Energy Research and Development Division
FINAL PROJECT REPORT

FINAL FUELS MANAGEMENT REPORT ON WESTCARB MANAGEMENT PILOT ACTIVITIES IN SHASTA COUNTY, CALIFORNIA

Prepared for: California Energy Commission
Prepared by: Winrock International

West Coast Regional Carbon Sequestration Partnership

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LEGAL NOTICE

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $12 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research

This *Final Report on WESTCARB Fuels Management Pilot Activities in Shasta County, California* is a report for the West Coast Regional Carbon Sequestration Partnership – Phase II (contract number MR-06-03L, work authorization number MR-045), conducted by Winrock International. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

ABSTRACT

This report summarizes efforts by Winrock International, WM Beaty and Associates, and other Shasta County, California partners to implement hazardous fuel reduction/biomass energy pilot activities in WESTCARB Phase II (2006-10). Wildfire is a significant source of GHG emissions in California and throughout the WESTCARB region. WESTCARB developed methodologies to evaluate, validate and demonstrate the potential of reducing hazardous biomass for biomass energy to contribute to GHG mitigation and adaptation. The report describes hazardous fuel reduction pilot activities on private lands in Shasta County; pre- and post-treatment measurements to quantify forest carbon impacted by treatment and/or fire; and analysis of data from these pilots to determine the net GHG impact of the fuel reduction treatments.

Keywords: Carbon, sequestration, hazardous fuel reduction, forest, Shasta County

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Introduction

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, is one of seven US Department of Energy regional partnerships working to evaluate, validate and demonstrate ways to sequester carbon dioxide and reduce emissions of greenhouse gases linked to global warming.

Earlier analyses by Winrock International showed wildland fire to be a substantial source of greenhouse gas (GHG) emissions throughout the region. Reducing hazardous fuel loads, and to an extent, the severity of wildfires, could result in lower net GHG emissions when compared to a baseline scenario without such treatments. Fuel reduction may also contribute to carbon sequestration by enhancing forest health or growth rates in post-treatment stands. Finally, for treatments where fuel removal to a biomass energy facility is feasible, additional GHG benefits may be created by substituting the biomass for fossil fuel rather than leaving the biomass in the forest to decompose.

Hazardous fuel reduction/biomass energy pilot activities were implemented in the two WESTCARB terrestrial pilot locations, Shasta County, California and Lake County, Oregon. These projects provide real-world data on carbon impacts of treatments, costs, and project-specific inputs to a related WESTCARB task, in which Winrock International and the WESTCARB Fire Panel are working to investigate whether the development of a rigorous methodology to estimate GHG benefits of activities to reduce emissions from wildland fires is feasible.

Purpose

This report provides results from the WESTCARB Phase II hazardous fuel reduction pilot activities in Shasta County, California.

Project Objectives

The overall goal of WESTCARB Phase II is to demonstrate the region's key carbon sequestration opportunities through pilot projects, methodology development, reporting, and market validation. WESTCARB research will inform policymakers, communities, and businesses on how to invest in carbon capture and storage technology development and deployment to achieve climate change mitigation objectives.

The specific objectives of the Phase II Shasta County fuel reduction pilots are to investigate the feasibility of fuels-treatment-based terrestrial sequestration by conducting pilot projects in a representative West Coast forest; compile information on site conditions, fuel treatment prescriptions, and costs; and inform and field- test the WESTCARB fire GHG emissions methodology.

Methodology for measuring impacts of hazardous fuels treatments

Pre- and post-treatment measurements were made on three fuels treatment projects in Shasta County, California: Berry Timber, Davis, and HH Biomass. The fuel reduction activities were located in the southeast corner of the county; all three projects were located on privately owned land. These projects involved removal of non-commercial biomass and sawtimber with the overall objective of reducing fuel loading and risk of catastrophic wildfire. Treatments also included chipping and removal of biomass fuel to a biomass energy plant. The actual fuels treatments were not initiated under WESTCARB support, but they provided an opportunity to conduct on-the-ground measurements of actual hazardous fuel reduction efforts.

Data were collected in a total of 35 plots (15 on Davis, 9 on HH, and 11 on Berry Timber). Pre- and post- treatment measurements on these plots addressed live trees greater than 5 cm diameter at breast height, canopy density, standing and lying dead wood, understory vegetation, forest floor litter and duff. These represent the forest carbon pools that are likely to be affected by fire, treatment, or both, and so are critical to the accounting of hazardous fuel reduction treatment impacts and potential wildfire impacts on forest carbon.

These measurements were used to determine the carbon stocks before and after treatment and before and after a potential wildfire, for each project area. Growth modeling was conducted with the Forest Vegetation Simulator for both with and without treatment stands. Emissions from a potential fire were modeled in both with- and without-fuels treatment scenarios using both the Fuel Characteristic Classification System and the Forest Vegetation Simulator fire and Fuels Extension (FVS-FFE). FVS was also used to project growth on burned stands, incorporating the impacts of fire on the future stand.

The substitution of harvested biomass for existing energy sources was taken into account where fuels were extracted to a biomass energy plant. Board feet of timber harvested was converted to metric tons of carbon, with retirement rates applied.

Project Outcomes

<u>Berry Timber</u>

Treated stands without wildfire have total stocks of 51.2 tons of carbon per acre, with 44.2 t C/ac in the same stands following a wildfire, including carbon stored in long term wood products and energy offsets.

Incorporating the risk of fire of 0.64% to calculate net emissions or removals, the fuels treatment on the Berry Timber project resulted in an effective immediate net carbon emission of 69.2 t CO_2-e/ac (18.9 tons of carbon per acre).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 83.2 t CO_2/ac and emissions of 116.2 t CO_2/ac over 60 years (Table A1).

Table ES-1. Berry Timber Net short and long term emissions from fuels treatment without fire on tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-4.5	-4.5
Commercial timber	3.7	2.6
Treatment emissions	-86.9	-118.8
NET	-83.2	-116.2

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest. According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 31.5 t CO_2/ac.

Davis

Including carbon stored in long term wood products and energy offsets, treated stands without wildfire have total stocks of 47.9 tons of carbon per acre compared to stocks of 38.7 t C/ac in treated stands following a wildfire.

Incorporating the risk of fire of 0.64% to calculate net emissions or sequestration (section 2.2.6), the fuels treatment on the Davis project resulted in a net carbon emission in year one of 11.0 t CO_2-e/ac (3.0 t C/ac).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 39.2 t CO_2/ac and emissions of 60.1 t CO_2/ac over 60 years (Table A2).

Table A2. Net short and long term emissions from fuels treatment without fire on Davis in tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-15.4	-15.4
Treatment emissions	-23.8	-44.7
NET	-39.2	-60.1

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest. According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 20.2 t CO_2/ac.

<u>HH biomass</u>

Including carbon stored in long term wood products and energy offsets, treated stands without wildfire have total stocks of 55 tons of carbon per acre compared to a stock of 45.3 t C/ac in treated stands following a wildfire.

Incorporating the risk of fire of 0.64% to calculate net emissions or sequestration (section 2.2.6), the fuels treatment on the HH Biomass project resulted in a net carbon emission in year one of 32.3 t CO_2- e/ac (8.8 t C/ac).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 83.6 t CO_2/ac and emissions of 90.5 t CO_2/ac over 60 years (Table A3).

Table A3. Net short and long term emissions from fuels treatment without fire on HH biomass in tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-23.8	-23.8
Treatment emissions	-59.8	-66.7
NET	-83.6	-90.5

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest.

According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 41.4 t CO_2/ac.

Conclusions and Recommendations

In all three projects, the treatments resulted in overall carbon emissions. This result clearly has negative implications for the future potential of fuels treatments as a carbon projects offset category. Within the treated areas, all three projects had significant net emissions when considering treatment and the risk of a potential wildfire. Davis experienced the lowest emissions, but the treatment on Davis did not decrease fire intensity. If a fire were to occur in the year of treatment, all projects would still experience net emissions, though the impact of treatment emissions would be approximately halved in all cases.

All three of the pilots led to a projected decrease in crown fire potential, which decreases fire severity and size. While treatments lead to net carbon emissions in both the short and long term in all three projects, there are, of course, additional benefits to fuels treatments, such as increased ability to successfully fight fires and decreased cost of fire fighting; reduced loss of life and property; and reduced potential damage to wildlife habitat.

The results from this study in combination with the paired study in Lake County and the allied study in Mendocino National Forest underlie the unsuitability of fuels treatment as a potential greenhouse gas offset generating activity. Instead we argue the shift should be made to policies minimizing greenhouse gas emissions from wildfires and from fuel treatments while minimizing wildfire risks to lives, homes, wildlife habitat, and livelihoods in the WESTCARB region.

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Table of Contents

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1.0 Introduction

1.1 Background and overview

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, is one of seven US Department of Energy regional partnerships working to evaluate, validate and demonstrate ways to sequester carbon dioxide and reduce emissions of greenhouse gases linked to global warming. Terrestrial (forestry and land use) sequestration options being investigated include afforestation, improved management of hazardous fuels to reduce GHG emissions from wildfires, biomass energy, and forest management. Shasta County, California and Lake County, Oregon were chosen for Phase II terrestrial sequestration pilot projects because of the diversity of land cover types present, opportunities to implement the most attractive terrestrial carbon activities identified in Phase I, and replication potential elsewhere in the WESTCARB region.

Earlier reports identified fire as a significant source of GHG emissions throughout the WESTCARB region. Estimated emissions from fires for the 1990-96 analysis period were: 1.03 $MMTCO_2e$ per year on average for Oregon (Pearson et al 2007a); 1.83 $MMTCO_2e$ per year for California (Pearson et al 2009); 0.18 $MMTCO_2e$/yr for Washington (Pearson et al. 2007b); and 0.47 $MMTCO_2e$/yr for Arizona (Pearson et al. 2007c).

The estimated baseline GHG emissions helped focus attention in Phase II on the questions: can actions by landowners to manage forest fuel loads be shown to produce measurable GHG reductions by decreasing the risk, severity, or extent of catastrophic wildfires? If so, can scientifically rigorous methods for measuring, monitoring, and verifying these GHG reductions serve as the basis for new protocols and market transactions, ultimately allowing landowners who reduce hazardous fuels to receive “carbon credit” revenues and improving the cost-effectiveness of fuel reduction? To explore these questions, hazardous fuel reduction (and where possible, removal of fuel for biomass energy generation) was chosen as a WESTCARB Phase II pilot activity in Shasta and Lake counties, and the WESTCARB Fire Panel was formed to develop fire GHG methodologies and protocols as needed.

Project Objectives

The overall goal of WESTCARB Phase II is to validate and demonstrate the region’s key carbon sequestration opportunities through pilot projects, methodology development, reporting, and market validation. WESTCARB research will inform policymakers, communities, and businesses on how to invest in carbon capture and storage technology development and deployment to achieve climate change mitigation objectives.

The specific objectives of the Phase II Shasta County fuel reduction pilots are to:

- Verify the feasibility of fuels-treatment-based terrestrial sequestration by conducting pilot projects in representative West Coast forests;
- Compile information on site conditions, fuel treatment prescriptions, and costs;
- Inform and field-test the WESTCARB fire GHG emissions methodology by:

- Collecting measurements of real-world fuel treatments to quantify:
    - the carbon stocks available to be burned before and after treatment,
    - the direct impacts of fuel treatments on carbon stocks in different carbon pools (e.g. increases in dead wood, decreases in dense growth), and
    - the fuel removed from the forest for potential biomass energy applications;
- Providing input data for fire models used to simulate fire behavior and emissions in the baseline (without-treatment) and with-treatment scenarios.

Report Organization

The report is organized into four sections: 1. Introduction; 2. project approach; 3. results; and 4. conclusions/ recommendations. Section 2 summarizes the private- and federal-lands fuel treatments chosen for study as WESTCARB pilot activities, and methods used for pre- and post-treatment measurements and data analysis. Section 3 provides results of those measurements and analyses. Section 4 discusses the findings and provides recommendations based on this research.

2.0 Project Approach

Fuel reduction project locations and descriptions

Pre- and post-treatment measurements were made on three fuels treatment projects in Shasta County, California. These projects all involved removal of non-commercial biomass and/or sawtimber with the overall objective of reducing fuel loading and risk of catastrophic wildfire. All also involved chipping and removal of biomass fuel to the Wheelabrator Shasta biomass energy plant in Anderson, California. The actual fuels treatments were not initiated under WESTCARB support, but they provided an opportunity to conduct on-the-ground measurements of actual hazardous fuel reduction efforts.

Fuel reduction on Berry Timber project (PG&E)

Location

The project area encompassed 845 acres and is shown in the map in Figure 1. It is located just southeast of the town of Shingletown in Shasta County, CA. The legal description is portions of Sections 25, 34, 35 & 36 Township 31 North, Range 1 East, M.D.B.&M. The forest type of the project area is Sierra Nevada Mixed Conifer, (Ponderosa Pine, Sugar Pine, White Fir, Douglas-fir and Incense Cedar.) Minor amounts of California Black Oak reside on the project area as well.

Treatment

The PG&E Berry timber harvest operation was conducted in the summer of 2007.

The area was treated under an individual tree selection silivicultural prescription focusing on the merchantable trees 10 inches diameter at breast height (dbh) and greater. Trees identified for harvest were trees showing signs of distress, mechanical defect, evidence of insects/disease and trees growing too close together. Biomass thinning of trees between 4 and 9 inches (dbh) was conducted on a small portion of the project area. Trees were extracted intact and tops and branches of commercial trees chipped and hauled to the Wheelabrator biomass energy facility along with the pre-commercial trees. A total of 3.461 million board feet of sawlogs were harvested from the project. A total of 173 loads of biomass were shipped to Wheelabrator Biomass Energy Plant in Anderson, comprised of 4,357 green tons of biomass with 39.3% moisture content (2,644 bone dry tons). The logging method was mechanical ground based, utilizing whole tree harvesting. All tree tops, limbs and biomass were chipped on the landing and sent to Wheelabrator Shasta Energy.

