Placer County
AIR POLLUTION CONTROL DISTRICT

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Erik C. White, Air Pollution Control Officer

September 9, 2020

Mr. Richard Corey, Executive Officer
California Air Resources Board
1001 I Street
Sacramento, CA 95814

RE: Comments on Draft E3 Report on Carbon Neutrality

Dear Mr. Corey:

Placer County Air Pollution Control District (District) attended the California Air Resources Board's (CARB) virtual workshop presenting the E3 report on carbon neutrality. We were pleased to hear that E3 confirms that use of organic waste, the most significant of which is forest biomass derived from forest health and restoration projects, is a critical part of our State's carbon goals and energy future. For this report to serve as a basis for this important realization, the District has three improvements to suggest.

First, as the District has commented many times before to your Agency, the inclusion of black carbon from wildfire (whether that fire was human caused or not) as a part of the analysis is critical. As stated in your Resolution 17-9:

> "WHEREAS, the final proposed SLCP Strategy finds that wildfire is the largest source of black carbon emissions in California, harmfully impacting both public health and the climate;
>
> WHEREAS, in general, wildfires are occurring at increasing rates and at increasing levels of severity, that these wildfires put California's forest in jeopardy and raise concern over the long-term resilience of these forests and their ability to sequester carbon, mitigate climate change and provide resource amenities;
>
> WHEREAS, many studies have demonstrated net benefits for fuel treatments and forest management activities designed to reduce both fire spread and fire severity at the experimental unit or stand level, both in modeled and real world scenarios, and fuel treatments are key elements of strategies to restore forest and the natural role of fire at the local, state and national levels;
>
> WHEREAS, natural and working lands are a key sector in the State's climate change strategy because storing carbon in trees, other vegetation, soils and aquatic sediment can effectively remove carbon dioxide from the atmosphere, and the proposed 2030 Target Scoping Plan recognizes the importance of reducing greenhouse gas and black carbon emissions from wildfire;"

Resolution 17-9 went on to reference the drafting of the Forest Carbon Plan, which was finalized later in 2017. Since that time, the importance of considering and accounting for wildfire emissions has become painfully apparent. There is no question that CARB should be requiring its contractors to incorporate total carbon emissions from wildfire into any work done in evaluating of carbon neutrality, and should be incorporating the work CARB itself has prepared on this issue.[1]

When considering the benefits of the use of forest biomass for energy, as this E3 report discusses in detail, the benefits to avoided wildfire must be taken into consideration. As you may be aware, the District has developed a protocol to quantify the significant benefit selective and strategic forest fuels thinning has on reducing wildfire size and severity. The protocol is an improved version of CARB's GGRF program's forest offset "Quantification Methodology", and we are working towards its adoption in the Climate Action Reserve's Climate Forward voluntary offset program. The District offers that this methodology should be used by E3 to better inform its research into understanding the benefits of avoiding wildfire emissions through the use of fuel reduction derived biomass materials. The District, as it has for over ten years, stands ready to provide any technical assistance your contractor, E3, may need in applying the protocol. Please find a copy of the protocol attached for your reference.

Additionally, black carbon from other sources including open pile burning and prescribed burning, in forest as well as agricultural operations, should be considered, as well as the associated reductions in emissions from the alternate fate of this biomass for energy or wood products.

The second suggestion is in regards to the assumptions E3 makes on California's biomass and biogas potential. E3's assessment of biomass potential based on population is far afield from other reliable studies that have been done here in California – it seriously underestimates the quantity of biomass wastes that are generated in California. For reference, we have included a literature review funded by our District for the Forest Management Task Force illustrating that the E3 report is significantly below other peer reviewed estimates, and we suggest a critical review of that aspect of the work.

Finally, the District strongly encourages E3 to include the carbon benefits of the production and use of biochar to sequester carbon. While E3 considers Carbon Capture and Storage, an extremely expensive and challenging option, biochar provides a much cheaper and technologically available way to sequester carbon. Biochar also provides significant ancillary benefits to our soils and water quality.

