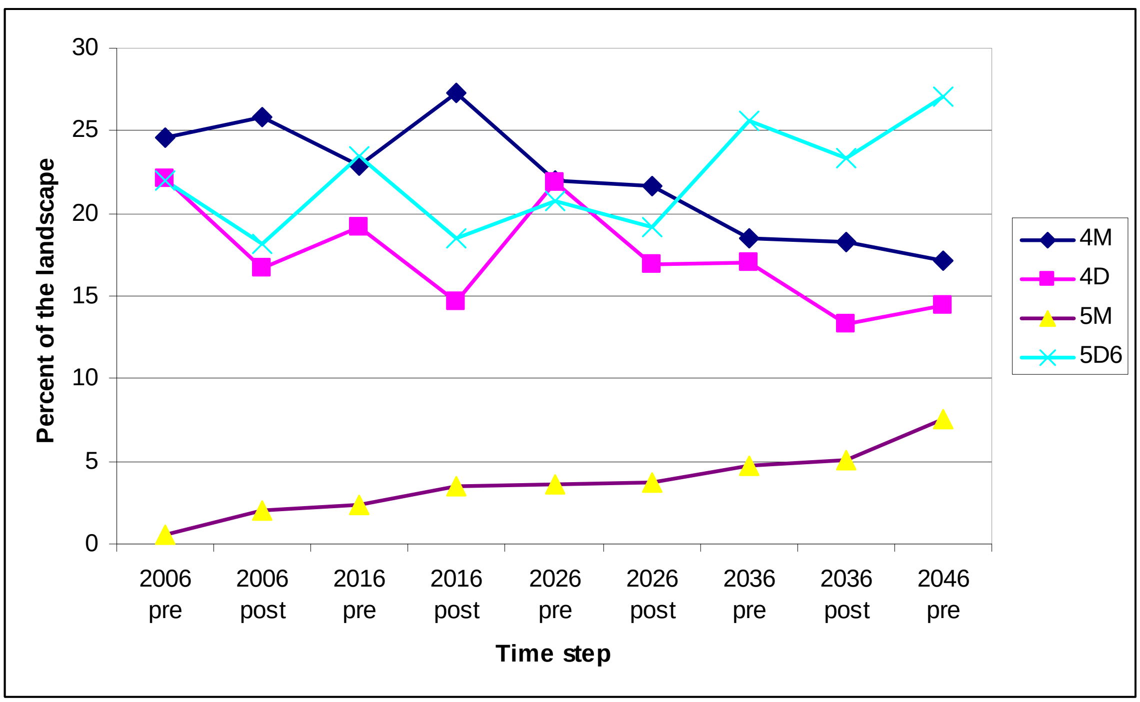

Figure 15 - Mid-seral (diameter class 4) and old forests (diameter class 5/6) with moderate (M; 40-60%) to dense (D, >60%) canopy closure, Test Scenario

3.5.2. Forest Structure Associated Species

Habitat guilds showed varied responses to changes in forest structure. Prior to treatment, nearly 70% of the landscape was occupied by 21 to 40 old forest associated species (n = 59 species total), followed by approximately 30% of the landscape occupied by 1 to 20 old forest species (Figure 16). No major changes were observed over time or between the Reference Case and the Test Scenario – in both, the proportion of the landscape with 21 to 40 old forest species declined by around 10%. However, in the Test Scenario the proportion of the landscape with greater than 40 species increased slightly (Figure 17). The team found that, according to CWHR, multi-layered old forests (diameter class 6) were considered to have lower suitability for a number of old forest associated species than single-layered old forests (class 5MD). Thus, as multi-layered forests were replaced by other conditions (e.g., small and medium/large diameter forests), CWHR indicated that habitat conditions improved for some old forest associated species.

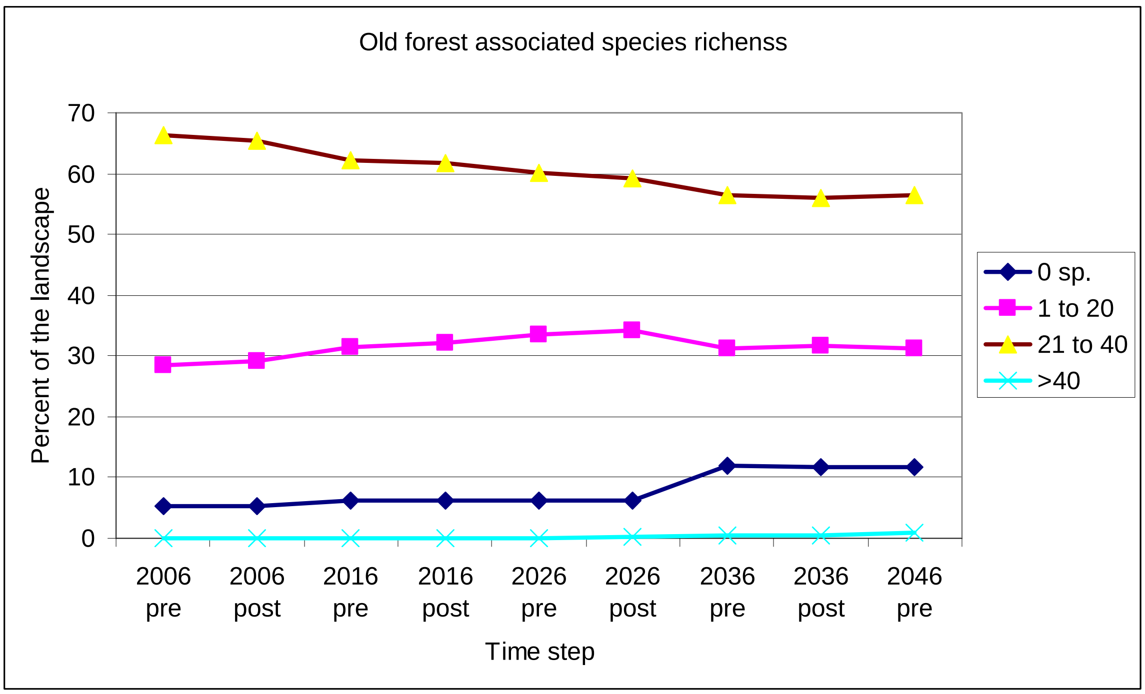

Figure 16 – Richness of old forest associated species (n = 59) supported across the landscape, Reference Case

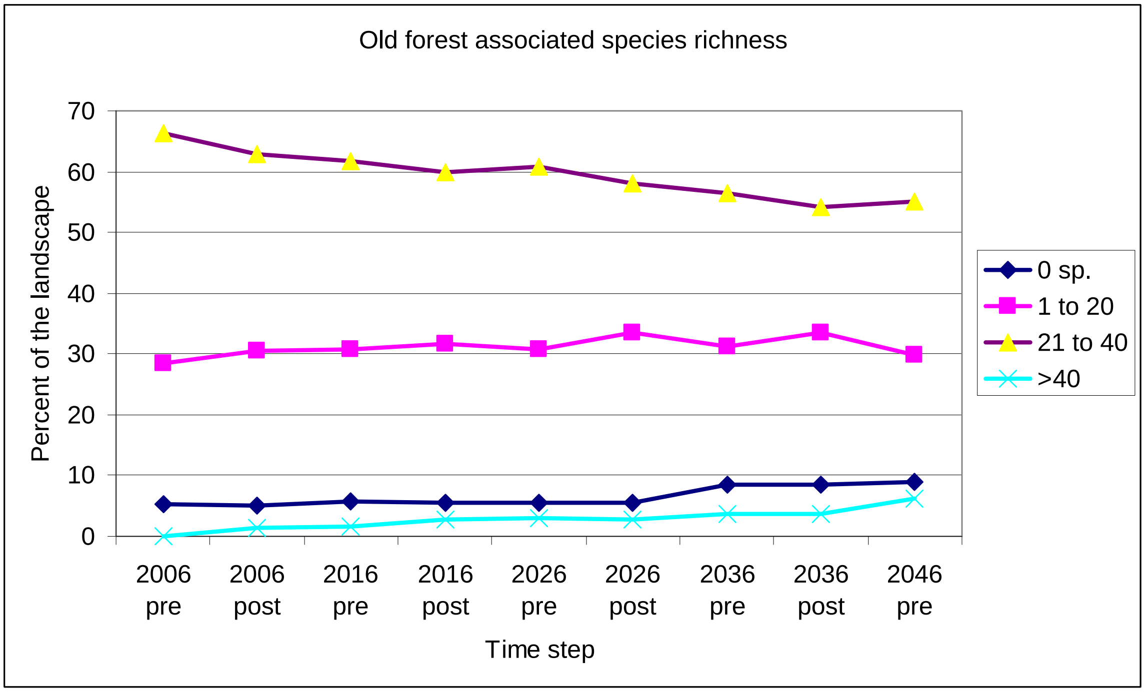

Figure 17 – Richness of old forest associated species (n = 59) supported across the landscape, Test Scenario

Patterns for old forest dependent species (which are a subset of 16 old forest associated species) were evaluated to see if they provided any additional information about the potential effects of harvest treatments on old forest associated species. Prior to treatment, nearly 40% of the landscape was occupied by the highest species richness class (>10 species), with the remaining landscape occupied equivalently (~20% each) by the other three richness classes (i.e., 0, 1-5, 6-10; Figure 18). In the Reference Case, an increasing proportion of the landscape supported high numbers of old forest dependent species, following the pattern seen in the kinds of multi-layered forests mentioned above. In the Test Scenario, the proportion of the landscape occupied by each of the richness classes did not change. However, the treatments in the Test Scenario reduced the species richness index from the highest richness class (>10 species) to the next lower richness class (6-10 species) immediately following treatment, then appearing to recover at the end of the 10-year growth period (Figure 19).