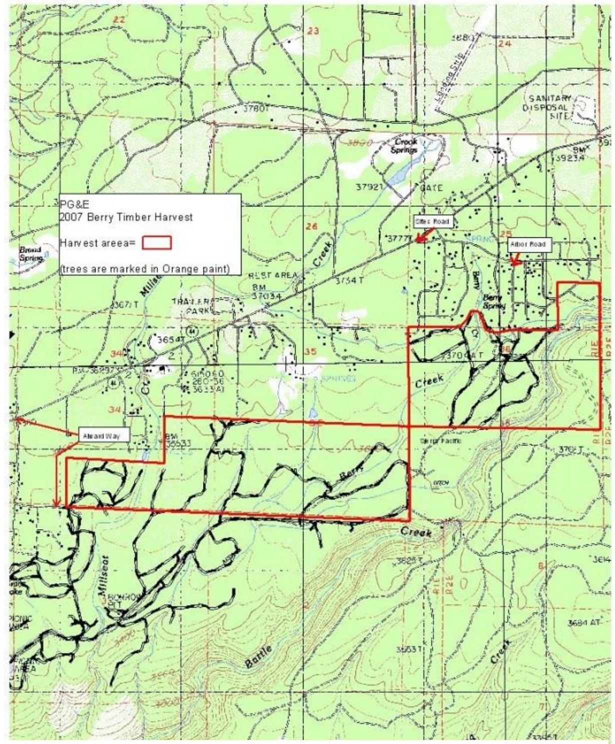

Figure 1. Map of harvest area for PG&E Berry Timber project

Fuel reduction on Davis Biomass project (W.M. Beaty & Associates, Inc. / Brooks Walker et al)

Location

The Davis Biomass project is located approximately three miles east of Whitmore, CA at approximately 3,000 foot elevation on the west slope of the Southern Cascades on forestlands managed by W.M. Beaty & Associates, Inc. The project area consists of 2,200 acres of uneven-age natural stands of mixed conifer and ponderosa pine along with a portion of a 30 year old ponderosa pine plantation that was established after the 1977 Whitmore Fire.

Figure 2: Loading thinned trees for delivery to biomass energy plant

Treatment

The objectives of the project were to thin small overcrowded trees in the understory of the conifer forest to improve the health and vigor of the remaining trees and reduce hazardous fuel ladders and fuel loading. Trees targeted for removal included suppressed trees between 4 and 12 inches (dbh) with poor live crown ratios. Vigorous trees of this size class with good live crown ratios were retained along with all live trees of larger size classes (12 inch dbh and greater). Although the logging contractor was not required to cut trees less than 3 inches dbh, some were thinned out to facilitate removal of the target trees.

The treatment was completed over three years (2007 – 2009) with the removal of 1,804 chip van loads totaling 24,998 bone dry tons (BDTs) that were delivered to Wheelabrator Shasta Energy Co., Inc. in Anderson for electricity generation. While this treatment might have been completed in one long operating season, the following factors contributed to extending the treatment over three operating seasons:

- the onset of early fire seasons,
- operators being called away to other jobs, and
- the inability to operate in this area during the winter.

As fire hazards increased with the onset of each summer, each year the humidity levels dropped below 20% by 9 or 10 o'clock in the morning and fire hazard restrictions forced operational shutdowns. However, the objectives of the project were accomplished by thinning the understory to promote residual stand health and vigor and reduce the risk of catastrophic loss by reducing fuel loads and ladder fuels which will aid fire suppression efforts should a wildfire occur.

Fuel reduction on HH Biomass project (W.M. Beaty & Associates, Inc. / Red River Forests Partnership and Bank of the West, Trustee)

Location

The HH Biomass project is located approximately two miles north of Shingletown, CA at approximately 3,500 foot elevation on mixed conifer forestlands managed by W.M. Beaty & Associates, Inc.

Figure 3. Stand in HH Biomass project after thinning

Treatment

Objectives of the 1,445-acre biomass thin project were to increase stand health and vigor, reallocate the species composition to mimic a more "natural" historic forest and to reduce the risk of loss from catastrophic wildfire by reducing ladder fuels and total fuel loading. Trees targeted for removal included suppressed trees between 4 and 12 inch dbh with poor live crown ratios. Except for a special "Shaded Fuel Break" prescription within 100 feet of the main roads, vigorous trees of this size class with good live crown ratios were retained along with all live trees of larger size classes (12 inch dbh to 36+ inches dbh). Within 100 feet of some main roads almost all understory trees were thinned out and the re-sprouting brush was then treated to create a “Shaded Fuel Break”. Although the logging contractor was not required to cut trees less than 3 inches dbh, some were thinned out to facilitate removal of the target trees.

The treatment was completed over three years (2007 – 2009) with the removal of 1,917 chip van loads totaling 26,104 bone dry tons (BDTs) that were delivered to Wheelabrator Shasta Energy Co., Inc. in Anderson for electricity generation. The objectives of the project were accomplished by thinning the understory to promote residual stand health and vigor and to reduce the risk of catastrophic loss by decreasing fuel loads and ladder fuels which will aid fire suppression efforts should a wildfire occur.

Methods

Field measurements before and after fuel treatments

The location of field sampling plots was pre-assigned in a geographical information system (GIS) prior to fieldwork (Figures 4a, b, c). Data were collected in a total of 35 measurement plots[1] (15 on Davis, 9 on HH, and 11 on Berry Timber). Plot coordinates were generated randomly in advance of the field work. The field team navigated to the pre-assigned points. Plot measurements were taken in accordance with USFS General Technical Report NRS-18 (Pearson et al. 2007d), and included the following measurements at each plot location within fuel treatment units:

- All trees >5 cm diameter at breast height, measured in nested plots and marked for post-treatment measurements;
- Canopy density, tree heights, and height to live crown, as inputs to fire behavior models;
- Standing dead wood;
- Lying dead wood, measured along transects (plus dead wood density from collected samples).
- Understory vegetation, forest floor litter and duff, measured in clip plots;

These represent forest dimensions that will influence fire severity and the forest carbon pools that may be affected by fire, treatment, or both. The protocols used for these measurements are described in Annex A.

[1] The number of plots was the result of available resources and field time rather than being statistically calculated.

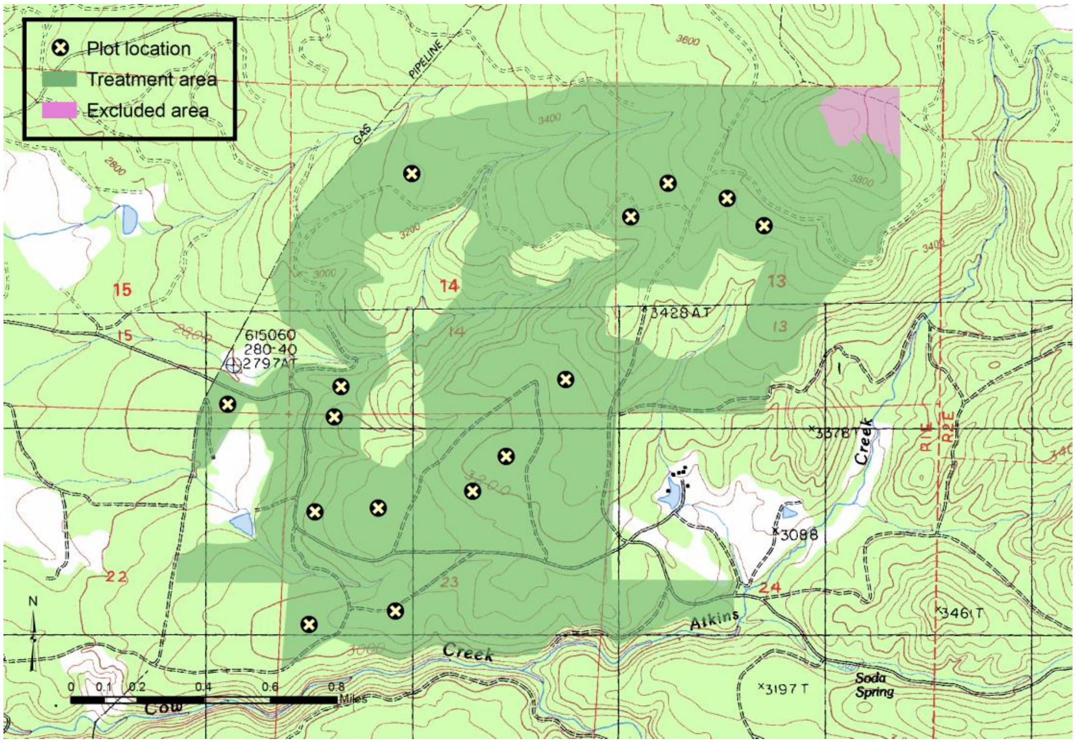

Figure 4a. Davis Mountain treatment area and plots

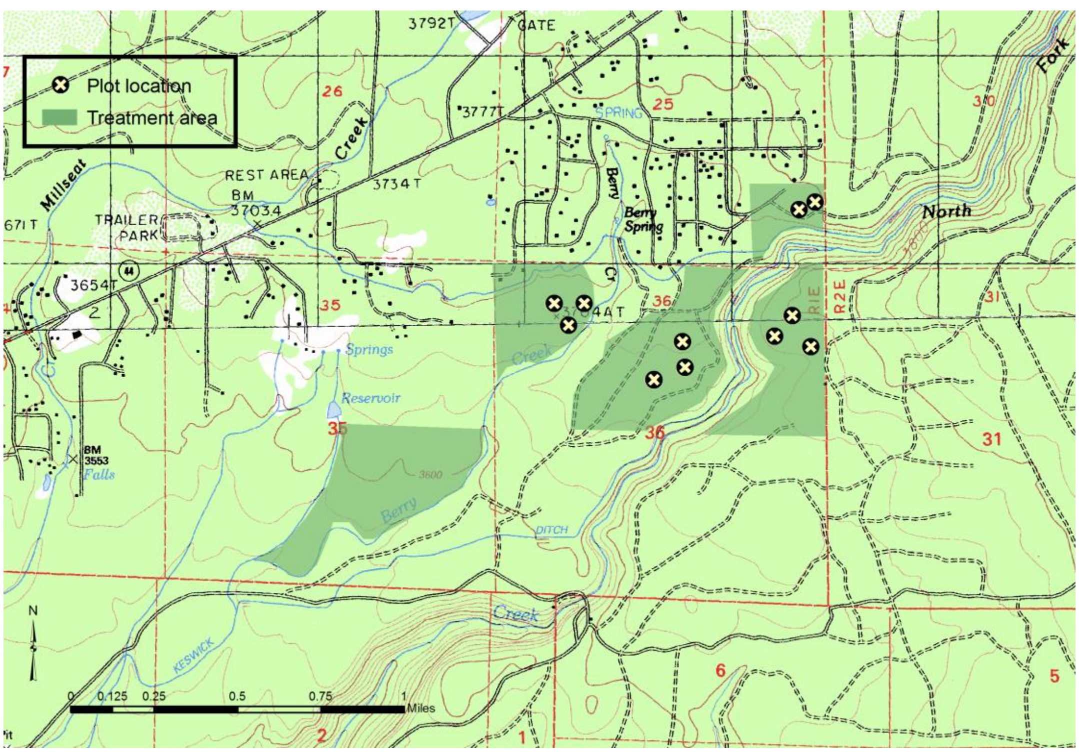

Figure 4b. Berry Treatment area and plots

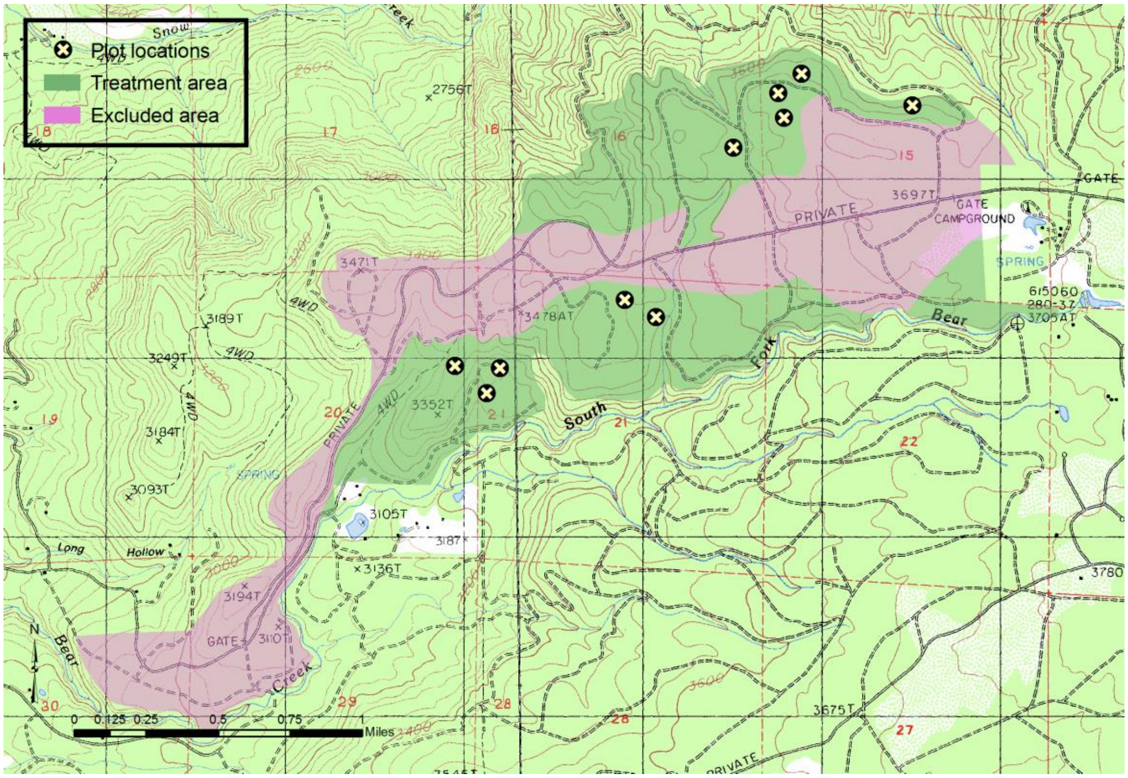

Figure 4c. HH treatment area and plots

The date of treatment at each site and the dates of pre- and post-treatment measurements by Winrock/Western Shasta RCD crews are shown in Table 1. In order to quantify the effects of treatment on the same carbon pools, the post-treatment measurements were conducted shortly after treatments were completed, on the same plots used for pre-treatment measurements, following a measurement protocol similar to pre-treatment fieldwork. The one difference in the post-treatment measurements was that tree diameters were not measured; instead, trees marked during pre-treatment measurements were counted and assumed to have the same diameter.