Thank you very much for your time, and again, overall we are pleased with E3's work on this project. If you have any questions, please feel free to contact our staff attorney Christiana Darlington at 530-305-4433 or by email at christiana@clereinc.net.

Sincerely,

Erik C. White
Air Pollution Control Officer

Attachments:
1) Greenhouse Gas Offset Protocol: Avoided Wildfire Emissions
2) Statewide Feedstock Availability Literature Review

[1] https://ww2.arb.ca.gov/wildfire-emissions

Greenhouse gas offset protocol:

Avoided wildfire emissions

For IFM projects in the following states:

California, Colorado

Version 03/28/2019

As part of the 2015-2018 project:

Quantifying ecosystem service benefits of reduced occurrence of significant wildfires

Lead authors: Thomas Buchholz (Spatial Informatics Group LLC; SIG), David Schmidt (SIG)

Contributing authors: Bruce Springsteen (Placer County Air Pollution Control District PCAPD), Shannon Harroun (PCAPD), Jason Moghaddas (SIG), David Saah (SIG)

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ABBREVIATIONS AND ACRONYMS

ACR	American Carbon Registry
AFOLU	Agriculture, forestry and other land use
C	Carbon
CAR	Climate Action Reserve
CBD	Canopy bulk density
CBH	Canopy base height
CBP	Conditional Burn Probability
CC	Canopy cover
CH	Canopy height
CH_4	Methane
CI	Crowning Index
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
ERT	Emission reduction tonne
FIL	Fire Intensity Level
FLP	Flame Length Probability
FM	Surface fuel model
GHG	Greenhouse gas
GIS	Geographic Information System
ISO	International Organization for Standardization
LCA	Life cycle assessment
MT	Metric tonne
MTT	Minimum Travel Time
N_2O	Nitrous oxide
TI	Torching Index
VCS	Verified Carbon Standard

1 METHODOLOGY DESCRIPTION

1.1. Scope

This methodology quantifies greenhouse gas (GHG) emissions from implementing fuel treatments in forests that are at risk for wildfire from fire-suppression and past harvesting history. The methodology is applicable in the following states (referred to in the following as 'the reference states'): California, Colorado. Fuel treatments qualifying for this protocol include fuel reduction thinning and prescribed fire. Fuel treatments modify fire behavior such that severity[1] and individual fire size are reduced compared to the baseline of no fuel treatment activity (Fulé et al., 2003; Liang et al., 2018; Miller et al., 2009; Moghaddas et al., 2010; Moghaddas and Craggs, 2007; Peterson et al., 2005; Stephens et al., 2012, 2009b, 2009a). Type, size, and distribution of fuel treatments greatly affects their effectiveness in changing fire behavior (Coen et al., 2018; Thompson et al., 2017).While identifying climate benefits of fuel treatments can be challenging (Campbell et al., 2012; Mitchell et al., 2009), this methodology seeks to identify ecological conditions and fuel treatment approaches that verifiably provide climate benefits.

Fuel treatments provide GHG emissions reductions through considering (see also Box 1):

- Forest carbon. Increase in stored carbon on the designated landscape (project area) over time, particularly in larger, more fire-resistant trees (Hurteau and North, 2010; Stephens et al., 2009b). This results from reducing individual wildfire size and severity on both the directly treated areas as well as untreated areas through fuel limitation (Collins et al., 2008). Treating even a small portion of the landscape can result in a decrease in probability of areas outside those treated areas being burned severely, referred to as the "treatment shadow effect" (Finney et al., 2007; Moghaddas et al., 2010).
- Wood products and renewable energy. Utilization of fuel treatment byproducts as: (1) long-lived wood products that sequester carbon and displace fossil fuel intensive alternatives to wood products such as concrete and steel[2]; and (2) renewable energy[3] production that displaces fossil fuel energy alternatives (Buchholz et al., 2016).
- Fossil fuel emissions required for harvesting and processing of wood. This also requires accounting for fossil fuel emissions associated with harvest and processing of wood products.
- Preservation of forest. High intensity fires in forests, particularly uncharacteristically severe active and passive crown fires, can cause high levels of tree mortality and soil impacts that result in delayed reforestation, i.e. a vegetation type change from forest to grassland or shrub types

[1] While recognizing that fire *intensity* (a physical parameter of the fire) and fire *severity* (describing the ecological effect of that fire) are different concepts, we generally use *severity* throughout to avoid confusion because in many forests the two concepts are closely related (e.g., a high intensity fire will result in high severity effects).