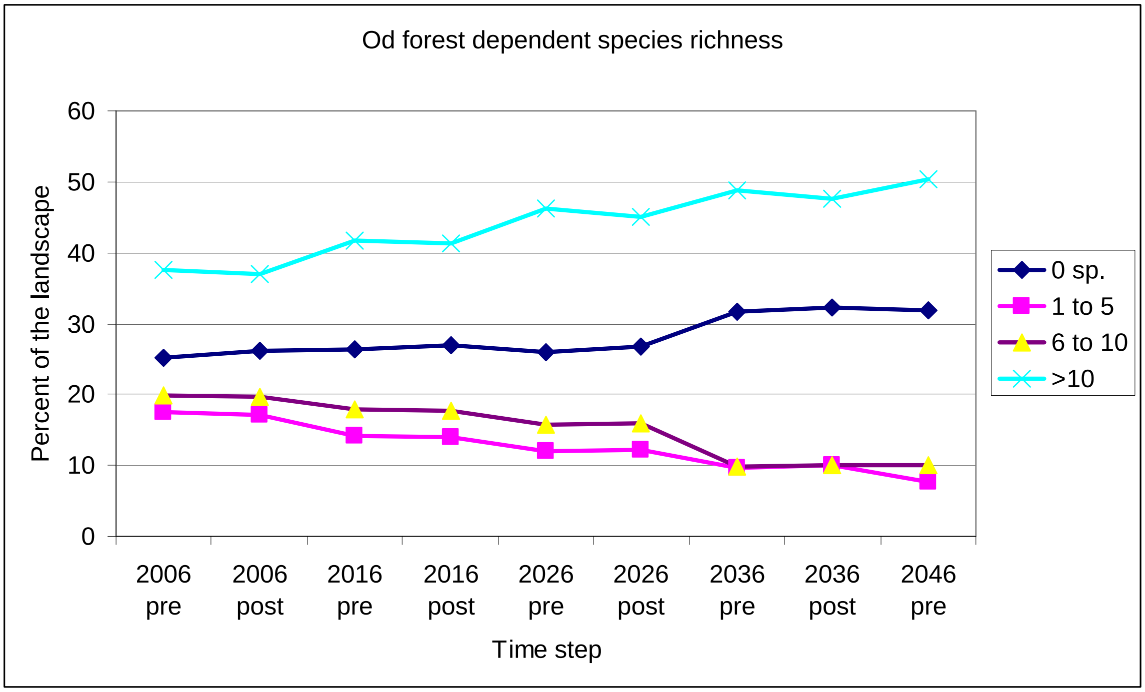

Figure 18 – Richness of old forest dependent species (n = 16) supported across the landscape, Reference Case

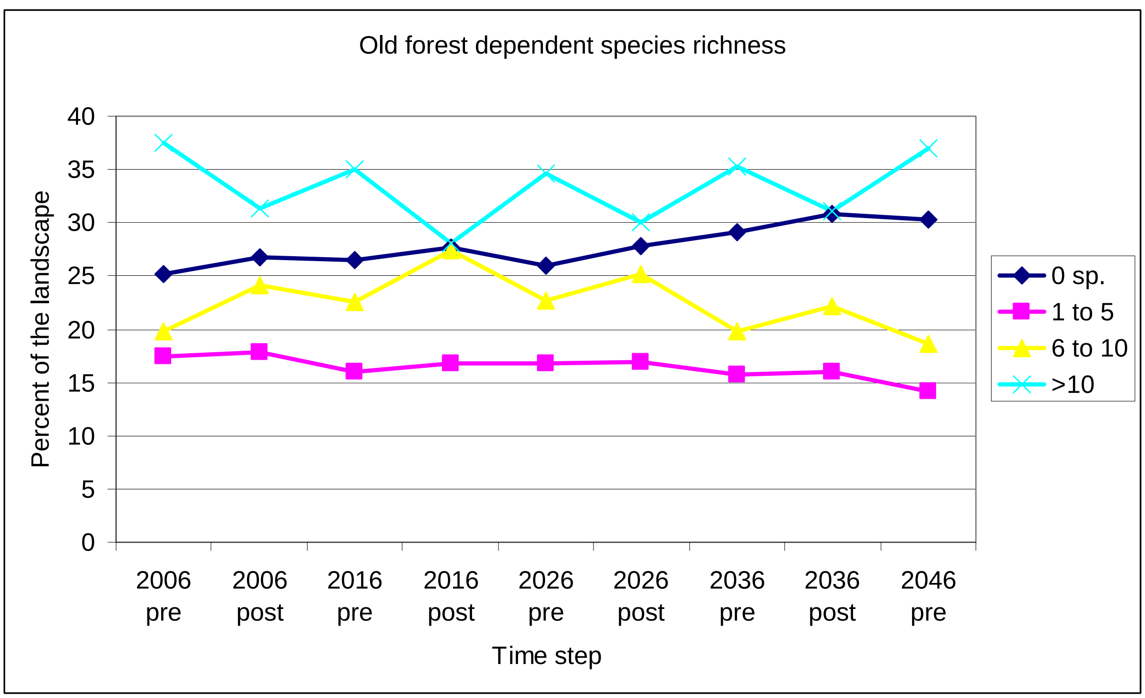

Figure 19 – Richness of old forest dependent species (n = 16) supported across the landscape, Test Scenario

The richness of early-seral associated species, that is, species that are best associated with the early stages of forest growth, (n = 118) followed the same pattern as changes in the prevalence of mid-seral and old forest conditions. Prior to treatment, approximately half the landscape supported 1 to 20 early-seral species, and the other half supported 20 to 40 early-seral species. In the Reference Case, approximately half of the sites supporting 20 to 40 species were reduced to supporting only 1 to 20 species. Little change was observed in the highest (>40 species) and the lowest (0 species) richness classes for early-seral associated species (Figure 20). In the Test Scenario, the richness classes remained relatively constant.

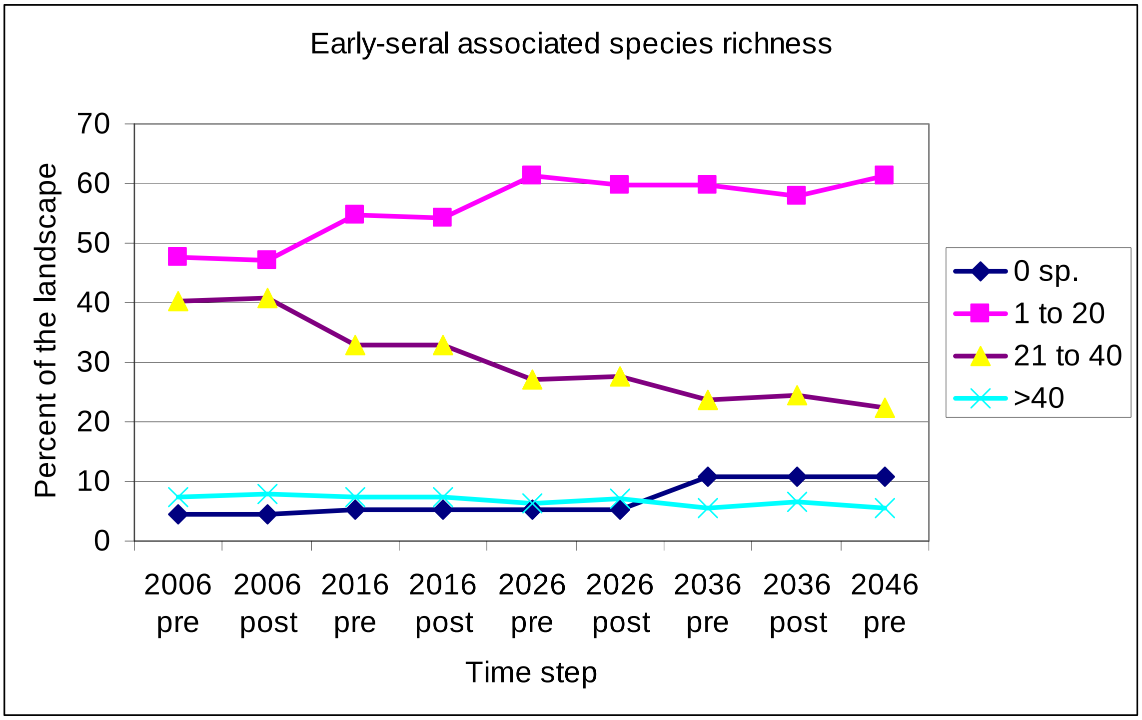

Figure 20 – Richness of early-seral associated species (n = 118) supported across the landscape, Reference Case

The final habitat guild evaluated was the oak and acorn associated species (n = 44). Prior to treatment, nearly 50% of the landscape supported 1 to 5 species, and nearly 30% of the landscape supported 5 to 10 species (Figure 21). In the Reference Case, an increasing proportion of the landscape (approximately 10% more) supported fewer oak associated species (1 to 5 species). However a roughly equal proportion supported the highest species richness class (>10 species) as seen in Figure 21. In contrast, the Test Scenario appeared to slightly improve conditions for oak associated species. Increases in oak associated species were significant with each increment of increasing treatment. The indications of these results would be strengthened if the presence of oaks in conifer forests could have been considered. However, data on the density of oaks was not available at the time of this analysis.

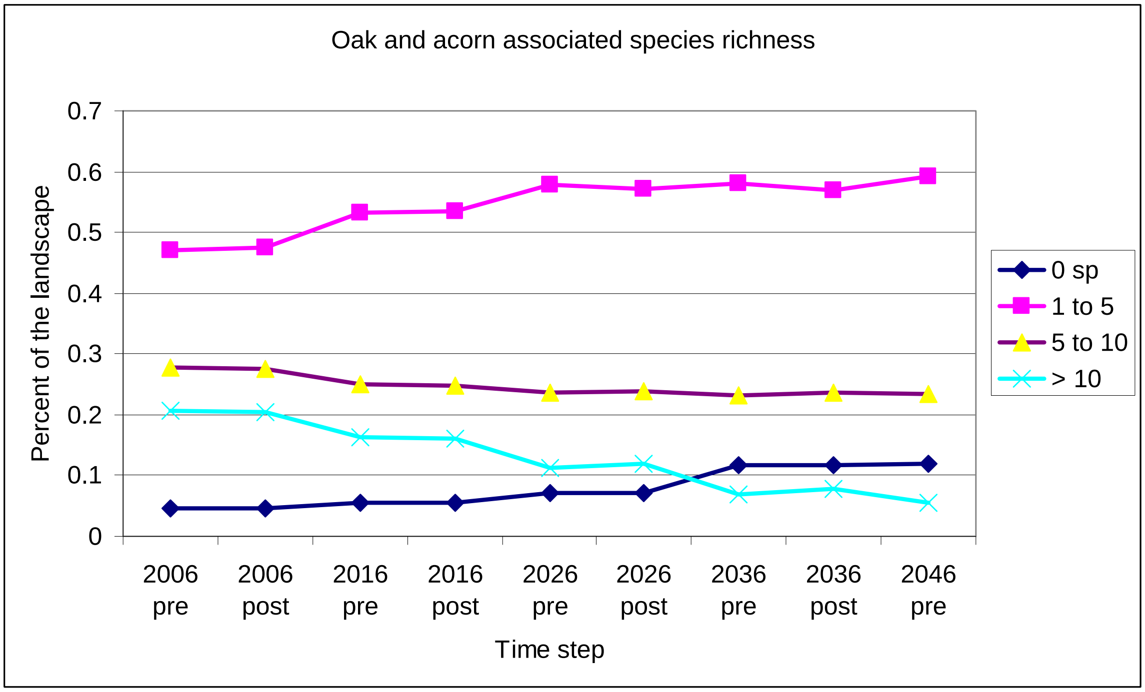

Figure 21 – Richness of oak and acorn-associated species (n = 44) supported across the landscape, Reference Case

The analysis of exotic species richness was not very informative. It simply showed that that proportion of the landscape with one or more exotic species started low (~10%) and did not change over time under the Reference Case or Test Scenario.

3.5.3. Service Providing Units

Seed dispersers (n = 22) and bioturbators (n = 15) had similar patterns of response within and among scenarios as early-seral associated species – as illustrated by the seed dispersers, which declined over time in the Reference Case (Figure 22), but remained at similar or higher levels over time in the Test Scenario (Figure 23).