Table 1. Dates of fuel treatment and pre- and post-treatment measurements for the three Shasta County fuel treatment sites

Location	Date		
	Pre-Treatment Measurement	Treatment	Post-Treatment Measurement
Davis Mountain	June 2007	2007-2009	June 2009
HH Biomass	June 2007	2007-2009	June 2009
Berry Timber	June 2007	July – August 2007	September 2007

The purpose of the measurements was to identify, in real as opposed to modeled forests, the carbon stocks available to be burned before and after treatment, the direct impacts of fuel treatments on carbon stocks in different carbon pools (e.g. increases in dead wood, decreases in dense growth), and the fuel removed from the forest for biomass energy during treatment. Measurements also provided input data for fire models used to simulate fire behavior and emissions in the baseline (without-treatment) and with-treatment scenarios.

The total carbon stocks were determined using the standard allometric equations of Forest Vegetation Simulator Fire and Fuels Extension Inland California and Southern Cascades variant[2].

Fire Modeling

Based on the field data disaggregated by carbon pool, emissions from a potential fire were modeled in both with- and without-fuels treatment scenarios. The modeling was conducted using two separate approaches.

1. The FCCS program (Fuel Characteristic Classification System) was developed by the Pacific Northwest Research Station to capture the structural complexity and geographical diversity of fuel components across landscapes and to provide the ability to assess elements of human and natural change. FCCS is a software program that allows users to access a nationwide library of fuelbeds or create customized fuelbeds. The fuelbeds are organized into six strata: canopy (trees), shrubs, nonwoody vegetation, woody fuels (lying deadwood and stumps), litter-lichen-moss, and ground fuels (duff and basal accumulations). FCCS calculates the relative fire hazard of each fuelbed, including crown fire, surface fire behavior, and available fuel potentials. It also reports carbon storage by fuelbed category and predicts the amount of combustible carbon in each category.[3]

2. In addition to the FCCS modeling, fire effects were modeled using the Forest Vegetation Simulator Fire and Fuels Extension (FVS-FFE). FVS provides different output to FCCS and FVS can be used to project growth, incorporating the impacts of fire on the future stand.

The two models produced slightly different results, as they use different modeling methodologies and different biomass equations. They also produce somewhat different output. Reported outputs from FCCS include flame length in feet; crown fire potential as a scaled index from 0-9; rate of spread in feet per minute; and carbon consumed for live canopy, dead wood, and total. Reported results from FVS-FFE include flame length in feet; the crowning index in miles/hour; and total carbon consumed. Results for both prescribed fire and wildfire are reported from FCCS, while only wildfire is reported from the FVS-FFE results.

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[2] More information, including the FVS User's Guide and variant descriptions, are available at http://www.fs.fed.us/fmsc/fvs/index.shtml.

[3] More information is available at the FCCS website: http://www.fs.fed.us/pnw/fera/fccs/. The modeling was conducted by Dr. David "Sam" Sandberg – Emeritus of the PNW Research Station Fire and Environmental Application Team.

Although FVS uses a somewhat simpler methodology than FCCS for projecting fire impacts, it is based on established fire models and allows for growth projections. In order to address growth over time, FVS projections are used throughout the results, but FCCS output is presented to demonstrate the range of potential fire emissions.

Fire Risk

Annual burn probability is difficult to project accurately, as it is a factor of the likelihood of ignition and the conditions on the ground at the time of ignition, including fuels, climate, temperature, and topography (see Finney, 2005). Saah *et al.* (2010) determined the relative fire probability and observed annual burn probability for Shasta County, which were used to identify a potential annual burn probability of 0.64% (Eric Waller, 2010, UCB CFRO, pers. comm.). It is important to note that this is a generalized probability and is not based specifically on pre- and post-treatment conditions for these projects, but rather for Shasta County as a whole.

Growth Modeling

Stand growth, both with- and without-treatment and considering all pools, was modeled with the US Forest Service's Forest Vegetation Simulator (FVS), using the Inland California and Southern Cascades variant. The standard allometric equations in the Fire and Fuels Extension (FFE) of FVS were used to produce biomass and carbon reports in conjunction with forest growth. Data from both the 2007 and 2009 inventories were used, with the pre-treatment inventory year counted as year zero to compare with and without treatment scenarios. Growth was projected over a 60 year period, and did not include any additional future treatments. To incorporate the effects of wildfire on growth, FVS-FFE was also used to model wildfire behavior.

Modeled Scenarios

For both fire and growth modeling, four different scenarios were modeled for all three projects. Each scenario includes the following carbon pools: aboveground live, belowground live, standing dead, and lying dead. The treated scenarios also include carbon stored in merchantable timber after 100 years. To simplify calculations, the emissions arising from wood product conversion and subsequent retirement are included at the beginning of the project. The treatment scenarios also incorporate average emissions from equipment use.

	Untreated	Treated
No Wildfire	1.Untreated, no fire	3.Treated, no fire
Wildfire	2.Untreated, wildfire	4.Treated, wildfire

- *Scenario 1* gives the situation where there is no treatment or fire. At time zero it represents simply the carbon stocks (tons of carbon per acre) prior to treatment.
- *Scenario 2* is the carbon emissions and remaining stocks following a wildfire on untreated lands.
- *Scenario 3* is the carbon stocks remaining after the treatment, incorporating any emissions that were a result of treatment activities but in the absence of any fire.
- *Scenario 4* is the carbon emissions and remaining stocks following a wildfire on treated lands.

Biomass Accounting

We assumed that biomass harvested from project areas and burned to produce energy offsets energy that would otherwise be derived from fossil fuels. In California power generation is dominated by natural gas with small contributions from clean energy/nuclear and coal. In January 2007 the California Public Utilities Commission established a performance standard that all new long-term baseload generation must meet (http://docs.cpuc.ca.gov/Published/NEWS_RELEASE/63997.htm). As this performance standard is equivalent to the minimum standard required for any new power generation in California it is considered to be a conservative comparison for this analysis. The CPUC performance standard is equal to 1,100 pounds of carbon dioxide emitted for each Megawatt hour of electricity produced, an amount equivalent to 0.499 metric tons of carbon dioxide.

Literature[4] and our partners at Wheelabrator indicate that one bone dry ton of biomass produces one MWh of electricity. One bone dry ton is 0.5 bone dry ton of carbon or 1.833 tons of carbon dioxide. Each ton of biomass extracted for biomass energy therefore effectively emits:

$$1.833 - 0.499 = 1.334 \text{ t } CO_2$$ [5]

[4] cf. http://bioenergy.ornl.gov/papers/misc/energy_conv.html, http://groups.ucanr.org/WoodyBiomass/documents/InfoGuides12929.pdf

[5] The assumption of many (including the IPCC) is that biomass burned to produce electricity is carbon neutral. The argument is that all biomass that is burned was once grown, and so one MWh of electricity derived from biomass leads to a positive emissions avoidance of 0.499 t CO_2 (i.e., avoiding natural gas emissions). This would be true if the biomass were grown as part of the project in a plantation, where in the absence of the project the biomass being burned would never have been sequestered from the atmosphere. However, natural forests in California are not plantations. In the absence of the project, CO_2 *was* sequestered out of the atmosphere by the forest biomass. In the project case, this biomass is burned and released into the atmosphere. In the baseline the biomass remains sequestered in the forest. Thus what the atmosphere "sees" is a net increase in carbon dioxide because of the project. However, because of the project some amount of natural gas does not need to be burned to produce electricity. Specifically, as shown above, for each 1.833 t CO_2 released to produce 1 MWh of electricity through biomass from hazardous fuels, 0.499 t CO_2 are saved due to natural gas not having to be burned. Therefore, burning hazardous fuels rather than natural gas results in a net emission of 1.334 t CO_2.

This subject often leads to confusion. Many interpret the fact that biomass is replaceable in the way that fossil fuels are not to mean that all biomass burned has no net impact on the atmosphere. But as the paragraph above demonstrates, burning biomass does increase the greenhouse gases resident in the atmosphere. Burning biomass might prevent emissions from fossil fuels, but this is by no means permanent. What is being achieved is a delay in the date at which all fossil fuels will be used. It is critical to focus on the atmosphere, i.e. does the project cause an increase or decrease in the concentration of carbon dioxide in the atmosphere? In this case, burning biomass

Because of the biomass removal treatment some amount of natural gas does not need to be burned to produce electricity. Specifically, as shown above, for each 1.833 t CO_2 released to produce 1 MWh of electricity through biomass from hazardous fuels, 0.499 t CO_2 are saved due to natural gas not having to be burned. This is equivalent to 27.2% of the net emission being offset.

Timber Accounting

Of the three projects, only Berry Timber included removal of sawtimber. Board feet of timber harvested is converted to metric tons of carbon according to Smith *et al.* (2006), that provides a factor of 0.44 per thousand board feet to convert softwood lumber to metric tons of carbon. The fraction of carbon in primary wood products remaining over time in end uses and stored in land fill, as described in Smith *et al.* (2006), are then applied: after 10 years, 42.4% of carbon will remain in use as long-term wood products, and 11.6% will be sequestered in landfills; after 60 years, 17.3% of carbon will remain in long-term wood products, and 21.8% in landfills; after 100 years, 11.2% will remain in wood products and 24.3% in landfills.

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rather than natural gas leads to an increase in CO_2 in the atmosphere because natural gas burns more cleanly than biomass. If coal were displaced instead of natural gas the savings would be greater while if the displacement is of electricity generated by nuclear power, solar, wind or hydro power then the result is an emission with no net saving.

If the stand is not treated the fuels are available in the forest to be emitted to the atmosphere through wildfires. However, this should not be considered under the biomass energy calculations. If it is then we are double-counting. The baseline fire risk multiplied by the stock gives the baseline emission from wildfires, which is the emission from fuels in the absence of fuel treatment.

Net Impact Calculations

Net project benefits following a treatment must incorporate

- *carbon stocks in the forest;*
- *carbon emissions in a wildfire, accounting for the probability of fire;*
- *growth;*
- *carbon stored as long-term wood products;*
- *emissions offset through energy production.*

The net emissions or removals in year one are calculated as

$$\left[(Ct+Cw+Ce-Cb)*(1-risk)\right]+\left[(Ctf+Cw+Ce-Cbf)*(risk)\right]$$

Where

Ct	carbon stocks remaining in the forest after treatment and without a wildfire
Cw	carbon stored as wood products
Ce	reduced emissions from using biomass for energy generation
Cb	carbon stocks in the forest before treatment and without a wildfire
risk	probability of fire
Ctf	carbon stocks remaining in the forest after treatment and with a wildfire
Cbf	carbon stocks remaining in the forest before treatment and with a wildfire

This equation states that the net emissions in year 1 are equal to:

The high probability that there will <u>be no fire</u> multiplied by the difference between stored carbon before and after treatment

Plus

The low probability that there will <u>be a fire</u> multiplied by the difference in total carbon storage after a fire in the treated stand and in the baseline stand.

3.0 Project Results

Berry Timber Results

Field results

Prior to treatment, the Berry Timber project had a stock of 70.1 tons of carbon per acre across all pools. Following the treatment, the average carbon stock was 49.4 t C/ac. Treatment therefore resulted in a decrease in carbon stocks of 20.7 tons per acre, 30% of pretreatment stocks. The breakdown by pool is shown in Table 2, and the confidence limits at a 90% confidence interval for the aboveground live carbon pool are shown in Table 2a.

Table 2. Berry Timber carbon stocks (metric t C/ac) before and after fuels treatments

Carbon pool	Pre-treatment	Post-treatment	Difference
Trees	39.7	27.1	*-12.6*
Roots	10.6	7.6	*-3.0*
TOTAL TREES	50.3	34.7	*-15.6*
Standing dead	0.5	0.3	*-0.2*
Down dead wood	12.0	9.3	*-2.7*
TOTAL DEAD WOOD	12.5	9.6	*-2.9*
Forest Floor	7.2	4.6	*-2.6*
Shrubs/herbaceous	0.2	0.4	*0.2*
TOTAL	70.1	49.4	*-20.7*

Table 2a. Upper and lower confidence limits at 90% CI for Berry Timber aboveground live carbon stocks (metric t C/ac) before and after fuels treatments

Aboveground live carbon	Pre-treatment	Post-treatment
LCL	32.3	20.4
mean	39.7	27.1
UCL	47.1	33.8
CI as a % of mean	18.6 %	24.7 %

Potential fire emissions

Using FCCS-created fuel beds, a wildfire in the untreated stands would yield 46.6 tons of CO_2 per acre of emissions, while a wildfire in the treated stands would yield 31.7 t CO_2 / ac (Table 3). Using the FVS Fire and Fuels Extension, a wildfire in the untreated stands would yield 42.5 t CO_2 / ac of emissions, while a wildfire in the treated stands would yield 26.4 t CO_2 / ac (Table 4).