[2] Climate benefits from wood product substitution are included as an optional part of this protocol as representative and reliable data are obtained.

[3] Offsets derived from the electricity and fossil fuel sector are covered by other offset markets than the forestry sector. The *Biomass Waste for Energy Greenhouse Gas Offset Protocol* (PCAPCD, 2013), approved in the CAPCOA GHG Registry, can be used to determine the GHG benefits of bioenergy from fuel treatment byproducts.

lasting at least several decades (Collins and Roller, 2013; Coppoletta et al., 2016; Roccaforte et al., 2012; Rother and Veblen, 2016, p. 20; van Wagtendonk et al., 2012; Welch et al., 2016). Fuel treatments can reduce the amount of forest that experiences delayed reforestation compared to the baseline, through moderating fire size and severity. This protocol provides a methodology to quantify delayed reforestation related GHG emissions.

Applicability of this methodology is restricted to forest ecosystems in the reference states where fire is a key ecological process (Safford and Van de Water, 2014) and therefore depends on the site-specific landscape and ecosystem context, particularly the fire return interval.

The methodology uses the latest science in wildfire dynamics. It employs probability-based wildfire models to calculate GHG emissions in the absence (baseline scenario) and presence (project scenario) of fuel treatments that are additional to current practice (Box 2).

Using field data, modeling, and probabilistic functions, this approach is fundamentally different from improved forest management methodologies where landscape carbon stock changes are solely identified using measured data. Emission credits are calculated prior to the project start (“ex-ante”) and following the fuel treatment implementation. Credits are distributed in five-year intervals over the crediting period of the project. Credits are refined and verified based on subsequent project area measurement assessments to confirm stand growth response to initial fuel treatments.

Uncertainties around emissions reductions are captured by appropriate buffer pool and conservative emission savings estimates (see 9.6.3).

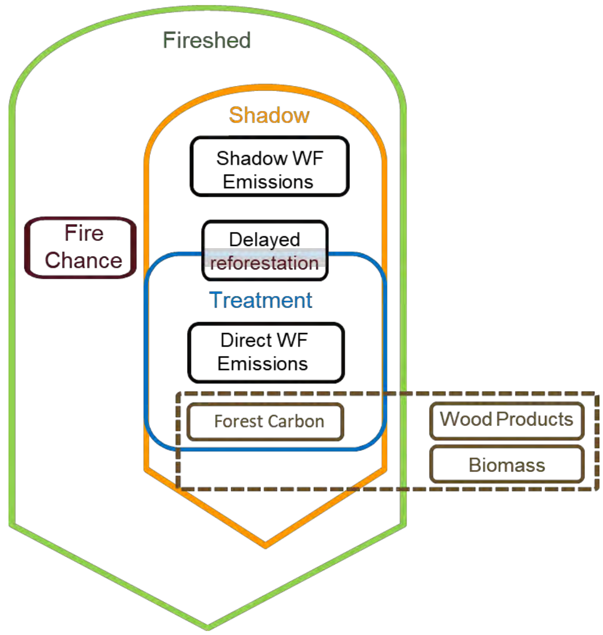
The methodology is applicable to private, public, or tribal forestland eligible for management that are at risk for wildfire and that exhibit no recent history of fuel treatments or a significant change in fuel treatment activity between the baseline and project scenario.