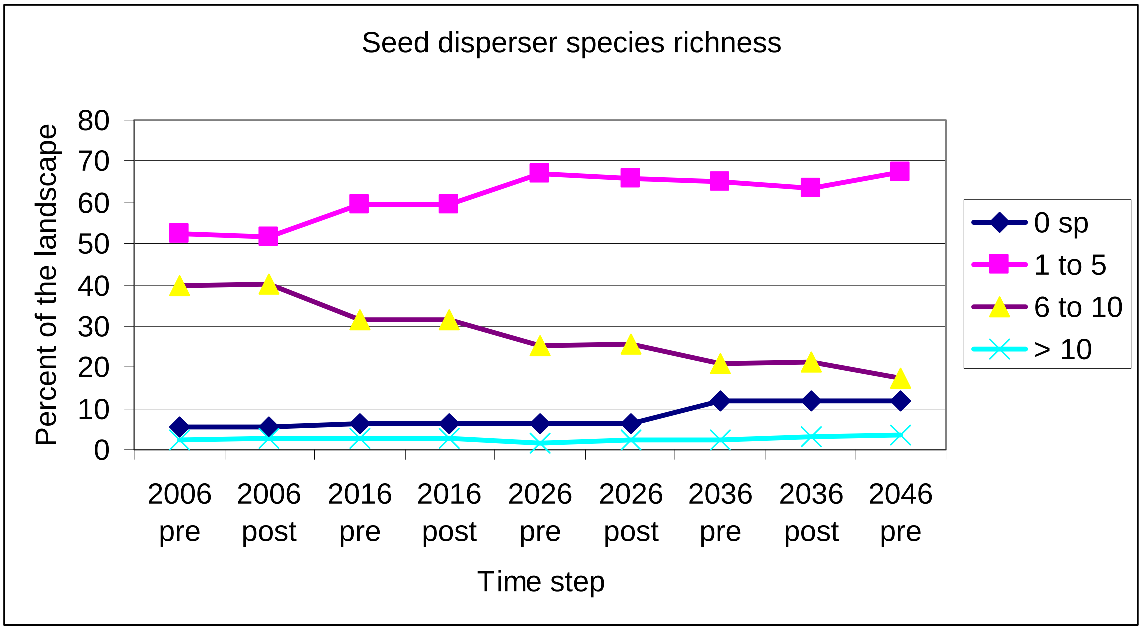

Figure 22 – Richness of seed dispersing species (n = 22) supported across the landscape, Reference Case

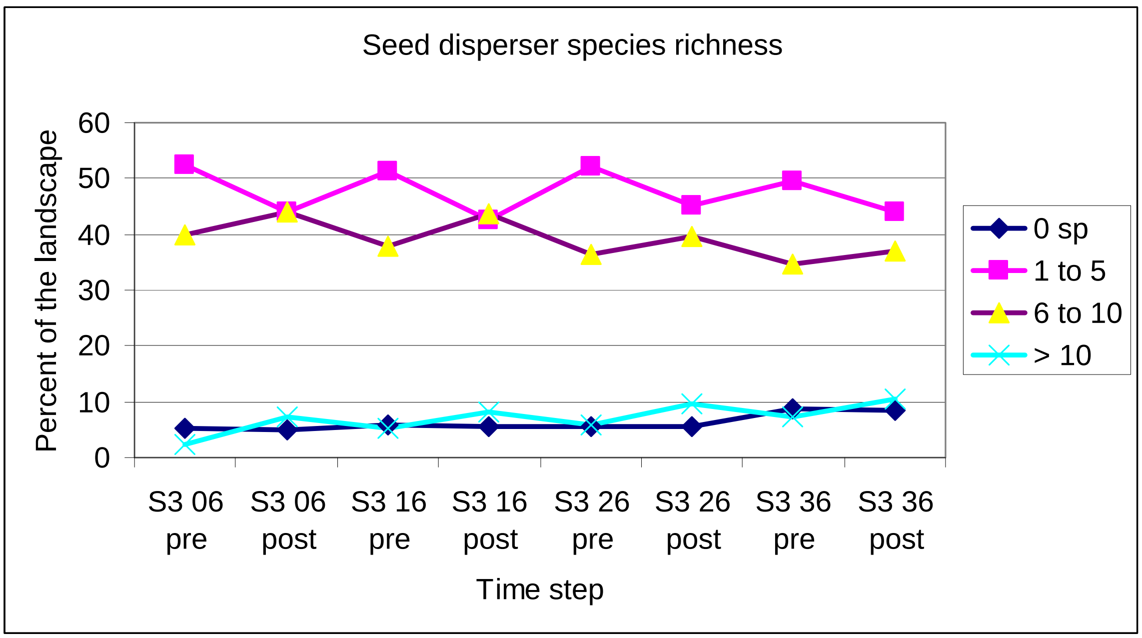

Figure 23 – Richness of seed dispersing species (n = 22) supported across the landscape in the Test Scenario

Pollinators (n = 3) and decomposers (n = 13) showed no substantive change either over the time of the study or between the Reference Case and the Test Scenario. Prior to treatment, less than 10% of the landscape had one or more pollinator species. No change was observed over time in the Reference Case. However the Test Scenario did show a 5% fluctuation in the proportion of the landscape supporting one or more pollinators, varying between 5% and 10%. Prior to treatment, 75% of the landscape supported one or more decomposer species. Both the

Reference Case and the Test Scenario showed about a 5% decline in the proportion of the landscape supporting one or more decomposer species.

Prior to treatment in the Test Scenario, approximately 15% of the landscape supported the highest richness (>40 species) of insect regulators (n = 93) and nearly 60% of the landscape supported 21 to 40 insect regulators, the second to the highest richness class for this guild. In the Reference Case, there was a 10% decline in the proportion of the landscape supporting the greatest richness of insect regulators, with a concomitant increase in areas that supported only 1 to 20 species, indicating a modest decline in the ability of the landscape to support a diversity of insect regulators. In the Test Scenario, the 20-to-40 species richness class declined and the 1-to-20 species richness class increased by about 10% each, indicating a minor decline in the landscape's ability to support a diversity of insect regulators as compared to the Reference Case.

Over 70% of the landscape supported habitat suitable for one or more herbivore regulators (top carnivores; n = 9), with 50% of the landscape providing habitat for 3 or more species (Figure 24). In the Reference Case, the proportion of the landscape supporting the highest species richness (>4 species) declined nearly 20% to 3 to 4 species (Figure 24). In the Test Scenario, only minor changes in species richness were observed and they appeared to balance out to minimal overall change in capacity to support herbivore regulators (Figure 25). No substantive response in the richness of secondary herbivore regulators (n = 21) was discernable over time for either scenario.

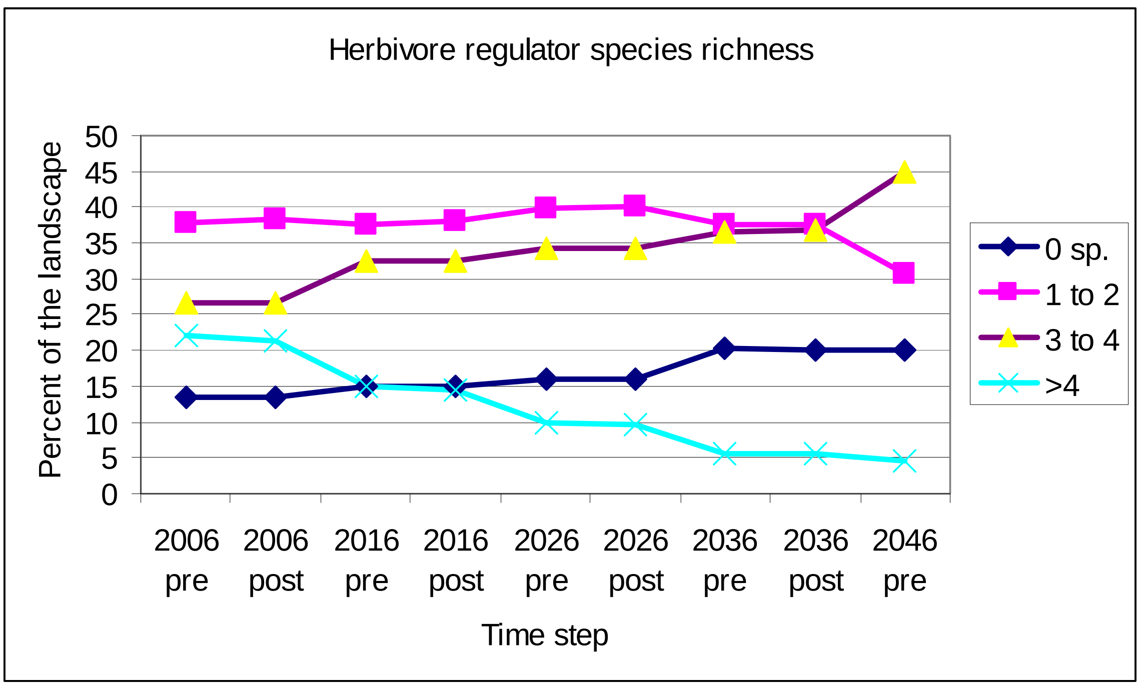

Figure 24 – Richness of herbivore regulating species (n = 9) supported across the landscape in the Reference Case

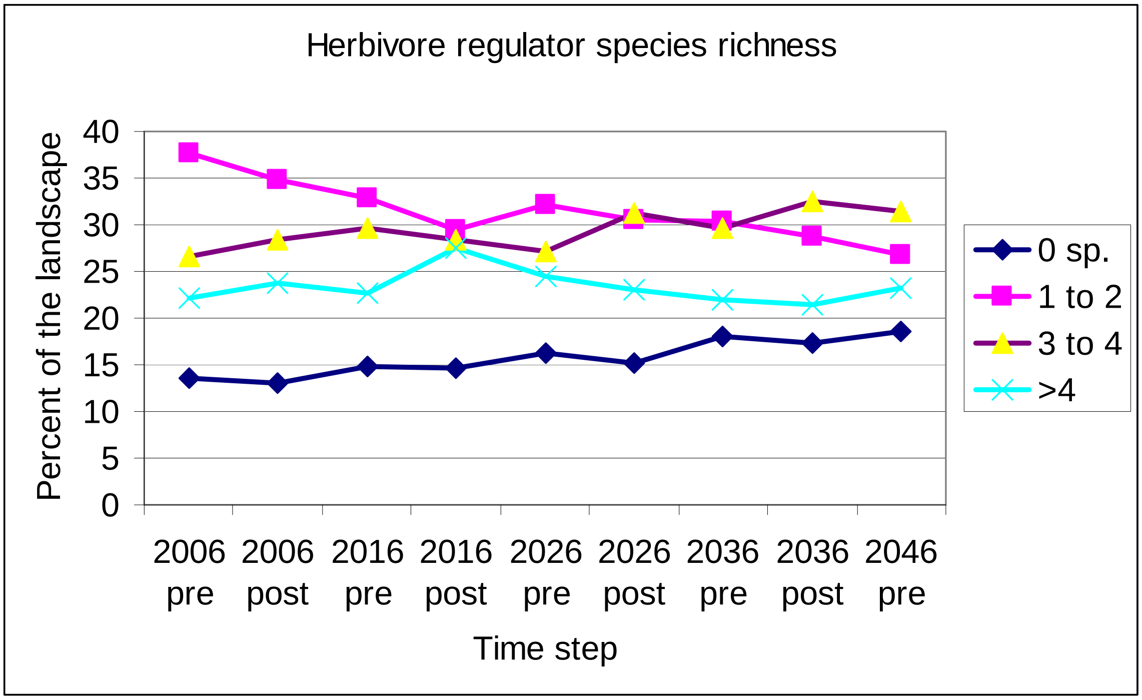

Figure 25 – Richness of herbivore regulating species (n = 9) supported across the landscape in the Test Scenario

3.5.4. American Marten

Surveys of the B2E landscape and a new predictive model were used to evaluate whether the landscape could support reproductive populations of American marten.