Table 3. FCCS fire modeling results for Berry Timber

	Prescribed Fire		Wildfire	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Flame Length (ft)	2.5	2.2	6.1	5.0
Crown Fire Potential (scaled index 0-9)	3.6	2.3	4.2	3.0
Rate of Spread (ft/min)	3.6	4.5	18.3	19.4
CO_2 emissions (t/ac)				
Canopy	-4.6	-1.8	-14.3	-6.2
Dead Wood	-22.4	-18.2	-28.2	-23.1
Litter	-2.9	-1.8	-3.5	-2.2
Total	-29.9	-21.8	-46.0	-31.5

Table 4. FVS fire modeling results for Berry Timber

	Wildfire	
	Pre-treatment	Post-treatment
Flame Length (ft)	6.5	5.7
Crowning index (miles/hr)[6]	31.4	49.8
CO_2 emissions (t/ac)	-42.5	-26.4
Total stand carbon remaining	58.1	42.4

Timber and biomass

The commercial harvest on Berry Timber yielded 4,096 board feet of timber per acre. According to the conversion factor in Smith *et al.* (2006), this equals 1.8 t C/ac. Based on carbon disposition rates, a total of 1.0 t/ac will remain stored in either long-term wood products or landfill after 10 years; 0.7 t/ac will remain stored in either long-term wood products or landfill after 60 years; and 0.6 t/ac will remain stored in either long-term wood products or landfill after 100 years.

Wheelabrator received 3.3 bone dry tons of biomass per acre from the Berry Timber project, which represents 1.7 t C/ac. Because this biomass was used to generate energy, it offset 1.7 t C/ac * 27.2% = 0.5 t C/ac, resulting in reduced total emissions of 4.5 t CO_2-e/ac (1.2 t C/ac).

Growth modeling

Based on FVS modeling (Table 5), in the absence of fire, the treatment resulted in an initial decrease in carbon stocks of 20.7 t C/ac (compare columns 1 and 2), and a reduced increase in carbon stocks of 11.7

[6] The 20-foot windspeed required to cause an active crown fire.

t C/ac after 60 years, for a total decrease in live stocks of 32.4 t C/ac over a 60 year period relative to no treatment.

In the event of a wildfire in year zero, the treated stands contain 15.7 t C/ac less than the untreated stands (difference between columns 3 and 4), but carbon stocks in the treated stands increase more than those in untreated stands over 60 years (25.5 t C/ac), for a total increase of 9.8 t C/ac relative to the untreated stand.

Table 5. Modeled total stand carbon pre and post treatment and with and without fire on Berry Timber project. Modeling conducting using the Fuels and Fire Extension of FVS. Data in metric tons of carbon per acre

Year	Untreated, no fire (1)	Treated, no fire (2)	Untreated, wildfire (3)	Treated, wildfire (4)
0	70.1	49.4	58.1	42.4
10	76.6	52.9	55.2	45.6
20	86.0	58.3	53.6	49.6
30	94.8	64.3	53.0	54.1
40	103.1	70.6	54.1	59.0
50	110.6	77.3	56.3	64.0
60	116.9	84.5	59.6	69.4
Total change	*46.8*	*35.1*	*1.5*	*27*
Total % change	*167%*	*171%*	*103%*	*164%*

FVS growth modeling (Table 6) indicates that after 60 years in the absence of wildfire, treated stands continue to have fewer trees per acre, lower basal area, and fewer cubic feet and board feet than untreated stands, while the quadratic mean diameter[7] (QMD) is greater in the treated stands. However, the rate of change (Table 7) is greater in the treated stands for all measurements except QMD. This indicates that while the treated stands did not catch up to the untreated stands in absolute numbers, they had a lower mortality rate and a higher per tree growth rate overall. In addition, the trees remaining in the treated stands remained larger, on average, than those in the untreated stands.

In the event of a wildfire, treated stands have fewer trees per acre after 60 years, but increased basal area, QMD, cubic feet, and board feet, and they have a higher rate of change in all categories than do untreated stands.

[7] The diameter corresponding to the mean basal area of a stand.

Table 6. Projected Growth on Berry Timber project, modeled in FVS

	Untreated			Treated		
	Year 0	Year 60 – no fire	Year 60 - wildfire	0	Year 60 – no fire	Year 60 – wildfire
Trees per acre	282	160	73	132	118	64
Basal area	173	251	113	121	213	172
QMD	10.6	17.0	16.8	13.0	18.2	22.3
Cubic feet	4,873	8,799	3,828	3,541	7,383	6,270
Board feet	22,683	47,077	20,509	16,450	38,703	34,334

Table 7. Percent change within each scenario after 60 years of growth on Berry Timber project

	Untreated		Treated	
	No fire	Wildfire	No fire	Wildfire
Trees per acre	57%	26%	89%	48%
Basal area	145%	65%	176%	142%
QMD	160%	158%	140%	172%
Cubic feet	181%	79%	209%	177%
Board feet	208%	90%	235%	209%

Net GHG emissions/sequestration

Including carbon stored in long term wood products and energy offsets, for treated stands without wildfire, the total stock is 51.2 tons of carbon per acre and 44.2 t C/ac in the same stands following a wildfire. Figure 5 shows the tons of carbon per acre sequestered on Berry Timber in each of the four scenarios, the total carbon stored following treatment when wood products and biomass energy are included, and the percent change from untreated to treated and unburned to burned lands.

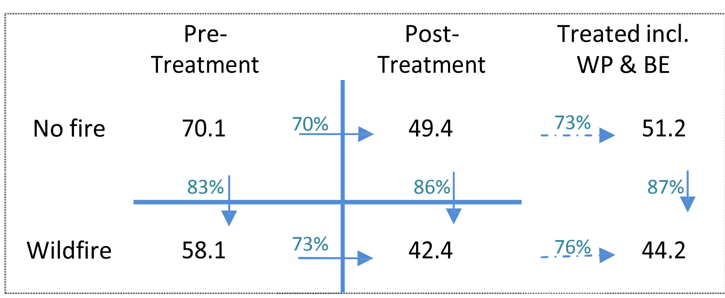

Figure 5. Tons of carbon per acre stored on Berry Timber project lands in each scenario, and included carbon stored in wood products and reduced emissions from biomass used to produce energy. Percentages show change from untreated lands to treated or from unburned to burned. BE = biomass energy. WP = storage in long term wood products and landfill after 5 years

Incorporating the risk of fire of 0.64% and utilizing the equation described above for net emissions or sequestration (section 2.2.6), [(Ct+Cw +Ce-Cb)*(1-risk)]+[(Ctf+Cw+Ce-Cbf)*(risk)], the fuels treatment on the Berry Timber project resulted in an effective immediate net carbon emission of 69.2 t CO_2-e/ac (18.9 tons of carbon per acre).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 83.2 t CO_2/ac and emissions of 116.2 t CO_2/ac over 60 years (Table 8).

Table 8. Net short and long term emissions from fuels treatment, without fire, on Berry Timber in tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-4.5	-4.5
Commercial timber	3.7	2.6
Treatment emissions	-86.9	-118.8
NET	-83.2	-116.2

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest. According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 36.0 t CO_2/ac.

Davis Results

Field results

Prior to treatment, the Davis project had a stock of 50.9 tons of carbon per acre across all pools. Following the treatment, the average carbon stock was 46.4 t C/ac. Treatment therefore resulted in a decrease in carbon stocks of 4.5 tons per acre, 8% of pretreatment stocks. The breakdown by pool is shown in Table 9, and the confidence limits at a 90% confidence interval for the aboveground live carbon pool are shown in Table 9a.

Table 9. Davis carbon stocks (metric t C/ac) before and after fuels treatments

Carbon pool	Pre-treatment	Post-treatment	Difference
Trees	26.7	22.4	*-4.3*
Roots	7.8	6.3	*-1.5*
TOTAL TREES	34.5	28.7	*-5.8*
Standing dead	0.6	1.1	*0.5*
Down dead wood	9.0	11.1	*2.1*
TOTAL DEAD WOOD	9.6	12.2	*2.6*
Forest Floor	6.6	5.1	*-1.5*
Shrubs/herbaceous	0.2	0.4	*0.2*
TOTAL	50.9	46.4	*-4.5*

Table 9a. Upper and lower confidence limits at 90% CI for Davis above ground live carbon stocks (metric t C/ac) before and after fuels treatments

Aboveground live carbon	Pre-treatment	Post-treatment
LCL	22.0	18.1
mean	26.7	22.4
UCL	31.4	26.7
CI as a % of the mean	17.6 %	19.2 %

Potential fire emissions

Using FCCS-created fuel beds, a wildfire in the untreated stands would yield 35.2 tons of CO_2 per acre of emissions, while a wildfire in the treated stands would yield 39.2 tons of CO_2 per acre (Table 10). Using the FVS Fire and Fuels Extension, a wildfire in the untreated stands would yield 37.0 tons of CO_2 per acre of emissions, while a wildfire in the treated stands would yield 34.1 tons of CO_2 per acre (Table 11).

Table 10. FCCS fire modeling results for Davis

	Prescribed Fire		Wildfire	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Flame Length (ft)	3.4	3.5	8.2	8.3
Crown Fire Potential (scaled index 0-9)	3.7	3.2	4.4	3.8
Rate of Spread (ft/min)	5.2	7.0	27.4	34.6
CO_2 emissions (t/ac)				
Canopy	-2.4	-2.4	-7.5	-7.5
Dead Wood	-18.9	-22.2	-23.7	-28.2
Litter	-2.8	-2.6	-3.5	-3.1
Total	-24.1	-27.2	-34.7	-38.8

Table 11. FVS fire modeling results for Davis

	Wildfire	
	Pre-treatment	Post-treatment
Flame Length (ft)	5.8	6.8
Crowning index (miles/hr)[8]	25.1	36.8
CO_2 emissions (t/ac)	-37.0	-34.1
Total stand carbon remaining	40.5	37.2

Biomass

Wheelabrator received 11.4 bone dry tons of biomass per acre from the Davis project, which represents 5.7 tons of carbon per acre. Because this biomass was used to generate energy, it offset 5.7 t C/ac * 27.2% = 1.5 t C/ac, resulting in reduced total emissions of 15.4 t CO_2-e/ac (4.2 t C/ac).

Growth modeling

Based on FVS modeling (Table 12), in the absence of fire, the treatment resulted in an initial decrease in carbon stocks of 4.5 t C/ac (compare columns 1 and 2), and a reduced increase in carbon stocks of 7.7 t C/ac after 60 years, for a total decrease in live stocks of 12.2 t C/ac over a 60 year period relative to an untreated stand. In the event of a wildfire in year zero, the treated stands sequester 3.3 t C/ac less than the untreated stands (difference between columns 3 and 4), but carbon stocks in the treated stands

[8] The 20-foot windspeed required to cause an active crown fire.

increase more than those in untreated stands over 60 years (3.6 t C/ac), for a total increase of 0.3 t C/ac relative to an untreated stand.

Table12. Modeled total stand carbon pre and post treatment and with and without fire on Davis project. Modeling conducting using the Fuels and Fire Extension of FVS. Data in metric tons of carbon per acre

Year	Untreated, no fire (1)	Treated, no fire (2)	Untreated, wildfire (3)	Treated, wildfire (4)
0	50.9	46.4	40.5	37.2
10	59.1	52.6	39.6	38.3
20	70.2	61.4	40.6	41.0
30	80.9	70.2	42.6	43.8
40	91.1	79.4	46.0	47.2
50	100.5	88.2	50.4	51.2
60	108.7	96.5	55.6	55.9
Total change	*57.8*	*50.1*	*15.1*	*18.7*
Total % change	*214%*	*208%*	*137%*	*150%*

FVS growth modeling (Table 13) indicates that after 60 years in the absence of wildfire, treated stands continue to have fewer trees per acre, lower basal area, and fewer cubic feet than untreated stands, while QMD is greater in the treated stands and the board feet is slightly higher.

Table 13. Projected Growth on Davis, modeled in FVS

	Untreated			Treated		
	Year 0	Year 60 – no fire	Year 60 - wildfire	0	Year 60 – no fire	Year 60 – wildfire
Trees per acre	405	205	98	164	128	46
Basal area	140	251	126	106	233	124
QMD	8.0	15.0	15.4	10.9	18.3	22.1
Cubic feet	3,141	8,246	4,181	2,730	8,072	4,612
Board feet	12,780	43,022	22,163	12,154	43,657	26,592

However, the rate of change (Table 14) is greater in the treated stands for all measurements except QMD. This indicates that while the treated stands did not catch up to the untreated stands in absolute numbers, they had a lower mortality rate and a higher growth rate overall. In addition, the trees remaining in the treated stands remained larger, on average, than those in the untreated stands.

In the event of a wildfire, treated stands have fewer trees per acre after 60 years and slightly lower basal area, but increased cubic feet, and board feet, and they have a higher rate of change in all categories than do untreated stands.

Table 14. Percent change after 60 years of growth on Davis project

	Untreated		Treated	
	No fire	Wildfire	No fire	Wildfire
Trees per acre	51%	24%	78%	28%
Basal area	179%	90%	220%	117%
QMD	188%	193%	168%	203%
Cubic feet	263%	133%	296%	169%
Board feet	337%	173%	359%	219%

Net GHG emissions/sequestration

Including carbon stored in long term wood products and energy offsets, treated stands without wildfirehave an estimated total stock of 47.9 tons of carbon per acre compared to a stock of 38.7 t C/ac in treated stands following a wildfire. Figure 6 shows the tons of carbon per acre sequestered on Davis in each of the four scenarios, the total carbon stored following treatment when wood products and biomass energy are included, and the percent change from untreated to treated and unburned to burned lands.

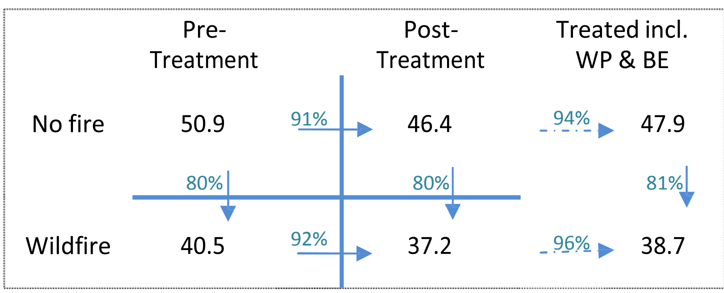

Figure 6. Tons of carbon per acre stored on Davis project lands in each scenario, and included carbon stored in wood products and reduced emissions from biomass used to produce energy. Percentages show change from untreated lands to treated or from unburned to burned.