Leakage effects through activity shifting or market effects are not considered in the protocol because the fuel treatment project activity will include greater removal of forest products than the baseline (Table 4), based on application of the conservativeness principle (section 6.1).

Many elements of this methodology have been adapted from ACR (2018).

Box 1: Avoided wildfire emissions accounting steps.

To quantify fuel treatment impacts on reducing emissions from wildfires, all relevant carbon pools -- forest carbon, wood products, and biomass -- are accounted for across the entire project area. This requires an ecologically relevant integration of wildfire probability (fire chance), wildfire behavior, delayed reforestation, and forest carbon accounting. Treatments to reduce high severity fires will impact fire behavior within their direct footprint, and indirectly beyond their direct footprint ("treatment shadow effect"). Emission savings from delayed reforestation are also considered in this methodology.



1.2. Methodology summary

The methodology quantifies the GHG benefits from fuel treatments (fuel reduction thinning, prescribed fire) that restore forest to desired ecological conditions and fire regimes (North, 2012). Fuel treatments reduce wildfire size and severity in forests that are at risk for wildfire from a fire-suppression and harvesting history.

The methodology involves the following steps, for both the baseline and project scenarios, as shown in Box 1 and Box 2:

1. Project area. Define the geographic boundary of the project. Quantify the forest condition - including tree stands, tree list, species, height, and diameter, and surface fuels - in the project area existing at the start of the project through site characterization measurements.
2. Management scenario development. Define the details of the fuel treatment - including fuel reduction harvesting levels, procedures, location, timing, and fate of residuals.
3. Forest carbon. Project the growth of the forested land over the project term (40 years) at five-year intervals.
4. Forest removals life cycle assessment. Determine sequestration in wood products, and avoided/displaced fossil fuels from wood products and bioenergy.[2,3]
5. Fire ignition probability. Determine the project area's expected fire return interval. Use the fire return interval to determine statistical fire probability over the project term.
6. Weather data. Define weather conditions under which to simulate fire over the project term.
7. Wildfire emissions. Determine emissions from wildfire that burns the entire project area, at five-year intervals over the project term. Amortize the emissions by the statistical fire probability.

8. Delayed reforestation. Quantify the area and emissions associated with project land temporarily or permanently over the project term converted from forestland to grass or shrubland following high severity fire.
9. Aggregated emissions accounting. Determine the difference between the baseline and project scenario GHG emissions, for each five-year interval period over the project term.

These assessment steps are followed by two post-implementation steps:

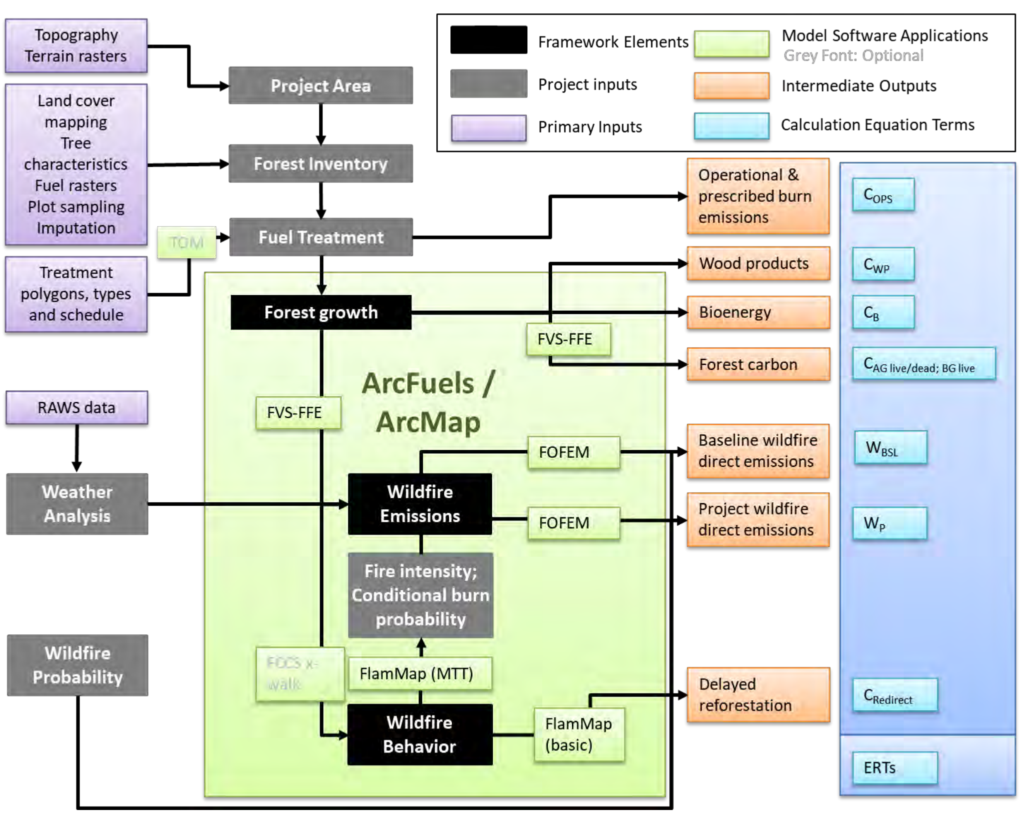
10. Fuel treatment project measurements. Over the project term, measure and document all applicable operational parameters, including fossil fuel engine usage, tree and brush removal rates, wood products generation, bioenergy[3], prescribed fire, and open pile burning. Use these to refine/adjust the aggregate emissions.
11. Project site inventory. At ten-year intervals, perform site measurements to characterize on-the-ground carbon. Use these to refine/adjust the aggregate emissions.

Leakage, both through activity shifting and market effects, will not occur because harvesting under the project scenario is greater than that in the baseline scenario.

Box 2. Modeling GHG emissions from fuel treatment projects.

Using coupled vegetation and wildfire models, the methodology calculates GHG emissions for wildfire occurrences over the project term timeframe for both the baseline and fuel treatment project scenarios:

- **Inventory and growth and yield modeling.** Using inventory and treatment data, vegetation models, such as the Forest Vegetation Simulator (FVS), are used to project carbon stock changes.
- **Fire probability.** Fire probability is based on determination of the fire return interval.
- **Wildfire emissions.** Inventory and growth data are used with fuel consumption models, such as First Order Fire Effects Model (FOFEM), to project emissions from wildfire burning through the entire project area.
- **Overall averaged wildfire emissions.** Wildfire emissions are amortized by the fire probability to obtain emissions during the project term.
- **Wood products and biomass life cycle.** Wood product, fossil fuel, and bioenergy[3] emissions are accounted for.
- **Credit issuance.** Offsets credits are determined based on initial inventory data, model projections, fuel treatment implementation, and ongoing periodic on-the-ground measurements. Issued credits are independent of actual wildfire activity on the project area during the project term.



2 ELIGIBILITY CONDITIONS

The following conditions must be met:

1. The U.S. Forest Service Forest Inventory & Analysis (FIA) Program definition must be used to demonstrate the project area meets the definition of forestland conditions. Forest land is defined as land at least 10 percent stocked by trees of any size, or land formerly having such tree cover, and not currently developed for non-forest uses.
2. This methodology applies to privately owned and public (state and federal) timberlands in the reference states able to document: 1) clear land title or timber rights, and 2) offsets title.
3. The methodology applies to lands eligible for commercial timber harvesting, non-commercial harvesting, and/or prescribed fire, held by entities owning or controlling management rights across the project area. Projects must also meet all other requirements of the governing program (e.g. ACR) such as sustainable harvesting and natural forest management practices.
4. Size, location, and geography correspond to the definition of a coherent project area that allows the ecologically relevant integration of wildfire probability, wildfire behavior, and forest carbon accounting. Participating ownership groups within the project area need to jointly apply and adhere to project agreements. Where exclusion parcels within the project area exist, they must be spatially identified.
5. The fuel treatments that are part of the project must exceed the pace or scale, or both, of previously planned or implemented fuel treatment practices.
6. Documentation must show that potential revenue from a planned forest management project is not sufficient to cover the cost of fuel treatment necessary to adequately reduce wildfire hazard.
7. The average forest carbon stocking at the start the project must be documented to exceed the regional average using site-specific FIA Assessment Area Data (CAR, 2010) or the historic range of natural variability for the project area forest cover type -- considering structural characteristics that include high surface and ladder fuels, size distribution skewed towards many small diameter trees, and contemporary fire regimes outside of the pre-suppression range of natural variability.
8. Evidence must be provided on scientifically justified contemporary fire return intervals.
9. Use of non-native species is prohibited where adequately stocked native stands were converted for forestry or other land uses after 1997.
10. Draining or flooding of wetlands is prohibited.