This element of the study was developed experimentally as an improvement in habitat modeling methods, comparing the results with the CWHR modeling used for the larger landscape. Field data from the landscape supported the assumption that no suitable habitat for marten occurred below 5,000 feet. Above 5,000 feet, modeling showed that the amount of land in old forest conditions (CWHR diameter classes 5 and 6 and canopy cover classes M and D) was the best predictor of American marten occurrence. Based on these data, the predictive model was used to determine the percent of the landscape in each of four categories of probability of occupancy: none (< 10%), low (10 to 30%), moderate (30-60%) and high (>60%).

The predicted values from vegetation mapping for the B2E project area showed only a small amount (3%) of highly suitable habitat (Figure 26). The majority of the B2E project area (89.9%) was characterized by habitat with low or no probability of occupancy (≤ 30%). The predictive model indicated that the western portion of the B2E project area (south of Lake Almanor) contained relatively little habitat that could support marten reproduction. This finding is consistent with the lack of marten detections by surveys in this region (Tom Kirk, personal communication). The west side was the most likely region to be used by dispersing martens as a corridor between known population centers located to the north and south.

Management scenarios had no appreciable effect on the amount of habitat suitable for marten. The only variable in the model that could be affected by forest management was the amount of old forest conditions (e.g., in CWHR 5M, 5D, and 6 habitat). Old forest habitat (a characteristic of suitable marten habitat) increased more over time in the Reference Case than in the Test Scenario. However, those increases occurred below 5000 feet, the typical lower elevation limit for habitat suitable for the American marten.

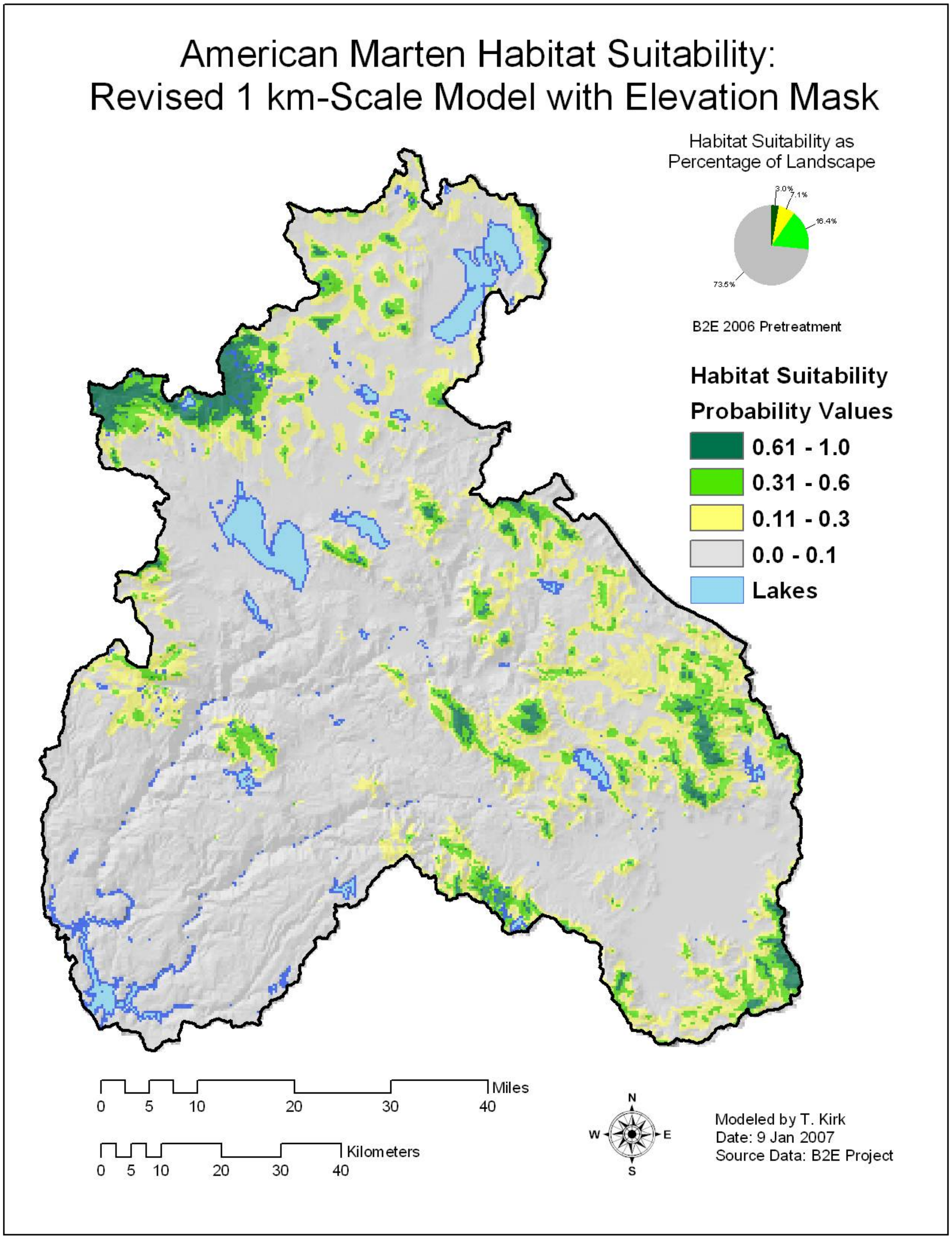

Figure 26 – Probability of occupancy within suitable reproductive habitat for marten (*Martes americana*) in the B2E landscape based on predictive models.

3.6. Cumulative Watershed Effects

Cumulative watershed effects analysis assesses the potential movement of soil and water to approximate synergistic effects at a watershed scale. A watershed may be defined differently, depending on the purpose and scale of the analysis: For the Beta landscape, watershed boundaries were determined by standardized Hydrologic Unit Codes (HUCs) at the 6th order of coding (U.S. Geological Survey 2009), which resulted in analytical units ranging in size from 2,500 to 46,000 acres. As described in the Approach section of this report, the CWE model is a disturbance-based model that normalizes all disturbances (treatments, wildfires, and so forth) to an acre of road. The resulting metric of equivalent roaded acres (ERAs) is compared with its established watershed threshold of concern (TOC) to assess the potential for cumulative watershed effects.

3.6.1. Total Equivalent Roaded Acres (ERAs)

Figure 27 shows the total ERAs for all watersheds in the Beta landscape by year for both the Reference Case and Test Scenario. The Test Scenario produced lower ERAs than the Reference Case, explained by the fact that treatments were effective in reducing the size and intensity of wildfires, as shown in the sections on wildfire and vegetation treatments in this report. Soil erosion, as modeled through ERAs, was reduced accordingly by wildfire reductions. Industrial Private Forestry (IPF) lands are included in the figure as an reference point of some interest, given the ongoing concerns expressed by the public about potential watershed impacts of commercial harvesting. This study shows that the impacts of no treatment under the Reference Case are slightly higher, as measured by ERAs, than IPF commercial treatments.

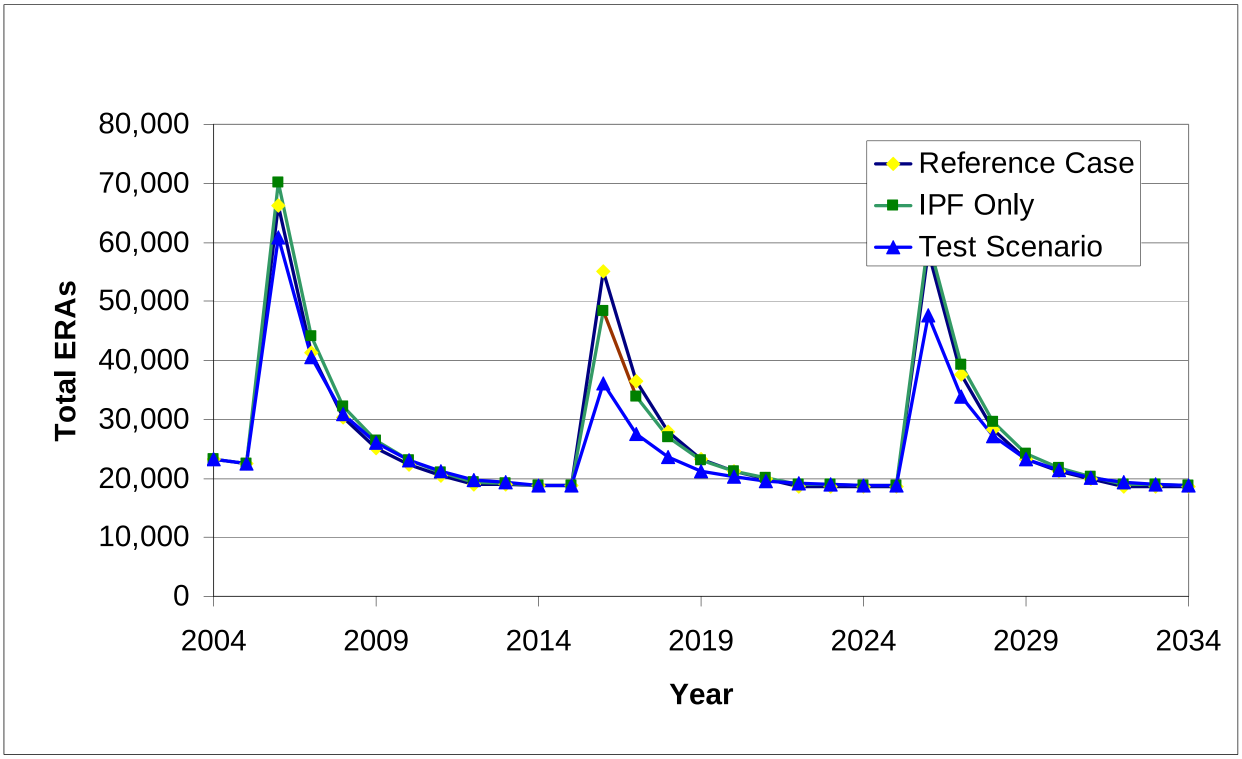

Figure 27 - Total Equivalent Roaded Acres by Year

Figure 28 shows ERAs by scenario, disturbance type and year. The Reference Case scenario has the highest wildfire sediment ERAs and the Test Scenario has the lowest. In the Test Scenario, the reduced ERAs from wildfire still exceed the increase in ERAs from treatment, which constitutes a net reduction. Roads were held constant in both the Reference Case and Test Scenario. IPF treatments and IPF wildfire effects are also shown, as in Figure 28, to give an additional reference point for analysis.