Incorporating the risk of fire of 0.64% and utilizing the equation described above for net emissions or sequestration (section 2.2.6), [(Ct+Cw +Ce-Cb)*(1-risk)]+[(Ctf+Cw+Ce-Cbf)*(risk)], the fuels treatment on the Davis project resulted in a net carbon emission in year one of 11.0 t CO_2-e/ac (3.0 t C/ac).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 39.2 t CO_2/ac and emissions of 60.1 t CO_2/ac over 60 years (Table 15).

Table 15. Net short and long term emissions from fuels treatment, without fire, on Davis in tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-15.4	-15.4
Treatment emissions	-23.8	-44.7
NET	-39.2	-60.1

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest. According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 20.2 t CO_2/ac.

HH Biomass Results

Field results

Prior to treatment, the HH Biomass project had 63.9 tons of carbon per acre across all pools. Following the treatment, the average carbon stock was 52.5 t C/ac. Treatment therefore resulted in a decrease in carbon stocks of 11.4 tons per acre, 18% of pretreatment stocks. The breakdown by pool is shown in Table 16, and the confidence limits at a 90% confidence interval for the aboveground live carbon pool are shown in Table 16a.

Table 16. HH Biomass carbon stocks (metric t C/ac) before and after fuels treatments

Carbon pool	Pre-treatment	Post-treatment	Difference
Trees	36.5	27.3	*-9.2*
Roots	10.7	7.7	*-3.0*
TOTAL TREES	47.2	35.0	*-12.2*
Standing dead	0.9	0.2	*-0.7*
Down dead wood	9.0	11.1	*2.1*
TOTAL DEAD WOOD	9.9	11.3	*1.4*
Forest Floor	6.5	5.9	*-0.6*
Shrubs/herbaceous	0.2	0.3	*0.1*
TOTAL	63.9	52.5	*-11.4*

Table 16a. Upper and lower confidence limits at 90% CI for HH Biomass carbon stocks (metric t C/ac) before and after fuels treatments

Potential fire emissions

Using FCCS-created fuel beds, a wildfire in the untreated stands would yield 39.2 t CO_2 /ac of emissions, while a wildfire in the treated stands would yield 38.3 t CO_2 /ac (Table 17). Using the FVS Fire and Fuels Extension, a wildfire in the untreated stands would yield 39.6 tons per acre of emissions, while a wildfire in the treated stands would yield 35.2 tons per acre (Table 18).

Table 17. FCCS fire modeling results for HH Biomass

	Prescribed Fire		Wildfire	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Flame Length (ft)	3.2	2.4	7.7	5.3
Crown Fire Potential (scaled index 0-9)	4.1	3.2	4.7	3.7
Rate of Spread (ft/min)	6.3	5.0	32.3	21.2
CO_2 emissions (t/ac)				
Canopy	-3.7	-2.8	-11.0	-8.4
Dead Wood	-19.3	-20.7	-24.0	-26.6
Litter	-3.3	-2.9	-4.0	-3.5
Total	-26.3	-26.4	-39.0	-38.5

Table 18. FVS fire modeling results for HH Biomass

[9] The 20-foot windspeed required to cause an active crown fire.

Biomass

Wheelabrator received 18.1 bone dry tons of biomass per acre from the HH Biomass project, which represents 9.0 tons of carbon per acre. Because this biomass was used to generate energy, it offset 9.0 t C/ac * 27.2% = 2.5 tC/ac, resulting in reduced total emissions of23.8 t CO_2-e/ac (6.5 t C/ac).

Growth modeling

Based on FVS modeling (Table 19), in the absence of fire, the treatment resulted in an initial decrease in carbon stocks of 11.4 t C/ac (compare columns 1 and 2), and a reduced increase in carbon stocks of 6.8 t C/ac after 60 years, for a total decrease in live stocks of 18.2 t C/ac over a 60 year period. In the event of a wildfire in year zero, the treated stands sequester 9.9 t C/ac less than the untreated stands (difference between columns 3 and 4), but carbon stocks in the treated stands increase more than those in untreated stands over 60 years (9.9 t C/ac), resulting in no net change in carbon sequestered after 60 years.

Table 20. Modeled total stand carbon pre and post treatment and with and without fire on HH Biomass project. Modeling conducted using the Fuels and Fire Extension of FVS. Data in metric tons of carbon per acre

Year	Untreated, no fire (10	Treated, no fire (2)	Untreated, wildfire (3)	Treated, wildfire (4)
0	63.9	52.5	52.7	42.8
10	75.4	59.1	49.7	44.9
20	88.9	68.5	49.5	48.9
30	100.0	77.7	51.7	52.8
40	108.2	86.1	55.7	57.5
50	114.6	94.1	61..5	62.7
60	119.9	101.7	68.3	68.3
Total change	*56.0*	*49.2*	*15.6*	*25.5*
Total % change	*188%*	*194%*	*130%*	*160%*

FVS growth modeling (Table 21) indicates that after 60 years in the absence of wildfire, treated stands continue to have fewer trees per acre, but the basal area is nearly the same, and they have greater cubic feet, board feet, and QMD than untreated stands.

Table 21. Projected Growth on HH Biomass, modeled in FVS

	Untreated			Treated		
	Year 0	Year 60 – no fire	Year 60 - wildfire	0	Year 60 – no fire	Year 60 – wildfire
Trees per acre	629	197	122	208	147	70
Basal area	197	251	156	132	247	166
QMD	7.6	15.3	15.3	10.8	17.6	20.8
Cubic feet	4,313	8,329	4,911	3,439	8,541	5,968
Board feet	16,521	42,748	24,613	14,849	45,528	33,357

The rate of change (Table 22) is greater in the treated stands for all measurements except QMD. This indicates that after 60 years, treated stands have a higher growth rate and have surpassed untreated stands in overall volume.

Table 22. Percent change after 60 years of growth on HH Biomass project

	Untreated		Treated	
	No fire	Wildfire	No fire	Wildfire
Trees per acre	31%	19%	71%	34%
Basal area	127%	79%	187%	126%
QMD	201%	201%	163%	193%
Cubic feet	193%	114%	248%	174%
Board feet	259%	149%	307%	225%

In the event of a wildfire, treated stands have fewer trees per acre after 60 years, but have higher basal area, and increased cubic feet and board feet, and they have a higher rate of change in all categories except QMD than do untreated stands.

Net GHG emissions/sequestration

Including carbon stored in long term wood products and energy offsets, treated stands without wildfire have a total of 55.0 tons of carbon per acre compared to a stock of 45.3 t C/ac in treated stands following a wildfire. Figure 7 shows the tons of carbon per acre sequestered on Davis in each of the four scenarios, the total carbon stored following treatment when wood products and biomass energy are included, and the percent change from untreated to treated and unburned to burned lands.

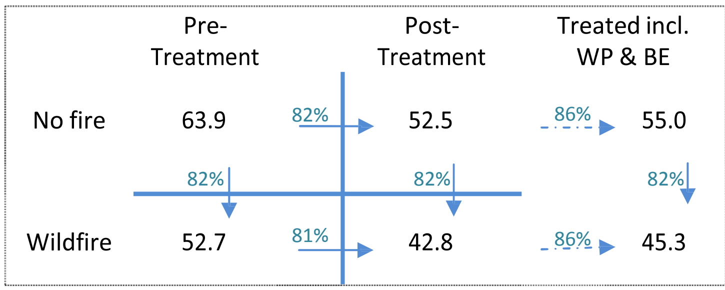

Figure 7. Tons of carbon per acre stored on HH Biomass project lands in each scenario, and included carbon stored in wood products and reduced emissions from biomass used to produce energy. Percentages show change from untreated lands to treated or from unburned to burned.

Incorporating the risk of fire of 0.64% and utilizing the equation described above for net emissions or sequestration (section 2.2.6), [(Ct+Cw +Ce-Cb)*(1-risk)]+[(Ctf+Cw+Ce-Cbf)*(risk)], the fuels treatment on the HH Biomass project resulted in a net carbon emission in year one of 32.3 t CO_2-e/ac (8.8 t C/ac).

In the absence of a wildfire, the fuels treatments and commercial harvest result in short term emissions of 83.6 t CO_2/ac and emissions of 90.5 t CO_2/ac over 60 years (Table 23).

Table 23. Net short and long term emissions from fuels treatment, without fire, on HH biomass in tons of carbon dioxide per acre (+ = removals; - = emission)

	Short term 10 years	Long term 60 years
Biomass energy	-23.8	-23.8
Treatment emissions	-59.8	-66.7
NET	-83.6	-90.5

For the treatment to yield benefits to the atmosphere, the emissions from treatments will need to be offset by reductions in emissions from a potential wildfire hitting the area. In order for the treatment to have an impact, such a fire would have to occur before fuels have returned to hazardous conditions, at which point it will be necessary to re-treat the forest. According to the FVS-modeled results, if a wildfire were to occur in the year of treatment, after 10 years the net emissions from treatment would be 41.4 t CO_2/ac.

4.0 Discussion

In all three projects, the treatments resulted in significant net carbon emissions[10]. This result clearly has implications for the future potential of fuels treatments as a carbon projects offset category.

The reasons for the net emission from hazardous fuel reductions are multiple. In the case of the Davis and HH projects, deadwood stocks increased following the treatment. This may be due to these projects' focus on removal of pre-commercial trees and a corresponding increase in the amount of limbs and branches left following the treatment. Because the Berry project included sawtimber removal, the live standing carbon removed was far greater than for the other sites. However, due to milling inefficiencies and the retirement of wood over time, only a fraction of the carbon removed as sawtimber is stored in wood products over the long term. The use of biomass for electricity generation also does not compensate for the loss of carbon stored as standing timber, especially given the common use of natural gas and the minimum performance standards required in California.

Both the Berry and the HH treatments led to a decrease fire intensity and in potential CO_2 emissions from fire. There was a greater decrease on the Berry project, likely due to sawtimber removal and the subsequent reduction in the forest crown. Despite the decrease in emissions from fire, both projects continue to have lower standing carbon stocks after a fire in the year of treatment. The treatment on the Davis project led to increased fire intensity. According to FCCS modeling, the treated stand also yielded slightly higher CO_2 emissions from fire, while FVS modeling indicated slightly lower CO_2 emissions after a fire in the treated stand[11]. The significant increase in both standing and lying deadwood on the Davis project explains the increase in fire intensity in the year following treatment. However, in subsequent years, as the deadwood continues to break down, the intensity of a potential fire is likely to decrease. In addition, the reduction in live ladder fuels improves the ability to control a fire.

The rate of growth on both Berry and HH increased following the treatment, but in the absence of a wildfire, total carbon stocks in the treated areas still had not surpassed those in untreated areas after 60 years. Growth rates on the Davis project were slightly lower following treatment. The treatment in the Davis project removed a smaller percentage of basal area than did the other two treatments, and may not have increased resources for residual trees enough to allow increased growth. However, when growth is projected following a fire in the year of treatment, all three projects experienced higher

[10] A complete accounting of emissions would have also incorporated equipment use. Though this project did not address equipment emissions, a similar project in Shasta County found emissions ranging from 0.8 to 1.8 tons CO_2/ac. While this is not an insignificant amount, it is a small fraction of the emissions which result from the removal of biomass from the forest.

[11] The difference between the two models is likely based on the specificity required of input data for each model. FCCS requires certain input data which is not required by FVS and which was not collected in the field. In order to run FCCS, base fuelbed data was used in cases where empirical data was not available.

growth rates with treatment. Treated stands in all three projects also have greater overall carbon stocks by year 30, though it's important to note that there is an annual risk of fire and subsequent wildfires were not modeled. Additionally, with each year following a hazardous fuels treatment, the benefits of the treatment are reduced and the maximum shelf life is probably less than 20 years.

Within the treated areas, all three projects had significant net emissions when considering treatment and the risk of a potential wildfire. Davis experienced the lowest emissions, but as discussed above, the treatment on Davis did not decrease fire intensity. If a fire were to occur in the year of treatment, all projects would still experience net emissions, though the impact of treatment emissions would be approximately halved in all cases.

One critical factor not addressed in this study is the impact of fuels treatment on fire intensity and emissions outside the treated area itself. In many cases, the reduced intensity of fire in a treated area decreases the intensity of fire in the surrounding untreated areas, increasing the beneficial aspects of the treatment without removing additional biomass. This is often referred to as a fire shadow. The size of a fire shadow along with the level of reduced emissions varies based on a number of factors, including topography, location of treatment, climatic conditions, and fire intensity. Incorporating the fire shadow in the overall emission calculations would decrease the net emissions in most cases, but given the extent of emissions for all three projects, it is likely that inclusion of a fire shadow would yield lower emissions but significant emissions would still result from treatment.

All three of the pilots led to a decrease in crown fire potential, which decreases fire severity and size. While treatments lead to net carbon emissions in both the short and long term in all three projects, there are, of course, additional benefits to fuels treatments, such as increased ability to successfully fight fires and decreased cost of firefighting; reduced loss of life and property; and reduced potential damage to wildlife habitat.

These results are mirrored well in the results from the Alder Springs treatment in Mendocino National Forest conducted under funding from the US Forest Service. In Alder Springs, net emissions of 26.3 tons of carbon dioxide per acre were recorded immediately after treatment climbing to a total of 86.9 t CO_2-e/ac after 60 years.

The results from this study in combination with the paired study in Lake County and the allied study in Mendocino National Forest underlie the unsuitability of fuels treatment as a potential greenhouse gas offset generating activity. Instead we argue the shift should be made to policies minimizing greenhouse gas emissions from wildfires and from fuel treatments while minimizing wildfire risks to lives, homes and livelihoods in the WESTCARB region.

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Appendix A:

Protocol for monitoring and estimating greenhouse gas benefits from hazardous fuels management in Western U.S. forests

Report for the
West Coast Regional Carbon Sequestration Partnership
Phase II

Protocol for monitoring and estimating greenhouse gas benefits from hazardous fuels management in Western U.S. forests

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Nick Martin and John Kadyszewski

Submitted by
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WINROCK INTERNATIONAL

Table of Contents

Overview

This paper introduces key concepts and provides an approach for developing baseline, measuring and monitoring methodologies as part of a protocol for estimating potential greenhouse gas benefits from improved fuel management programs in western U.S. forests. First, we outline what is needed and provide our preliminary approach and calculations. We then discuss the specific factors involved in our approach, and introduce several ***key questions and uncertainties*** that will guide discussions at the WESTCARB Fire Workshop (Redding, October 24-25, 2006).