3 PROJECT BOUNDARIES

4 SPATIAL BOUNDARY

The project area must be a contiguous spatial unit in one of the reference states. Aggregation across sections of a landscape are not allowed. It is recommended to use one or multiple firesheds to maximize offset credit generation. A fireshed is delineated based on fire regime, condition class, fire history, fire hazard and probability, and potential wildland fire behavior of a scale that allows the ecologically relevant integration of wildfire probability, wildfire hazard, and forest carbon accounting (Bahro et al., 2007). The project area is delineated, and vegetation within the project area is quantified and classified. Results must be made available as maps and GIS shapefiles to define the project boundary. The project area can be delineated in various ways, including using watershed boundaries or natural and man-made features that modify fire spread.

A detailed description of the geographic boundary of the project area must be defined. Information to delineate the project boundary must include:

- Project area delineated on USGS topographic map.
- General location map.
- Property parcel map.

Aggregation of forest properties with multiple landowners is permitted under the methodology consistent with the ACR standard (2018)[4].

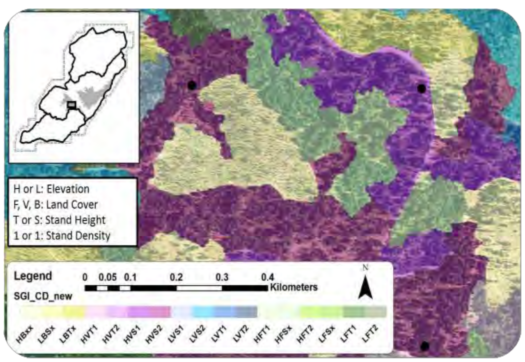
[4] See chapter 7, which provides guidelines for aggregating multiple landholdings into a single forest carbon project, as a means to reduce per - acre transaction costs of inventory and verification.

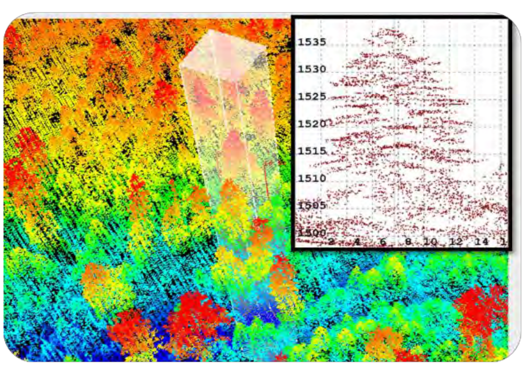
Box 3: Fireshed definition.