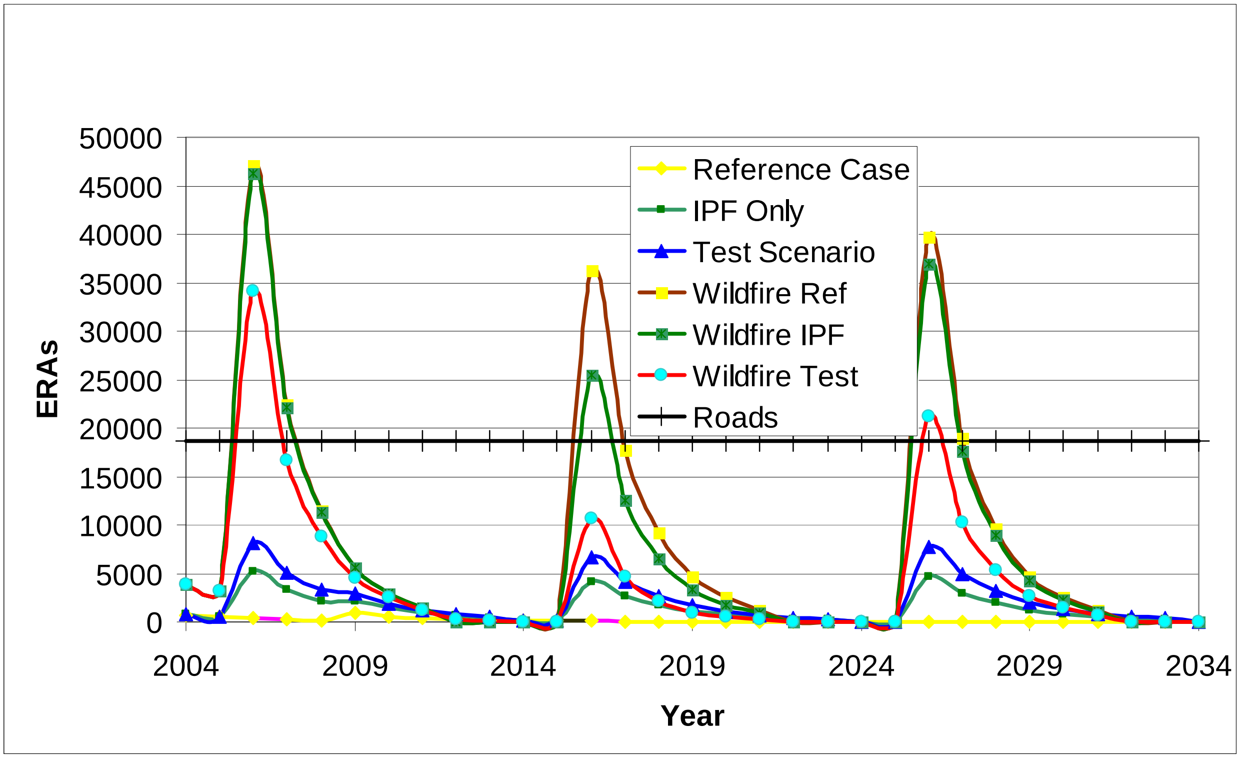

Figure 28 - ERAs by year and disturbance type

3.6.2. Cumulative Watershed Effects Analysis

The findings of the cumulative watershed effects analysis strongly parallel the findings in the wildfire analysis. The study shows that fuels treatments reduce the overall potential for cumulative watershed effects, as measured by ERAs, when compared to the effects of wildfire. Table 39 shows the risk ratios for the Reference Case and Test Scenario for those watersheds over the threshold of concern (TOC) for year 2006, 2016 and 2026. (As described in the "Approach" section, the TOC is based on a watershed's sensitivity to disturbance and the beneficial uses of its water. A watershed exceeds the TOC when the risk ratio exceeds 100.) The Reference Case shows a higher number of HUC6 watersheds over TOC, and by a greater percent, compared to the Test Scenario.

Table 39. Risk ratios for watersheds over threshold by model decade

	Reference Case			Test Scenario		
HUC_NAME	2006	2016	2026	2006	2016	2026
Stoney Creek	490			434		
Lower Last Chance Creek	488			413		
Clarks Creek	275			142		
McClellan Canyon	295			218		
Mc Dermott Creek	270			190		
Middle Last Chance Creek	258			177		
Pineleaf Creek	184			87		
Otis Canyon	122			35		
Lower Pine Creek	114			107		
Upper Red Clover Creek		572			216	
Dixie Creek		297			49	
Big Grizzly Creek		200			74	
Bald Rock Canyon		138			38	
Adams Neck		180			75	
Wild Yankee Creek		112			48	
Last Chance Creek		101			42	
Carman Creek			419			251
Antelope Creek			267			123
Clairville Flat			154			69
Seneca			172			143

In the Test Scenario, the treatments by themselves did not push any of the HUC6 watersheds over TOC. In all cases, the TOC was exceeded due to modeled wildfires. In watersheds that did not have fires modeled in them, there were more disturbances due to treatments and small increases in sediment, but not enough to exceed TOC. The slight increase in sediment runoff by treatments was entirely compensated by the reductions in fire intensity and fire size in watersheds where wildfire was modeled. Recovery from the effects of wildfire commonly happens in a relatively short time period (2 to 4 years). However, the initial adverse watershed effect can be severe if a high intensity rainfall event occurs shortly after the fire. In the Test Scenario, the number of watersheds over TOC dropped from seven to one as a result of the fuel treatments. An example, as seen in Table 39, is the change in the risk ratio of Upper Red Clover Creek, which decreased from 572 to 216 because the fuel treatments reduced modeled wildfire intensity.

The following two Figures (28 and 29) compare watersheds in the B2E Beta landscape by threshold class for the Reference Case and the Test Scenario in model years 2006 and 2016. The fuel treatments moved a few watersheds from one threshold class to the next higher class, but none of the treatments exceeded the watershed threshold. The B2E modeled wildfires moved the watershed well over TOC in most cases. Treatments did not shift any of the study's watersheds over TOC. Eight watersheds were shifted by treatments from over TOC in the Reference Case to under TOC in the Test Scenario in years 2006 and 2016.