Tables

Figures

SECTION 1: General Approach

1.1 What is needed and why?

Our goal is to develop a **cost-effective, practical, transparent protocol** for estimating, to acceptable levels of accuracy and precision, the carbon benefits associated with improved management of hazardous fuels in forests susceptible to wildfires. We assume that fuels management activities would be executed by private or public landowners as specific "projects" that would occur over finite areas while remaining embedded in the larger surrounding landscape.

Developing protocols for project activities that are designed to **reduce or avoid emissions** of greenhouse gases present several major challenges, the main one being the baseline. The reason for this challenge is that the baselines for such projects, by their very nature, are projections into the future of what would happen, and generally what would happen in the future is based on what has happened in the past. For the project type presented here, there is potentially a greater challenge because of the very nature of fires—they are unpredictable. The key for developing the protocols is to recognize that the baseline will never be perfect, but that an agreed on methodology can be reached using the best science available.

Like some other types of forestry projects implemented for carbon credits, the development of a fuels management protocol will likely require the collection of project-specific data. Assumptions and default factors will be warranted in cases where collecting data is cost-prohibitive and/or the project is overly complex (such as for the development of the baseline methodology, outlined below). The use of default values is common practice under both national and international accounting guidelines, but it is essential that these assumptions remain both conservative and transparent.

Improved fuels management can reduce losses of carbon stocks from forest ecosystems; reduce the areal extent of burning; reduce fire severity; increase carbon sequestration in residual forest stands; and increase substitution of forest fuels for more carbon-intensive fossil fuels – all which lead to potential **greenhouse gas benefits**. These benefits are estimated as the difference in selected carbon pools between a "baseline" case and a "with project" case, with various fuel reduction treatments as project scenarios. Other greenhouse gases to consider in addition to carbon dioxide might include methane (CH_4) and nitrous oxide (N_2O).

For example, **Figure 1** illustrates how the carbon that would burn in a "business as usual" case (hatched box) might be diverted into a fuel reduction treatment plan (gray box) to reduce the severity of catastrophic wildfires and their associated carbon emissions. Removing hazardous fuel loads before they burn would lead to less intense fires and would thereby cause a larger unaffected vegetation pool. This pool would need to be managed continuously to prevent the excessive buildup of new fuels, but resources allocated towards suppressing fires could be re-directed towards preventing them through better forest management. Because fuels removed from forests could be transported to biomass energy plants and burned as alternative energy sources to fossil fuels, landowners could potentially generate two streams of revenue: dollars from selling carbon credits and dollars from selling biomass.

The focus of this protocol will be on elucidating the carbon benefits that arise from decreasing the extent of fires and the emissions from fires within project boundaries. Project emissions will include the emissions associated with fuel treatment including cutting, transporting and burning of fuels.

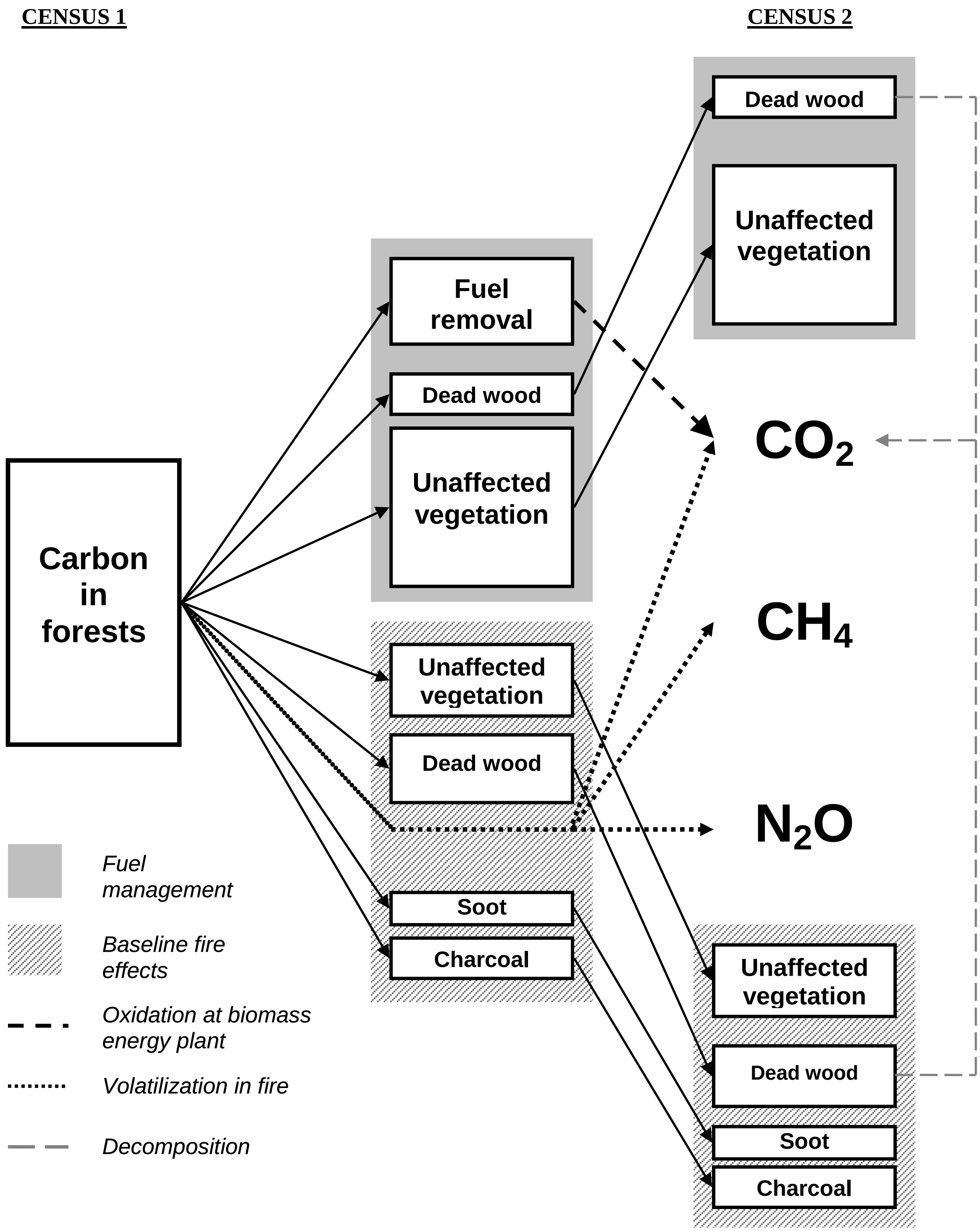

Figure 1. The fate of carbon in forests under baseline (no fuel management) and with-project (with fuel management) scenarios. The goal of a fuel management program would be to divert carbon that would ordinarily burn in a fire (hatched box) towards a program involving fuel removal (gray box). The fate of the fuels removed would depend on the specific treatment; this figure shows fuel removed and transported to a biomass energy plant. Such a management program would result in less intense, less severe fires and a larger pool of unaffected carbon.

1.2 Approach to calculations

Baselines are used as a reference case to estimate the emissions and removals of greenhouse gases attributed to changes in the use and management of land. Baseline scenarios are defined by projecting and quantifying the carbon emissions of a "business as usual" approach to forest management, i.e., the emissions that would occur if current management practices were to continue into the future. In this case, the baseline is related to the likelihood that a fire event would occur at any given location as well as the net carbon, as CO_2 (and potentially other non-CO_2 greenhouse gases such as methane and nitrous oxide), that would be emitted during a typical fire event. A carbon baseline has three components: (1) **a projection of the area** of the forest that burns over a given time frame**,** (2) the change in forest **carbon stocks and associated GHG emissions** resulting from the fire (e.g., Census 1 and Census 2 in Figure 1), and (3) the **pre-fire and post-fire rates of carbon accumulation** in the forest. Each of these can be addressed separately.

The **with-project case** is the net emissions of carbon resulting from project implementation. In the case of fuels management, projects would involve treatments that would reduce the quantity of hazardous fuels. The difference between this "with-project" value and the baseline value would then be calculated as the **carbon benefit** (Figure 2). Initially, net carbon emissions may increase temporarily as a result of project implementation, but these emissions would be offset by the treatment effect.

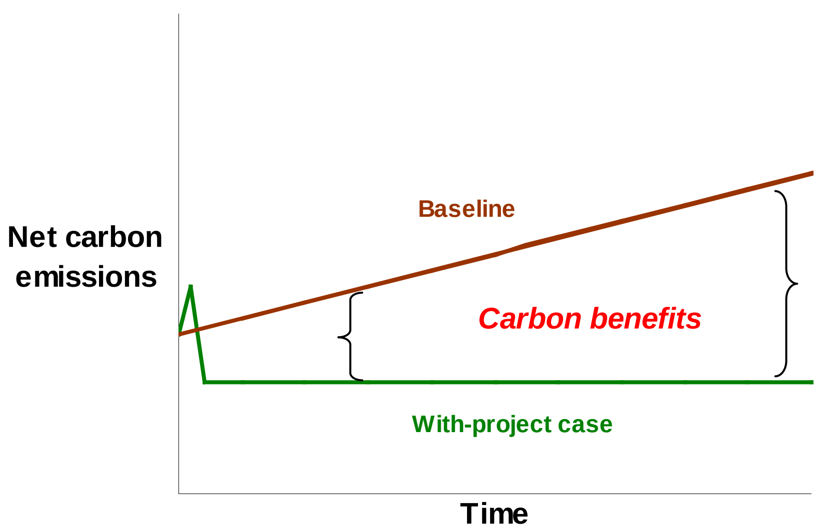

Figure 2. Hypothetical baseline emissions, with-project emissions, and the resulting carbon benefits from changes in management of the land.

1.2.1 Potential calculations

The carbon benefits of fuel reduction activities *could* be estimated as follows:

A. Baseline Emissions

1. Determine the project area (areas of treatment)
2. Stratify lands by age class and fuel load
3. Measure the fuel loads on project lands for each age class stratum

4. Estimate the mean forest carbon stock based on standard protocols procedures (existing within the CA Climate Action Registry [CCAR])
5. Obtain an estimate of the baseline area burned per year from "registry" tables (to be established specific to this methodology) for most recent past 10-yr period and assume fixed for future 10-yr period
6. For each stratum, solve the following equations, then add together for total baseline emissions:

$$BE = BE_{CO_2} + BE_{CH_4} + BE_{N_2 0} \pm BE_R$$

$$BE_{CO_2} = \sum_{1}^{n} A_n \times (C_n \times F_n) \times 3.67$$

where:
BE = Baseline emissions (t CO_2-e/ 10 yr)
BE_{CO2} = Baseline carbon dioxide emissions (t CO_2-e/ 10 yr)
BE_{CH4} = Baseline methane emissions (t CO_2-e/ 10 yr)
BE_{N2O} = Baseline nitrous oxide emissions (t CO_2-e/ 10 yr)
BR_R = Emissions/removals of carbon dioxide due to the differential pre- and post-fire effects on rates of carbon accumulation (t CO_2-e/ 10 yr)
A = Area burned =percent per year (ha/yr) x area of treated strata *n* x 10 years
C = Carbon stock in age class *n* (t C/ha)
F = fraction of initial carbon stocks lost to fire in age class *n* and fuel load *n* (from Table 3)

7. Repeat analysis every 10 years for duration of "project" (could extend for several decades) to reassess the rate of emissions as a result of new treatments, regulations, climate change scenarios, etc. – or just develop updated baselines if management conditions have remained unchanged.

B. Project Emissions

1. Track biomass of fuels removed from forest
2. Track any fires that occur during the project period on the project lands. Measure carbon stock in all pools immediately after any fire.
3. For each stratum, solve the following equation then add together for total project emissions.

$$PE = FE + FTE + EE \pm RE$$

where:
PE = Project carbon emissions (tCO_2-e)
FE = Emissions from any fires that occur on project lands (tCO_2-e)
FTE = Emissions that occur due to fuels treatment (tCO_2-e)
EE = Emissions that occur due to transport and/or combustion of fuels (tCO_2-e)
RE = Emissions/removals due to the differential pre- and post-treatment effects on rates of carbon accumulation (tCO_2-e)

C. Project Benefits

In any given year, project benefit is equal to average annual baseline emissions minus project emissions.

$$PB = BE - PE$$

where:
BE = Baseline carbon emissions (t CO_2-e)
PE = Project carbon emissions (tCO_2-e)

SECTION 2: Baseline

2.1 Background

The WESTCARB II project focuses on terrestrial sequestration pilot activities in two counties: Shasta County, CA, and Lake County, OR (to facilitate early protocol development Shasta County will initially be the sole focus). Although there are several different forest types in these counties, for initial protocol development we focus on the **mixed conifer forest type** (including ponderosa pine, mixed conifer, etc.[1]) found typically in large parts of southern Oregon and northern California. We selected this general forest type based on Schoennagel et al. (2004), who proposed that western forests at **low and mid-elevations** that historically had low to mixed severity fires are good candidates for fuel treatments to restore their historical stand structure and fire regimes.

Historically, the surface fuel layer of low-elevation, ponderosa pine forest were dry during the summer fire season that resulted in frequent and low-intensity surface fires. More recently, fire suppression activities have disturbed this historical fire regime and have resulted in a build-up of ladder fuels at intermediate heights that carry surface fires into the crown, where they can lead to large, catastrophic fires. Mixed-intensity fire regimes occur mostly at mid-elevations, in mixed conifer forest stands defined by a mixture of tree species and densities. The frequency, severity and size of fires in these forests are affected by fuel accumulation and climate, and the impact of suppression practices on fuel loads in these forests varies depending on the tree composition of the forest stand.

2.2 Estimation of area that would burn

The area component of the baseline is a projection into the future of the likely area that would burn in a fire. This raises two key issues:

What should be the spatial scale?
And what should be the temporal scale?