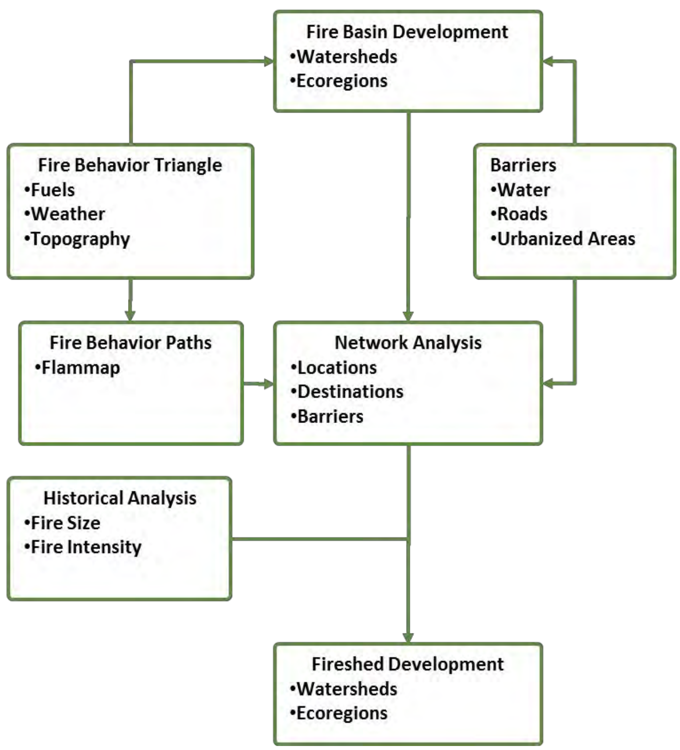
A fireshed is an area of land of a scale that allows the ecologically relevant integration of wildfire probability, wildfire hazard, and forest carbon accounting. This is similar to the notion of natural resources being managed on a “watershed” basis, with actions in different portions of the watershed having effects on other parts within the watershed, or on the ultimate output (water resources) of the unit. Integrating built infrastructure, watersheds and ecoregion-specific considerations, it has distinct fire characteristics derived from fuels, weather, and topography. A project area might include several firesheds or fractions of it.

Events or actions such as wildfire or fuels management activities in a fireshed can also have effects on areas greater than just the local area immediately affected. Forest thinning in one area may have a “shadow effect”, not only altering fire behavior and emissions in the treatment unit, but in adjacent areas as well. The cumulative effects of multiple treatments in an area may therefore result in greater effects across the entire area than just the sum of the individual treatments when treatment locations are selected considering the topology of fire spread. Choosing a larger project area might increase credit generation through maximizing the “shadow effect.”

Fuel treatments on a smaller scale than a fireshed will be fraught with uncertain efficacy. A fireshed-wide assessment allows for cost-efficient implementation of modeling results since insights gained from representative case studies can be applied fireshed-wide.







4.1 Temporal boundary

4.1.1 Start date

Projects with a start date of November 1, 1997, or later are eligible. The start date is when the project proponent verifiably began to apply the land management regime to reduce long-term emissions through forest fuel treatment activities.

4.1.2 Crediting period

The minimum crediting period must be 20 years and the minimum project term is 40 years. The crediting period can be extended for another 20 years in order for a project to earn credits over the full project term.

4.1.3 Project term

The minimum project term begins on the start date (not the first or last year of crediting).

4.2 GHG assessment boundary

Carbon pools to be included are listed in Table 1:

Required:

Live and dead aboveground tree carbon pools and in-use and post-use harvested wood products.

Optional:

Live belowground tree carbon pools as well as biomass waste byproducts used for energy.

Excluded:

The litter (forest floor/duff) carbon pool is conservatively excluded for GHG sequestration accounting due to high uncertainties in quantifying the carbon content. However, the litter pool must be characterized for wildfire modeling and associated litter emissions from wildfires and prescribed fires are included (see Table 1).

The soil carbon pool can be significant but is relatively unaffected by fuel treatments and is excluded (Boerner et al., 2008; Kashian et al., 2006; Woodbury et al., 2007). This conservatively underestimates fuel treatment project benefits as reducing fire severity increases carbon soil through reducing erosion, reducing soil carbon vaporization, and decreasing soil respiration.

Other carbon pools can be excluded where it can be documented that the net difference between the baseline and project scenarios is de minimis or difficult or unreliable to measure. This might include shrubs or herbaceous understory carbon (for forests only, i.e., not carbon stored in shrub and grassland related to delayed reforestation – see section 9.1.1.8).