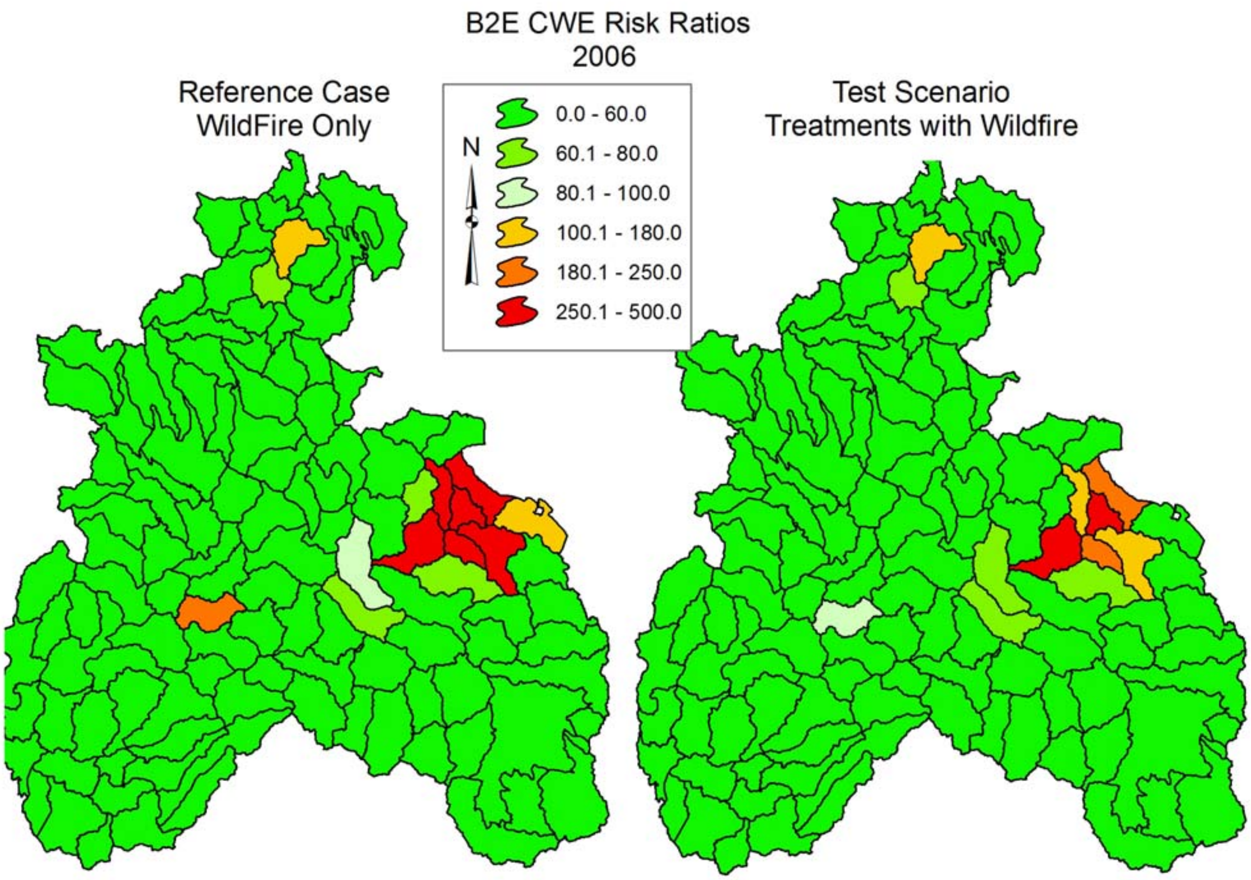

Figure 29. CWE risk assessment by watershed in 2006 model year

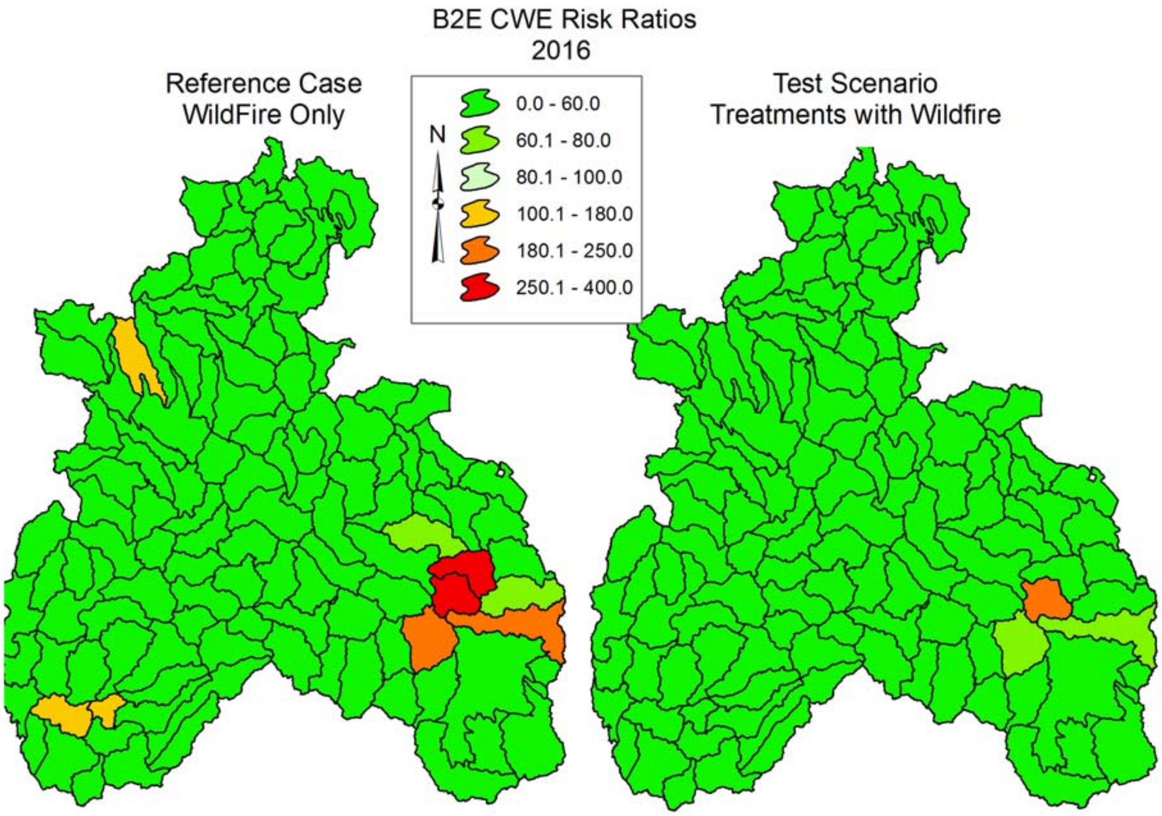

Figure 30. CWE risk assessment by watershed in 2016 model year

3.7. Economic Results

The economic analysis of the B2E project was intended to span all domains wherein costs could be measured. Pricing of non-market values or ecosystem services was used where studies in the peer-reviewed literature were deemed robust enough to warrant reporting in this study. Additional studies to prince non-market ecosystem services were beyond the scope of this analysis. Reasonable attempts were made to capture values, such as recreation damage functions, where possible. The analysis is intended to show benefit-cost relationships, and does not attempt to resolve for economic efficiency.

As with the other domains, the economic analyses were conducted on a Reference Case (with no treatments, but including impacts of wildfire) and a Test Scenario. The detailed economic analysis can be found in Appendix 8. Additionally, a spreadsheet model is available for download, and may be accessed through the Energy Commission's web services.

Table 40 shows estimates of the initial value of assets in the study area at risk to fire damage and fire-related losses (in present value) to these assets over the 40-year analysis period. Of the $20.8 billion in initial value, timberland resources comprise more than $18.1 billion in asset value, followed by structures ($2.4 billion), recreation resources ($117.8 million), infrastructure ($102.3 million), and agricultural lands ($41.3 million).

Table 40 - Study Area Market Asset Value Changes by Treatment Scenario (in millions of 2006 dollars)

Asset Type	Initial Value	Loss in Value Due to Fires	
		Reference Case	Test Scenario
Agricultural lands	$41.3	$3.6	$2.8
Recreation resources	$117.8	$1.7	$0.95
Infrastructure	$102.3	$3.0	$1.9
Structures	$2,364.5	$43.0	$27.2
Timber	$18,144.2	$612.7	$385.6
Total	$20,770.2	$664.1	$418.5

Note: The loss in value for the treatment scenarios represents the accrued present value of the losses from fires over the 40-year project period.

The present value of losses due to fire over the 40-year period is $664.1 million under the Reference Case and $418.5 million under the Test Scenario. The reduction in asset value losses, relative to the Reference Case, is attributable to timber harvest and fuels treatment activities associated with the vegetation management treatments under this scenario.

Table 41 shows the annualized costs and revenues associated with the Reference Case and the Test Scenario. The costs include capital and operations and maintenance (O&M) costs for fuels treatment and power production, and the revenues are those generated from the sale of power and saw logs, both from timber harvest and salvage activities. (Note that the costs of timber harvesting are accounted for in saw log revenues in Table 41, which are revenues net of production costs.) The volume of chips generated by thinning activities are sufficient to fuel seven power plants at an average capacity of 9.8 MW per plant under the Test Scenario.

Table 41 - Annualized Costs and Revenues for No Treatment (Reference Case) and With Treatment (Test Scenario), in millions of 2006 dollars.

Value Category	Reference Case	Test Scenario
Project costs:		
Fuels treatment		
-- Capital costs	N/A	$4.2
-- Operations & maintenance costs	N/A	$15.0
Power Plant Operations		
-- Capital costs	N/A	$15.6
-- Operations & maintenance costs	N/A	$31.9
Fire suppression	$2.05	$1.6
Rehabilitation	N/A	$0.03
Total costs	$2.05	$68.3
Project revenues:		
Power generation	N/A	$27.9
Saw logs from timber harvest	N/A	$72.3
Saw logs from salvage	N/A	$4.2
Total revenues	N/A	$104.4

Fuels treatments under the Test Scenario also produce biomass that would be available for power plant operations. Based on treatment and transportation requirements under this treatment scenario, biomass fuel delivered to power plants would cost an estimated $68 per BDT. Based on the modeling of power plant financials (see Appendix 10) power plant operators can pay up to $8.20 per BDT in order to achieve an acceptable rate of return on investment under the Test Scenario. (The financial model assumed that power plant project investors would require a long-term after-tax return to equity of 14.5 percent to attract investment for a project.) Barring some other source of revenue, such as revenue from steam sales or government grants, constructing and operating biomass power plants would not be feasible at a fuel cost of $68 per BDT.

This last finding, that biomass plant operators may only be able to afford $8.20 per BDT for feedstock, is counterintuitive, and contradicted by the existing evidence of the biomass power industry in California (which typically pays between $25 and $45 per BDT for forest fuels).

However, it must be recognized that the current biomass power industry in California is in large measure dependent upon the subsidies for capacity payments under the federal Public Utility Regulatory Policy Act (PURPA), passed in 1978 in response to the 1973 energy crisis. Among its provisions was to require purchase of renewable power by investor owned utilities. In addition, biomass power plants negotiated prices for power that were typically at least 1.5 to 2 cents above the wholesale price of electricity, under long-term contracts. In California, many of the biomass power facilities built in the late 1980s and early 1990s had retired their debt by 2006, the year in which this analysis begins. The combination of capacity payments and debt-free power sales accounts for the difference between the current (2006) market, and a *greenfield* power plant developed in 2006 without PURPA subsidies.

From a broader societal perspective, subsidies based on the value of avoided asset losses and avoided fire suppression and rehabilitation costs could be offered to power plant operators to offset the relatively high cost of biomass as a feedstock. Under the Test Scenario, the avoided fire damage to assets and reduced fire suppression and rehabilitation costs in the B2E landscape would total about $4.6 million annually. When this asset benefit is incorporated into the power plant financials (by lowering annual O&M costs by $4.6 million), the analysis indicates that a power plant operator could pay up to $54.80 per BDT for biomass fuel, while still achieving the targeted return on investment. Fuel subsidies for biomass power plant operations of up to $46.60 per BDT ($54.80 minus $8.20) would be required in order to achieve break-even based on total costs and benefits.

Although environmental costs and benefits are not monetized and included in the economic analysis, results from evaluating effects of the treatment scenarios on habitat indicate that implementation of the treatment scenarios would likely have an overall beneficial effect that would positively contribute to the net present value of these scenarios. On the other hand, the evaluation of carbon sequestration effects of the treatment scenarios indicate that, in the short term, carbon sequestration of the treated forest would be reduced and greenhouse gases would increase. In the long term, however, the increased productivity and fire resiliency of the treated forest would result in a substantial and prolonged net decrease in the level of atmospheric greenhouse gases. Effects on air quality would vary under the treatment scenarios, with CO and NOx emissions increasing and particulate matter, VOC, and SOx emissions decreasing over the four-decade study period. Overall, it appears that consideration of habitat, carbon, and air quality effects would likely contribute positively to the net economic value of the treatment scenarios.

3.7.1. Conclusions and Key Findings

The Test Scenario, which includes treating public and private lands, generates annualized benefits that exceed estimated costs, indicating that implementing the Test Scenario would incrementally contribute to net economic value.

Vegetation management treatments on public lands in the Beta landscape cost an estimated $5.3 million annually and generate about $4.6 million annually in benefits from avoided asset damage (due to fire) and reduced fire suppression and rehabilitation costs, in addition to $22 million in saw log net revenues. The benefits from vegetation management treatments (i.e., avoided asset damages and reduced fire suppression and rehabilitation costs) are relatively small in the context of total economic benefits of the Test Scenario, which are generated primarily by revenues related to the sale of sawlogs from vegetation treatments. The relatively small effect on avoided fire-related damages to agricultural, recreation, structural, and infrastructure assets from vegetation management treatments reflects the undeveloped and generally rural characteristics of the Beta landscape. Only avoided fire-related damages to timberland assets are significant.

The estimated net operating deficit of power plants that use chips produced from forest biomass in the study area reflects the relatively high cost of producing and delivering chips. Break-even analysis indicates that, under the Test Scenario, the cost of chips for fuel would need to decrease from about $68 per BDT to about $8.20 per BDT for the power plants to be economically viable. Subsidies based on avoided asset damage and reduced fire suppression and rehabilitation costs would need to contribute an estimated $46 per BDT.

Although environmental costs and benefits were not monetized and included in the economic analysis, results from evaluating effects of the treatment scenarios on habitat, carbon sequestration, and air quality suggest that consideration of these effects would likely contribute positively to the net present value of the scenarios

4.0 Conclusions, Observations and Recommendations

Overall conclusions and recommendations of the B2E project can be summarized in four key categories, as briefly described below. The following figure is repeated from the introductory section, as a reminder to the reader of the complex interactions of the processes modeled by the project. Detailed recommendations for further model improvements or development are included in many of the appendices, pertaining to specific components of the B2E project.