The **spatial scale** needs to be large enough to capture the trend, but not so large that it masks more localized trends caused by differences in state and county-level regulations that govern forest management practices, human demographics and infrastructure, boundaries related to policies, variation in climate and precise species composition. After looking at various scales, we decided to use the two California Department of Forestry **CA-FRAP** (California Fire and Resource Assessment Program) northern California analysis units: **Cascades Northeast** and

[1] The mixed conifer forest type contains the following WHR types: Sierran mixed conifer, Klamath mixed conifer, ponderosa pine, eastside pine and jeffrey pine.

North Coast. (Figure 3) We also stratified the forests by land ownership class (publicly and privately owned) to reflect differences in management practices, and suggest developing separate carbon baselines for public and private lands to account for these differences. We expect a similar approach could be used, with some modifications, for forests in the remainder of the WESTCARB region.

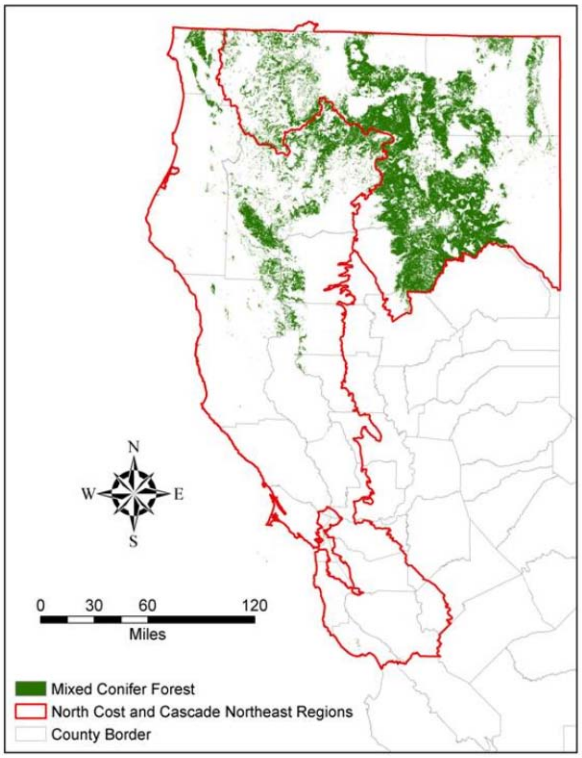

Figure 3. Distribution of mixed conifer forest across the North Coast and Cascades Northeast regions based on the California Land Cover Mapping & Monitoring Program

For the **temporal scale**, the question is: how far back in the historical record does one go to develop a trend for projecting into the future? How far into the future? In many respects, developing an estimate for the area component of the baseline is akin to developing baseline estimates of avoided tropical deforestation. After extensive investigation and model-testing, Brown et al. (2006) concluded that a reasonable and reliable estimate of the rate of deforestation could be obtained from change detection of remote sensing imagery over a recent **past period of about 10 years**. This 10-year rate is then expressed as an average percent of the forest remaining (area deforested over the about 10-year period divided by total area at the beginning of the period, expressed in percentage terms).

Future rates of deforestation, like fire, can be hard to project because they are subject to many factors. However, in the case of deforestation, a general consensus is developing that the rate of deforestation can be reliably projected about **10 years into the future**, with reassessments occurring every 10 years thereafter to adjust the baseline area component. We propose that these time periods could also be appropriate for fire baselines as this time frame is long enough to incorporate natural variations in forest dynamics among years, but also reflects the more recent forest management situation upon which other scenarios will be based.

Using the forest class map and fire data from CA-FRAP (California Fire and Resource Assessment Program), the area of mixed conifer class in the Cascades Northeast and North Coast counties is about 4.6 million acres, with the majority of this area as public land (2.7 million acres, or 58%) and 1.9 million acres (42%) as private land. The total area of forests that have burned in the last 10 and 20 years is 110,776 ac and 283,801 ac, respectively (Table 1, Fig. 4), with approximately 80% of this area burned on public lands in the last 10 years. It is clear from Fig. 4 that many large fires that occurred in this region were not located in the mixed conifer forest type.

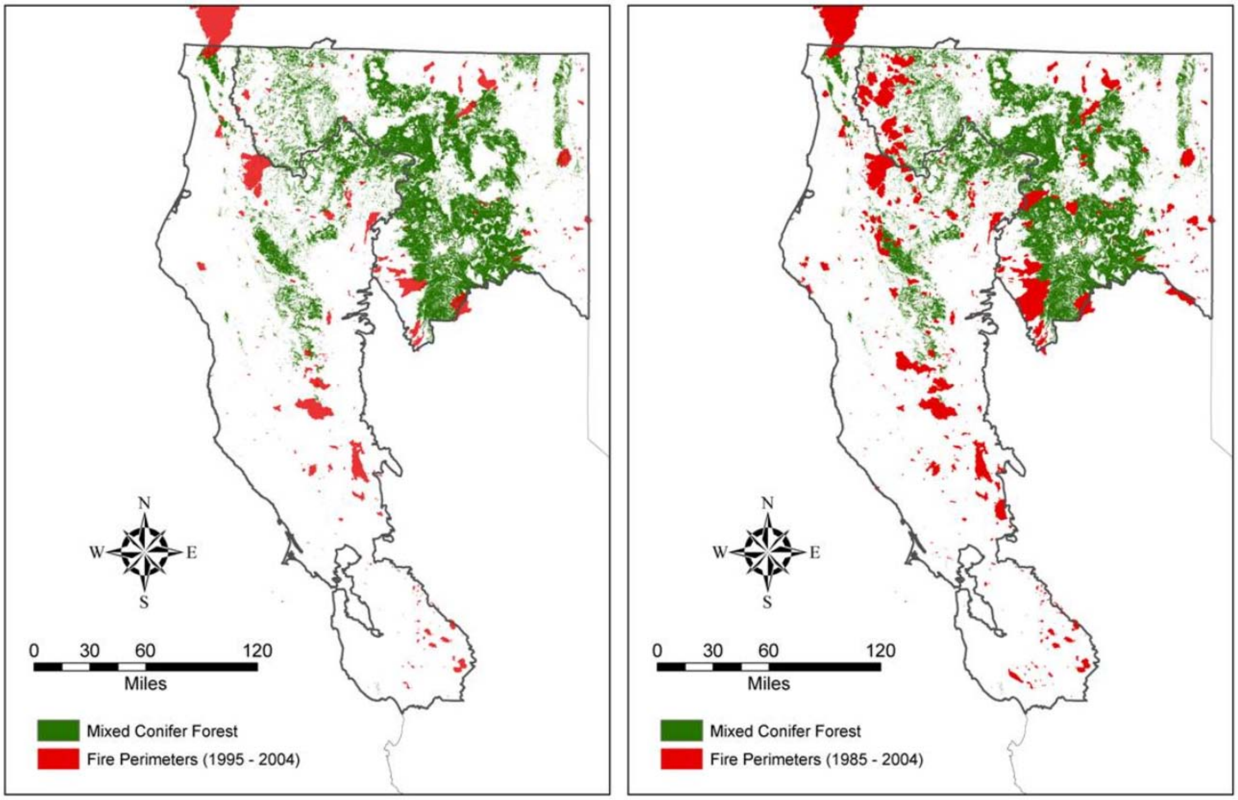

Figure 4. Distribution of mixed conifer forest and fire perimeters for 10-yr period (left) and for 20-yr period (right) across the North Coast and Cascades Northeast regions of the California Land Cover Mapping & Monitoring Program

Table 1. Area of mixed conifer forests that burned in the Cascades Northeast and North Coast analysis regions of CA between 1985 and 2004 (data from CA-FRAP)

Year	1 **Area (ac)** Public	2 **Area (ac)** Private	1 **Percent** Public	2 **Percent** Private
1985	1,863	367	0.070	0.019
1986	129	393	0.005	0.021
1987	83,344	4,272	3.116	0.224
1988	1,976	4,881	0.074	0.256
1989	400	379	0.015	0.020
1990	4,505	15,175	0.168	0.795
1991	314	818	0.012	0.043
1992	5,132	41,741	0.192	2.188
1993	81	1,013	0.003	0.053
1994	5,241	1,001	0.196	0.052
1995	103	0	0.004	0.000
1996	7,342	392	0.275	0.021
1997	79	39	0.003	0.002
1998	3,836	1,020	0.143	0.053
1999	13,670	5,547	0.511	0.291
2000	20,959	4,757	0.784	0.249
2001	16,906	4,345	0.632	0.228
2002	19,895	2,272	0.744	0.119
2003	1,988	3,016	0.074	0.158
2004	2,809	1,799	0.105	0.094
Total 20 years	190,573	93,228		
Total 10 years	87,588	23,188		

Table 2. Ten year average annual percentage of the total mixed conifer forest area burned in the Cascades Northeast and North Coast analysis regions of CA (data from CA-FRAP)

	Annual percentage **Public**	 **Private**
1985-1994	0.385	0.367
1986-1995	0.378	0.365
1987-1996	0.405	0.365
1988-1997	0.094	0.343
1989-1998	0.101	0.323
1990-1999	0.151	0.350
1991-2000	0.212	0.295
1992-2001	0.274	0.314
1993-2002	0.329	0.107
1994-2003	0.337	0.117
1995-2004	0.328	0.122

Based on the data in Table 2, the average baseline area burned in the 10-yr period 1995-2004 in the region is 0.12%/yr for private lands and 0.33%/yr for public lands. Both Tables 1 and 2 illustrate the annual variation in area burned and the impact of catastrophic fires on the annual percentage. The integration of ten years worth of data, however, moderates the impact of catastrophic fires and captures trends in fire incidence (Table 2).

We propose that the area component of the baseline be developed collaboratively between the state Department of Forestry and the relevant US Forest Service units within the state. We envision that the **baseline for area burned will be expressed as an annual percentage for the most recent past 10-year period, and projected forward for the next 10 years**. Lookup tables could provide these projections as values (rates) for each agreed-upon subregion/forest type within the state for a given 10 year period, and could be modified annually to produce updated values. One could imagine that, if indeed landowners became engaged in this type of project for carbon benefits, a project registry could provide the baseline rate of area burned by a "vintage year", which would then be applicable for the next 10 years of the project.

TOPIC 1: Questions, issues and uncertainties for the area baseline:

1. How many years to include in project baseline calculations?
2. Should we separate by forest type and regions within a State?
3. Or should it be by all forests within a region of a State?
4. Are the LCMMP regions a reasonable way to aggregate forests to reflect the factors that affect fire (climate, humans, etc.)?
5. Or should it just be by forest type and State?
6. Is the grouping of 5 WHR types into a mixed conifer forest type reasonable? (Klamath mixed conifer, Sierran mixed conifer, ponderosa pine, eastside pine, Jeffrey pine)
7. Is it reasonable to separate public from private lands? Would it make more sense to separate industrial forest lands which will have different fire relations and then lump the remaining private lands with the public lands?
8. Is the method for calculating baseline area sufficient? Or is it necessary to require modeling for every project?
9. Is an index of climate needed as a modifier for the projected area likely to be burned, and if so what index and how used?
10. Should we try to account for the expected reduction in area burned outside of the treated area that results from treatments inside a project areas?

2.3 Estimation of carbon emissions

The **baseline** emissions are basically equal to the **area** that would burn in the absence of the project **multiplied by the carbon emissions** estimated to result from the burned area. **Pre-fire carbon stocks** exist in live and dead standing trees, understory vegetation, litter and downed dead wood; all of these carbon stocks are potential fuel for fire. Historically, in the mixed conifer forest type, fires would pass through the understory relatively quickly and consume downed dead wood, understory vegetation, and litter. One hundred years of fire suppression has led to a growth in the stocks of all potential fuels. In particular, **tree density has increased** so that young trees can carry fires directly into the canopy of the forest (ladder fuels), and understory vegetation and dead wood stocks have grown so that flame lengths can threaten the canopy.

Pre-fire carbon stocks have five potential endpoints during and after a fire (Figure 1). The first proportion survives the fire to continue as live vegetation, a second proportion is volatilized during the fire and immediately released to the atmosphere, and the remainder is divided between pools of dead wood, soot and charcoal. Soot and charcoal are stable forms of carbon and can remain virtually unchanged for long time periods, while dead wood releases the stored carbon gradually into the atmosphere as it decomposes. The amount of carbon that transfers to these various forms during a fire depends upon a variety of factors, including the quantity of fuel (relative to the carbon stocks in non-fuel tree vegetation), its moisture content, and prevailing weather conditions.

The question becomes: what data are needed to develop the carbon stock component of the baseline that is specific to a particular parcel of land? It is assumed that the resulting **changes** in the forest carbon stocks and thus C emissions due to a fire are related to the **quantity of fuel** on the land and the **initial carbon stock**. For a similar relative amount of fuel (and all else equal), it is assumed that a young forest with low carbon stocks will suffer a greater proportion of loss in carbon stocks after a fire than an older forest with higher carbon stocks.

To quantify the impact of fire on changes in carbon stocks and the resulting C emissions, we propose using tables for both land ownership types (public vs. private) that contain values for the fraction of initial carbon stocks burned and emitted as CO_2. These values would vary as a function of **fuel load** (3-5 classes, assuming, initially, all exist under dry climatic conditions) and **forest age class** (**Table 3**).

A significant proportion of the live pre-fire carbon stocks will remain as dead wood post-fire. Under normal, non-fire conditions, carbon in dead wood is released gradually into the atmosphere through the process of decomposition. During a fire, however, it is likely that all stocks of dead wood will be consumed by the fire and all dead wood that remains after the fire is the result of recently-killed vegetation. To simplify the accounting, we could assume that the carbon in any dead wood that remains after the fire would also be emitted at this time. (This is similar to the assumption used in the IPCC national greenhouse gas inventory methods for carbon accounting of harvested forests.)