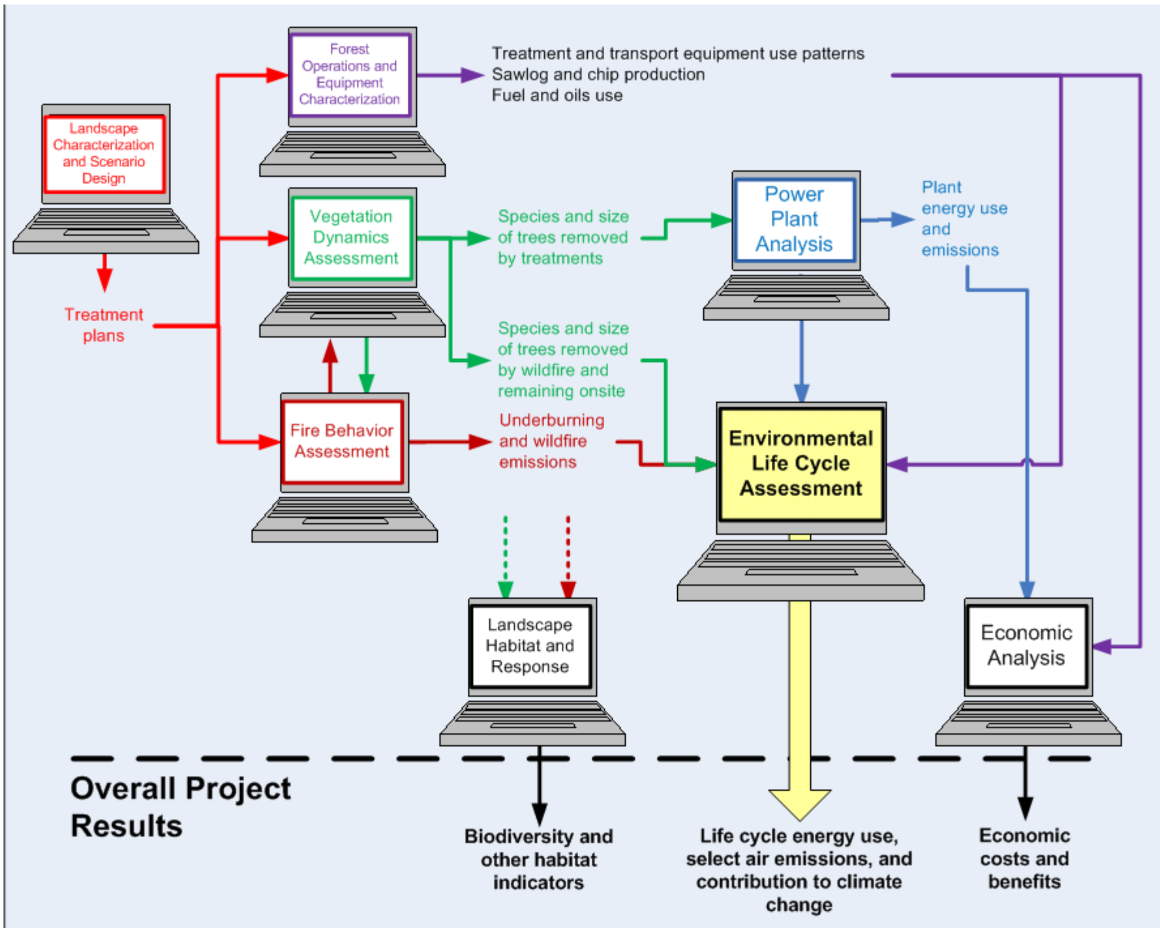

Figure 31 - Review of B2E Process Models and Results

4.1.1. Scenario development recommendations

Further development of the B2E model would include varying the size, spatial distribution, and types of treatments to determine the impacts of pursuing other goals and objectives on the same land base. For example, the research team determined that further model development would include the following scenarios on PMU lands (with private forest land treatments being held constant):

- Natural Disturbance Regime: PMU lands managed to maximize long-term biological diversity and integrity in the face of anticipated climate change dynamics

- Maximum Fire Resilience Regime: PMU lands managed to maximize resilience to natural wildfire regimes, with aggressive reduction of fire severity; heavy thinning in most forest areas not specifically reserved for sensitive species habitat
- Carbon Sequestration Regime: PMU lands managed to maximize in-forest carbon sequestration (i.e., harvested wood products not counted in C sequestration accounting scheme), while reducing risk to wildfire (as threat to Carbon assets)

While these scenarios were not developed fully in the B2E Project analysis, the analytical basis for them has been recorded in treatment prescription specifications on PMU lands. These specifications can be achieved either by application of algorithms to the existing tree lists (i.e., proportional changes in treated strata), or by altogether new runs of altered prescriptions on the original 2006 tree lists, generating new tree lists for each out-year, as was done for the Test Scenario.

4.1.2. Life Cycle Assessment Recommendations

The life cycle assessment for the B2E project has provided important insights on at least two levels: 1) what has been learned about application of LCA principles to complex and multi-objective systems; and 2) the quantifiable life cycle results of the Test Scenario compared with the Reference Case, and what it suggests for further research and development.

On the first level, the team has concluded the following:

1. It is possible to construct a set of interconnected forest operations and equipment characterization, fire behavior assessment, and the power plant analysis models in support of LCA.

2. Data and models are available to represent the life cycle of a range of technologies for developing U.S. forest bioproduct systems.   Reliance on the discipline-specific B2E project models (the forest operations and equipment characterization, the vegetative dynamics assessment, the fire behavior assessment, and the power plant analysis) combined with the U.S. EPA NONROAD and MOBILE models and the U.S. DOE's GREET model provided a wealth of data for systems assessments. Similar data availability is expected for technology alternatives, as demonstrated in the assessment of power plant alternatives. However, shortcomings herein included the limited scope (e.g., the small number of impacts assessed, the omission of infrastructure construction models, and the limited number of possible treatment scenarios investigated), lack of uncertainty data for all assessments, and the need to project estimates for all models into the future. These shortcomings do not appear to be insurmountable in the short term, and are recommended for future research.

3. In addition to addressing scope and modeling shortcomings, there are a number of remaining forest bioproduct questions that can be explored with currently available data. For example, investigations of power plant and transfer station citing and optimization of regional utilization of forest residuals, agricultural residuals, and bio-based municipal solid waste could be built around the data presented here.

4. Presentation of results in gross and followed by a variety of computational interpretations provide insights for decision making and a starting place for future assessments.

On the second level, the LCA modeling and assessment work suggestions at least the following:

1. The Test Scenario provides a net benefit for total energy consumption and reduces fossil and petroleum consumption when compared to the Reference Case. Also, whereas the B2E power plant efficiency is critical to the overall energy balance, the consumption of fossil and petroleum fuels during harvest, chip transport, or power plant operation play a less important role.

2. The Test Scenario results show an improvement for NMVOCs, CO, and SOx when compared to the Reference Case. Alternatively, little difference is seen in NOx and PM10 emissions.

3. Forest processes related to photosynthesis, plant respiration, decomposition of litter and soils, despite the uncertainty in estimates, are the most important to understanding whether or not the Reference Case and the Test Scenario contribute to climate change.

Recommendations for future work include the addition of sensitivity analysis to the assessments, comparison of the results to related LCAs, consideration of additional process alternatives throughout the life cycle, and other aspects needed to complete the study as described in the goal and scope document.

4.1.3. Wildlife habitat modeling recommendations

The wildlife habitat modeling team calculated the probability of any given acre having certain structural conditions and being suitable for co-occurring species in a given ecological grouping. Changes in the seral condition of forests were expected and observed to change as a result of forest management. As expected, the starting probability of 23% of any given acre having a large average diameter increased under all scenarios, but increased twice as much in the Reference Case compared to the Test Scenario. Canopy closure was expected to decline in harvested areas, and indeed the probability of a given acre having high canopy cover started at 44% and went from a 50% increase in the Reference Case to a slight decrease in the Test Scenario. The combination of large diameter and high canopy cover represents optimal old forest conditions, and we see the probability of this condition starting at near 20%, more than doubling in the Reference Case, and still increasing a modest 23% in the Test Scenario.

The probability of a given acre supporting a high number (>20; maximum observed = 46) of co-occurring old forest associated species started high (66%), and experienced a minor decline for all the scenarios (see Table 42). This response is attributable to the fact that many species associated with old forests are also associated with earlier seral conditions (e.g. American robin), so some will respond positively to a shift to more early seral conditions, while others will respond negatively. The probability of conditions supporting a high number (>10; maximum observed = 14) of old forest dependent species closely followed that of high canopy cover conditions, with an over 30% increase in probability occurring in the Reference Case, and a decline occurring in the Test Scenario. Approximately half of the existing landscape is estimated to support a high number (>20; maximum observed = 81) of early seral associates. Habitat for early seral associates declined by nearly half in the Reference Case and showed a slight increase in the Test Scenario.

The habitat analysis team examined a number of species groups that have been demonstrated to perform important ecosystem services. Insect regulators consist of invertivores, and the probability of suitability for this group was high (nearly 75%) declined between 10 and 20% across all scenarios. Seed dispersers is one group, and since it is comprised primarily of species associated with early seral conditions, suitability for the majority of these species was nearly identical to early seral associates.

Table 42. Probability that any given acre will support a particular forest condition or suite of species as defined by ecological groupings, and how that probability changes with each scenario

		Reference Case		Test Scenario	
Attribute	Starting point	End point	% change	End point	% change
Large average diameter (>24 in)	0.23	0.53	+134.4	0.37	+63.8
High canopy closure (>60%)	0.44	0.68	+52.5	0.43	-1.4
High canopy closure and large average diameter	0.22	0.49	+123.5	0.27	+23.3
Old forest associates (>20)	0.66	0.57	-13.6	0.62	-7.5
Old forest dependents (>10)	0.38	0.50	+34.1	0.37	-1.3
Early seral associates (>20)	0.48	0.28	-41.7	0.50	+5.5
Insect regulators (>20)	0.73	0.59	-19.7	0.65	-12.1
Seed dispersers (>5)	0.42	0.21	-50.4	0.42	-1.5

4.1.4. Economic analysis limitations and recommendations

Although benefit-cost analysis is widely used in the analysis of regulations and public policy, the approach is based on a number of underlying assumptions that have been challenged over the years. These assumptions include equating changes in income with social well-being, assuming that willingness-to-accept compensation and willingness-to-pay measures are essentially equal and substitutable, and using straight-line discount rates. According to Gowdy (2007), these and other basic assumptions underlying benefit-cost analysis are coming under increasing scrutiny because the assumptions are at odds with observed human behavior.

The successful application of benefit-cost analysis to natural resource policy issues depends on a scientific understanding of underlying physical and biological processes that shape the valuation of environmental costs and benefits. If these processes are not well understood, deriving valid estimates of monetary values is difficult. Boyd (2007) addresses the measurement challenges inherent to valuation of ecosystem services in the B2E study area. The lack of observable data from market transactions greatly increases the challenge to monetizing most of the environmental costs and benefits from the B2E Project.

Although sensitivity analysis was used to test the validity of certain conclusions drawn from the benefit-cost analysis, a more rigorous application is needed to thoroughly evaluate the sensitively of the results to the omission of monetized environmental costs and benefits and to data uncertainties. Conducting a comprehensive economic assessment at the B2E landscape would require a research effort that is an order-of-magnitude greater than this one.

Effects of Population Growth and Future Land Use Development

Although the economic analysis considered costs and benefits over a 40-year analysis period, changes in baseline conditions due to external forces such as population growth, recreation growth, and urban development were not considered. With the exception of tree growth in the supporting vegetation analysis, the economic analysis is considered static and does not account for important dynamic effects that would affect the value of assets at risk to wildfire.

More research is needed to refine the damage functions and asset recovery rates that were incorporated into the benefit-cost model. This is partly responsible for the fact that rehabilitation costs are difficult to capture adequately in the economics model. Rehabilitation costs associated with wildland fires are highly variable. The per acreage rehabilitation cost estimate incorporated into the benefit-cost model likely does not accurately capture probable rehabilitation costs within the study area. Similarly, assumptions built into the benefit-cost model concerning the number of acres that would be rehabilitated under each scenario may have considerable error.

4.2. Benefits to California

The Biomass to Energy project has contributed to California's capacity to analyze forest biomass utilization opportunities at the landscape scale. Even in draft form, the Secretary of the United States Department of Agriculture has identified the project as a "highly influential scientific assessment," with implications for how the USDA Forest Service would use life cycle assessment to evaluate the benefits of biomass power.

California has approximately 40 million acres of forest lands, nearly half of which are managed by private landowners. The economics of private forest land management historically have constrained opportunities for effective and sustainable management. The Biomass to Energy project's approach is likely to assist policy makers and landowners in evaluating comprehensive and long-term benefits to the environment, as well as enhancing economic opportunities in forest-dependent communities.

The benefits of thinning forests, and using the waste products for energy production, are largely a matter of public choice and policy making. Many of the benefits of managing California's forests – such as reducing wildfire effects, saving fire suppression costs, providing clean air and water and other climate benefits – may be better reflected in future markets and public policy as a result of this project. Biomass power is a rare form of renewable energy in that it provides a broad range of benefits at relatively low cost to the consumer and substantial ancillary benefits to the environment. Further quantification and analysis, building on the work presented by the project, will help California's policy makers and legislators evaluate how forest biomass will contribute to larger societal and environmental goals.

Acronym Key

Original Term	Acronym/Abbreviation
Biomass to Energy	B2E
bone dry tons	BDTs
USDI Bureau of Land Management	BLM
California State Board of Equalization	BOE
break-specific fuel consumption	BSFC
British thermal unit, one million Btu, one trillion Btu	Btu, mmBtu, tera Btu
Clearcut	CC
CALFIRE (formerly California Department of Forestry and Fire Protection)	CDF
California Department of Fish and Game	CDFG
methane	CH4
carbon monoxide, carbon dioxide	CO, CO2
Commercial Thinning	CT
Cumulative Watershed Effects	CWE
California Wildlife Habitat Relationships	CWHR
diameter at breast height	dbh
defensible fuels profile zone	DFPZ
emission factors	EF
Equivalent Roaded Acre	ERA
Fire Emissions Joint Forum	FEJF
Fire and Fuels Extension	FFE
Forest Inventory Analysis	FIA
First Order Fire Effects Model	FOFEM
USDA Forest Service	Forest Service/FS
Fuel Management Erosion	FuME
Forest Vegetation Simulator (Model)	FVS
Geographic Information System	GIS
global warming potential	GWP
hydrogen ions	H+
Inland California Southern Cascades	ICASCA
Industrial Private Forests	IPF
International Standards Association	ISO
kilogram	kg
kilowatt hour	kWh
life cycle assessment	LCA

thousand board feet	mbf
moisture condition	MC
mean diameter	MD
Megawatt/megawatt hour	MW/MWh
nitrous oxide	N2O
NFDRS	National Fire Danger Rating System
National Environmental Policy Act	NEPA
National Forest Management Act	NFMA
Non-Industrial Private Forests	NIPF
non-methane volatile organic compounds	NMVOC
non-greenhouse gas	Non-GHG
nitrogen oxides	NOx
Public Conservation and Recreation	PCR
Pre-Commercial Thinning	PCT
particulate matter, particulate matter less than 2.5 microns in diameter, particulate matter less than 10 microns in diameter	PM, PM 2.5, PM10
Public Multiple Use	PMU
Restrictive Thinning	RT
Salvage	SAL
Stewardship and Fireshed Assessment	SFA
Selective Harvest	SH
sulfur dioxide	SOx
strategically placed area treatment	SPLAT
threshold of concern	TOC
Tool for the Reduction and Assessment of Chemicals and Other Environmental Impacts	TRACI
Urban and Other	U
United States Department of Energy	U.S. DOE
United States Environmental Protection Agency	U.S. EPA
volatile organic compounds	VOC
Watershed Erosion Prediction Project	WEPP
Western Regional Air Partnership	WRAP

5.0 Glossary

biomass	non-commercial component of the wood produced in forest harvesting operations
California Wildlife Habitat Relationships (CWHR)	a state-of-the-art information system for California's wildlife. CWHR contains life history, geographic range, habitat relationships, and management information on 692 species of amphibians, reptiles, birds, and mammals known to occur in the state.
catastrophic fire	stand replacement or high intensity fires that cause damage to ecological and/or economic assets and values. The B2E Project also refers to these types of fires as uncharacteristically severe wildfires.
defensible fuels profile zones (DFPZs)	shaded fuelbreaks which are designed with the objective of providing a place to deploy firefighters in the event of a wildland fire. Firefighters use DFPZs to make a stand to hold or contain a fire.
domains	discrete segments of modeling and analysis in the B2E Project
ecological endpoints	ecological functions that have a directly measurable human welfare function, and that can be quantified in an accounting system that makes them fungible
equivalent roaded acre (ERA)	equates all disturbances to one acre of road
fire adapted forests	forests that have evolved with wildfire
fire line intensity	behavior of the flames at the perimeter of the fire as it moves through vegetation
First Order Fire Effects Model (FOFEM)	a computer program developed to predict and plan for fire effects. First order fire effects are those that concern the direct or indirect or immediate consequences of fire. FOFEM provides quantitative fire effects information for tree mortality, fuel consumption mineral soil exposure, smoke and soil heating.
national fire danger rating system (NFDRS) codes	a Forest Service rating system which defines fuel models based on the primary carriers of fire
service providing units	categories of species including insect regulators, seed dispersers, decomposition aides, and herbivore regulators which provide ecological services to forest management
side	common term used by harvest contractors to denote a separate and distinct blend of harvest equipment conducting harvest activities as a separate operation.
slash	woody residues that are generated in the forest from harvesting activities
speciose	relative term for species richness

stated preference method	a classification system for economic analysis. Stated preference methods fall into three primary categories: a) contingent valuation, in which the respondent is required to make a comparison of value between the resource value in question and known trade-off values; b) travel-cost analysis, in which travel effort and investment constitutes a proxy for the value of the resource; and c) hedonic pricing, which uses property values as a proxy for the value of the resource as compared with comparable purchase prices.
strategically placed area treatments (SPLATs)	pattern of treatment areas distributed across a landscape oriented according to the prevailing wind direction in order to intercept a spreading wildfire
thousand board feet (mbf)	volume of the log based upon board foot measure. One board foot represents the amount of wood contained in an unfinished board measuring one inch thick, one foot long, and one foot wide.
treatment activities	discrete management actions or events, such as thinning or understory burning.
treatment prescription	a series of management activities applied over the 40-year timeframe to a specific piece of ground
tree lists, including The Larch	forest inventory datasets which consist of (a) site reference information (plot location, inventory date, slope, aspect, elevation) and (b) the characteristics (species, size, canopy position, and so forth) of the trees sampled, including The Larch.

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7.0 Appendices

General note on appendices: key terminology evolved throughout the course of this project. Most importantly, what became the Reference Case and the Test Scenario had early iterations that were based on separating Industrial Private Forest (IPF) from Public Multiple Use (PMU), creating a "third" interim scenario in order to analyze the impacts of IPF management apart from the broader landscape. Thus, the following notice has been inserted at the beginning of each Appendix.

Notice of Change in Scenario Naming Conventions

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

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

7.1. Appendix 1: Landscape Vegetation Changes (Barber, Perrot, et al.)

Describes the sources of data and the modeling processes used to establish the inventory and changes in vegetation on the B2E Beta landscape. Approximately 65 pp.

7.2. Appendix 2: B2E Fire Behavior Domain (Ganz, Saah, Barber, et al.)

Explains processes of using vegetation modeling outputs and applying fire behavior models to each of the scenarios during each modeling time period. Approximately 10 pp.

7.3. Appendix 3: Forest Operations and Equipment Configuration (Mason, Hartsough, et al.)

Describes all equipment used in the life cycle assessment and analysis, including variations under different treatment prescriptions and land management regimes. Approximately 10 pp.

7.4. Appendix 4: Life Cycle Assessment of Producing Electricity from California Forest Wildfire Fuels Treatments (Cooper)

Presents a detailed report on the life cycle assessment model developed to integrate life cycle inventory information, calculate impacts and support LCA interpretations. Approximately 78 pp.

7.5. Appendix 5: Wildlife Habitat Evaluation (Manley, et al.)

Reports the methods, data sources and analyses used to assess wildlife habitat conditions under all scenarios. Includes a case study on American Marten, which demonstrates alternatives to using California Wildlife Habitat Relations (CWHR) data and modeling. Approximately 68 pp.

7.6. Appendix 6: Cumulative Watershed Effects Analysis (Wright, Perrot, et al.)

Uses results of vegetation and fire dynamics modeling to model cumulative watershed effects on the B2E beta landscape. Approximately 20 pp.

7.7. Appendix 7: Counting Ecosystem Services: Ecological Endpoints and their Application (Boyd)

Presents an independent consultant report on new methodologies developed for the B2E landscape using “ecological endpoints” as a means to focus and narrow the description and valuation of ecosystem services. This appendix is not technically a part of the Energy Commission contract; the research and writing was funded separately by USDA Forest Service, Pacific Southwest and Pacific Northwest Research Stations. Approximately 55 pp.

7.8. Appendix 8: Project Economic Analysis (Wegge, Trott and Barnett)

Presents methods, applications and results of the economic analysis, including data derived from the Excel spreadsheet model developed for the B2E project. Approximately 57 pp.

7.9. Appendix 9: Landscape Carbon Model (Morris)

Describes in an independent consultant report forest landscape level greenhouse gas changes through wildfire, treatment and forest decay over the 40 year modeling period of the B2E project. Approximately 23 pp.

7.10. Appendix 10: Power Plant Analysis for Conversion of Forest Remediation Biomass to Renewable Fuels and Electricity (Schuetzle, Tamblyn, Tornatore, et al.)

Analyzes five powerplant technologies for the B2E project, three of which are included in the life cycle assessment domain. Two additional technologies included options for ethanol or other liquid fuel production, and were not directly used in the life cycle assessment because of the differences in outputs. The additional technologies were analyzed in anticipation of further work stemming from the B2E project that would include a life cycle assessment for transportation fuels. Approximately 6 pp.

7.11. Appendix 11: Synthesis of Economic Valuation Studies of Forest Landscape Disturbances (Berkenklau)

Synthesizes in an independent consultant report the broad range of research on the economic valuation of disturbance on forested landscapes. Approximately 12 pp.

7.12. Appendix 12: Biomass to Energy Project Team, Committee Members, and Project Advisors

Lists the members of the research team, the Technical Advisory Committee and the Policy Advisory Committee.