The values (as fractions) in Table 3 represent the fraction of the initial carbon stock emitted as CO_2 and is calculated as the sum of all aboveground biomass components (live and dead) that are oxidized during the fire *and* the biomass of the fire-killed dead wood that remains after the fire, divided by the pre-fire total aboveground carbon stocks. Filling in the values in Table 3 would rely on the literature, other studies from WESTCARB partners, output from stand/fire models, and new field data. The goal of a fire management program would be to move up Table 3 by reducing fuel loads from high (or medium) to low so that a lower proportion of existing forest carbon stocks are burned by fire.

Table 3. Sample table for calculating the fraction of initial carbon stocks emitted as CO_2 resulting from a fire, as a function of fuel load (low moisture conditions) and forest age. Two such tables would be developed, one each for public and private lands.

Fuel load	**Age Class (yr)**					
	0-20	21-40	41-60	61-80	81-120	121+
1 – Low						
2						
3 - Medium						
4						
5 – High						

The impact of fire on the changes in carbon stocks is not only a function of fuel load and age class—the **moisture condition** of the fuel (related to precipitation and temperature conditions) is also a key determinant of how much of the biomass will burn on site during a fire. For example, a high fuel load with low moisture content will lead to a more severe fire than the same fuel load that is moist. The moisture condition of the fuel will also affect how the fire burns (flaming vs. smoldering) and consequently the relative emissions of methane and nitrous oxide (each with higher global warming potential than CO_2).

How non-CO_2 greenhouse gases will be included and whether airborne soot should be included as a carbon dioxide equivalent will rely on the output of the workshop, on the literature, other studies from WESTCARB partners, and on output from stand/fire models.

An additional baseline consideration is **rate of carbon accumulation in the forest pre-and post-fire**. Pre-fire rates are related to several factors such as species mix, age, management, etc. Post-fire carbon accumulation rates are strongly influenced by factors such as fire intensity (heat of burning), fire severity (extent of burning), soil moisture conditions, nutrient availability, availability of seed sources, etc.

Carbon accumulates during regrowth after a fire, and the rate depends, in large part, on the fire's severity (Figure 5). A severe fire that burns through the entire canopy would likely have a slower rate of post-fire carbon accumulation than a less severe surface fire that leaves a majority of the vegetation intact. On the other hand severe fires increase light and soil nutrients for regeneration, reduce competition for water resources (but reduce the organic carbon base in the soil for regenerating seedlings). Severe fires may lead to an arrested succession whereby a dominant understory species such as manzanita prevents tree reestablishment or where soil conditions are altered to the point where the site is not immediately suitable for seedling establishment at all.

How to incorporate the differences in rates of carbon accumulation resulting from different intensities of fire? Three possible conditions exist: (1) pre- and post-fire rates of accumulation are the same, (2) pre-fire rates are greater than post-fire rates (severe fire), and (3) pre-fire rates are less than post-fire rates. If the pre- and post-fire rates of C accumulation are the same (condition 1), then there is no impact on the baseline as the removals of CO_2 from the atmosphere are the same. For condition (2), the pre-fire forest was removing more CO_2 from the atmosphere than the post-fire forest, thus the baseline net emissions of CO_2 due to the fire need to be increased by the difference in the rates. For condition (3), the post-fire forest is now removing more CO_2 from the atmosphere than the pre-fire forest, thus the baseline net emissions of CO_2 due to the fire need to be decreased by the difference in the rates. Thus in essence is it only the differential rate of carbon accumulation during the post fire situations that needs to be known.

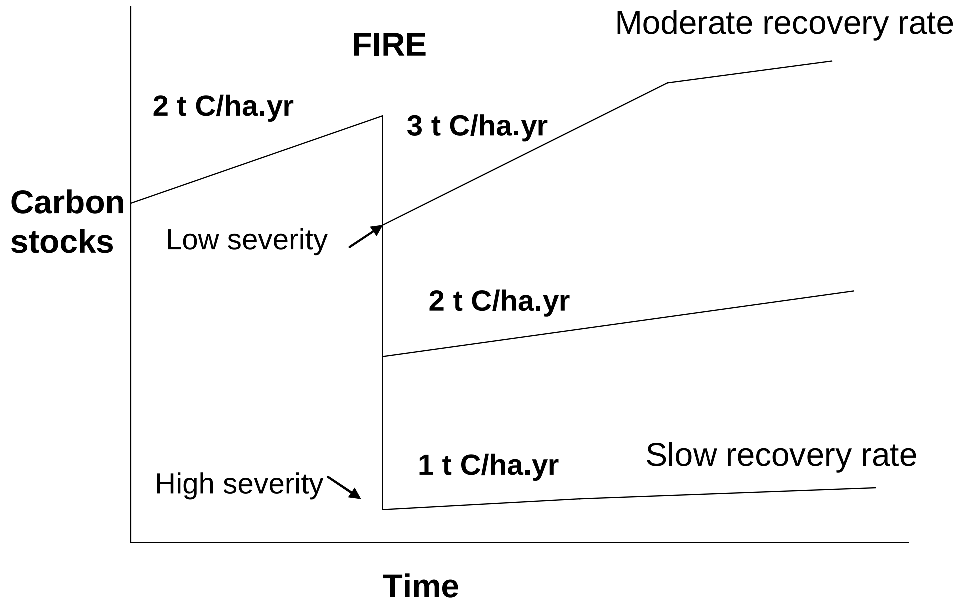

Figure 5. Illustration of hypothetical time course of carbon stocks in a forest stand pre-fire and after fires of various severities. Values on the lines are hypothetical rates of carbon accumulation pre- and post-fire

To illustrate the effects of the pre-and post fire rates of C accumulation discussed above, we use the hypothetical graphs in Fig. 5. For condition (1), the pre- and post-fire rates are the same at 2 t C/ha.yr; there is no difference in the rates of CO_2 uptake from the atmosphere and thus this component of the baseline can be ignored. For condition (2), pre-fire rate is 2 t C/ha.yr and the post-fire rate is 1 t C/ha.yr, and the difference is 1 t C/ha.yr (pre minus post). This means that the pre-fire forest was removing 1 t C/ha.yr more from the atmosphere than the post-fire forest. Thus the baseline net emissions caused by the fire is the gross emissions **plus** an amount equal to the product of the projected area that would have burned and the 1 t C/ha.yr difference in regrowth rate over the 10-yr time interval (assumed duration for the area-burned baseline component). For condition (3), the pre-fire rate is 2 t C/ha.yr and the post-fire rate is 3 t C/ha.yr, and the difference is -1 t C/ha.yr (pre minus post). In this case the post-fire forest is removing more CO_2 from the atmosphere than the pre-fire forest. The baseline net emissions are now the gross emissions from the fire **minus** the product of area projected to be burned and the 1 t C/ha.yr difference in regrowth rate over the 10-yr time interval.

TOPIC 2: Questions, issues and uncertainties for the carbon stock baseline:

1. How should 'hazardous fuel' be defined?
2. Where should boundaries be set in terms of fuel loads?
3. Is age class an appropriate method to classify the forest, and if so, where should boundaries be set in terms of age classes?
4. Should the age class categories in Table 3 be replaced by carbon stock categories?
5. How could fuel moisture condition be incorporated into the baseline calculations in a credible manner without producing an overly complex set of calculations?
6. How can we calculate CH_4 and N_2O emissions? Can we and should we do better than IPCC defaults?
7. Should the greenhouse impact of airborne soot be considered? How could this be quantified?
8. How should the differential rates of carbon accumulation between pre- and post-fire conditions be treated? Over what time interval?
9. To what extent are fuel treatments happening on public and private lands currently? And should we consider them as part of the baseline?

SECTION 3: With-Project Carbon Benefits

Once the baseline has been developed and projected, the next steps involve measuring and estimating the change in carbon stocks and resulting C emissions resulting from the treatment. Then the carbon benefit that could be "credited" to the activity is the difference between the baseline projection over an agreed-upon time frame (e.g. 10 years) and the actual C emissions monitored and estimated from applying fuel treatments on specific areas of land. In the baseline case, the C emissions are estimated from a projected percentage of the project area burned. However, in the with-project case, it is expected that the whole project area will need to be treated to claim that the occurrence of severe fires has been reduced. A first step then is to assess what types of fuel treatments make sense for such projects.

3.1 Treatment considerations

Several potential hazardous fuel reduction (HFR) treatments are available to reduce fuel loads in forests and to decrease severity of potential fire. Each of these treatments have different applications, constraints, costs, yields of merchantable and submerchantable material, revenues, air quality impacts, ground impacts and greenhouse gas emission impacts (**Table 4)**.

The important question will be to define what minimum level of treatment will be required in order to qualify the HFR treatment as producing a benefit relative to the baseline and thus eligible for crediting.

Table 4. Benefits, constraints and representative costs for hazardous fuel removal (HFR) treatments.

Fuels reduction treatment	Biomass product yield	Benefits	Constraints	Representa tive costs ($/acre)
R_x fire	No	Re-introduces fire	Air quality, ground impacts, fire escape, seasonal restrictions, immediate CO_2 emissions	35-300;average 92
Masticate – leave on site	No	Efficient, useful for less accessible sites	Leaves fuel on site, gradual CO_2 emissions	100-1,000
Cut-pile-burn	No	Can be used on less accessible or steep sites	Leaves fuel on site, air quality, immediate CO_2 emissions	100-750
Cut-lop-scatter	No	Can be used on less accessible or steep sites	Leaves fuel on site, gradual CO_2 emissions	105-280
Cable yarding for biomass removal	Yes	Can be used on less accessible or steep sites	Expensive, ground impacts	$80-130/CCF*
Cut-skid-chip-haul (for submerchantable biomass)	Yes	Removes fuel from site; some product value; allows renewable energy generation; greatest CO_2 benefit	More expensive; limited to gentler slopes, areas closer to roads for removal, limited haul distance to biomass plant	$34-48/BDT* + haul cost $0.35/BDT. mile $560-1,634/acre

CCF= 100 cubic feet; BDT = bone dry tons

3.2 With-project carbon emissions and removals

Implementing a hazardous fuel treatment results in carbon emissions to the atmosphere from several sources:

- Emissions resulting from the burning of fossil fuel by harvest equipment used in cutting and removing biomass, and emissions from transporting biomass to a power plant if this type of treatment is implemented.
- Emissions from the decomposing biomass fuel if left on site.
- Emissions from burning the biomass fuel either the piles left on site or in a power plant. If done in a power plant, the biomass fuel burns more efficiently than in an on-site fire, producing less soot, charcoal, and non-CO_2 GHG.

The treatment is also likely to have an effect on the rate of carbon accumulation of the treated forest, and as with fire the effect could cause the rates to increase, decrease, or be no different from the pre-treatment forest (see discussion above in relation to Fig. 5).

Unlike the baseline case, most of the emissions and removal will be monitored and estimated as would be required of any registry. The only variable that could not be readily monitored and estimated is the pre-treatment rate of carbon accumulation (also the pre-fire rate in the baseline).

However, using e.g. tree cores, well parameterized models, and other data, it is possible that acceptable rates of pre-treatment carbon accumulation could be estimated with a desired precision and accuracy (however, as illustrated in Annex 1, it is possible that knowledge of the pre-treatment and pre-fire fire rate of carbon accumulation is not needed).

3.3. Steps for monitoring a carbon project

To participate in a fuel management program, we propose the following conservative requirements for project monitoring:

1. Assume benefit for 10 years after treatment
2. Benefit only possible for treated areas
3. Re-treatment possible after 10 years for continued benefit (new baseline must be applied every 10 years
4. A minimum (as yet undefined) level of treatment is required to qualify for benefits relative to the baseline
5. Measurement required of all carbon pools immediately after fuels treatment
6. Measurement required of biomass of all fuels extracted from the forest
7. Tracking required of vehicle usage for fuels transport
8. Measurement required of any fires that occur in the project area and stocks remaining after fire.

TOPIC 3: Questions, issues and uncertainties for calculating project carbon benefits:

1. What is the minimum level of treatment that should be required to qualify for carbon benefits?
2. Is it reasonable to give benefit for 10 years following initial treatment? Is this too generous or too conservative?
3. Is there any way to consider benefits that arise beyond the project boundaries?
4. What treatments should be considered for hazardous fuel management?
5. Which treatments are most commonly used?
6. Which treatments are most profitable, in terms of both dollars and carbon benefits?
7. How long does the impact of fuels treatment last? Is the ten year constraint before re-treatment appropriate?

SECTION 4: General Considerations on Methodology

<u>TOPIC 4: General questions, issues and uncertainties for methodology:</u>

1. Is the approach taken here conservative to the point where it is hard for a project to receive benefit for the genuine good its treatments have caused?
2. What is the balance between being conservative so as not to over-credit and reflecting genuine decreases in fire extent and fire severity?
3. What is the balance between creating a simple methodology that can be applied by someone without great experience, and accurately capturing on the ground impacts?
4. Should we allow the option of using more complex methods (e.g. modeling) to quantify benefits if capacity exists (the concept of using a tier approach for such activities does exist in national accounting methods)?

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Annex 1

Here we illustrate how it may not be necessary to know what the pre-treatment and pre-fire rates of carbon accumulation are (for the baseline and with project cases, they are the same value). In the baseline and with project equations given in section 1.2.1 A and B the following terms are included:

BR_R = Emissions/removals of carbon dioxide due to the differential pre- and post-fire effects on rates of carbon accumulation
RE = Emissions/removals due to the differential pre- and post-treatment effects on rates of carbon accumulation

The term BR_R can be expressed as equal to CB-CP, where CB= background carbon accumulation rate pre fire and CP = carbon accumulation post fire.

The term *RE* can be expressed as equal to CB-CT, where CB is the same background carbon accumulation rate as pre fire or in this case pre treatment (the same forest in both cases) and CT is the carbon accumulation rate post treatment.

The carbon benefits are the difference between the baseline emissions and the project-case emissions. When simplifying the two equations representing the baseline and project emissions, the terms for BR_R and *R*E can be replaced by
(…baseline emissions eq.………+CB-CP) – (…project emissions……+CB-CT)

Simplifying this, the term CB drops out and one only needs to know the difference in the rate of carbon accumulation post fire and post treatment. Post treatment would be measured, but post fire would have to be modeled. However, this discussion does show that at least knowledge of one quantity is not needed for the fire methodology.