Included GHGs are CO_2 as well as CH_4 and CO from forests, silvicultural operations and wood products. Other GHG relevant emissions that are optional include NMHC (non-methane hydrocarbons) and particulate matter (Table 2). If the project proponent chooses to account for detailed GHG emissions of wildfire, i.e. chooses to include the climate warming effects of NMHC and particulate in the calculations, the climate cooling effects of NO_X have to be accounted for as well (Appendix 2).

Table 1: Carbon pools.

Carbon pools	Included / excluded	Justification / explanation of choice
Aboveground live tree carbon	Included	Major carbon pool subjected to the project activity.
Belowground live tree carbon	Optional	Belowground tree biomass is not required for inclusion in the project boundary because omission is conservative, but projects may elect to include it.
Dead wood	Included	Major carbon pool subjected to the project activity. Includes both standing and lying dead wood.
Harvested Wood Products	Included	Major carbon pool subjected to the baseline and project activity. Both in-use and post-use (landfill) pools must be considered. Climate benefits from wood product substitution may be considered once reliable data is available.[2]
Bioenergy	Excluded	Biomass slated for energy use will be accounted for as immediate emissions identical in impact to pile burning. Avoided/displaced fossil fuel emissions from using biomass for heat or electricity generation could be considered under a separate offset protocol.[3]
Litter / Forest Floor	Excluded	Baseline and project scenarios include burning landscape, net difference is infeasible to measure.
Shrubs or herbaceous understory carbon	Excluded	Baseline and project scenarios include burning landscape, net difference is infeasible to measure.
Soil organic carbon	Excluded	Baseline and project scenarios include burning landscape, net difference is infeasible to measure.

337 Table 2: Climate relevant emissions.

Gas	Source	Included / excluded	Justification / explanation of choice
CO_2	Wildfire, prescribed fire, pile burning	Included	All stock changes and wildfire emissions are expressed in CO_2 equivalent
	Silviculture/fuel treatment Emissions	Included	All operations related fossil fuel emissions associated with management activities, including harvesting, skidding, and hauling.
	Decay	Included	All decay related emissions over the project term (100 years for wood products).
	Biomass utilization	Excluded	Avoided fossil fuel emissions from using biomass for heat or electricity generation could be considered under a separate offset protocol.[3]
	Wood products alternatives	Optional	Avoided fossil fuel emissions from using wood products that displace alternatives such as steel, concrete, and/or plastics.[2]
CO	Wildfire, prescribed fire, pile burning	Included	Based on modelled percentage of carbon emissions emitted as CO. All stock changes and wildfire emissions are expressed in CO_2e.
	Silviculture/fuel treatment Emissions	Optional	Based on modelled percentage of carbon emissions emitted as CO and expressed in CO_2e. May be considered optional if emissions are de minimis
	Biomass utilization	Optional	Avoided fossil fuel emissions expressed in CO_2e from using biomass for heat or electricity generation.
	Decay	Optional	Based on modelled percentage of carbon emissions emitted as CO and expressed in CO_2e. May be considered optional if emissions are de minimis
CH_4	Wildfire, prescribed fire, pile burning	Included	
	Silviculture/fuel treatment emissions	Optional	Based on modelled percentage of carbon emissions as CH_4 from fire and expressed in CO_2e.

Gas	Source	Included / excluded	Justification / explanation of choice
	Biomass utilization	Optional	Avoided fossil fuel emissions expressed in CO_2e from using biomass for heat or electricity generation.
	Decay	Included	Based on modelled percentage of carbon emissions as CH_4 from decay in forests and landfills and expressed in CO_2e.
NMHC*	Wildfire, prescribed fire, pile burning	Optional	Emissions estimated by fuel models such as CONSUME or FVS-FFE
N_2O	Burning of biomass	Excluded	Potential emissions are negligibly small
NO_x	Burning of biomass	Optional	NO_x have to be included if NMHC and particulate matter is accounted for. Emissions estimated by fuel models such as CONSUME or FVS-FFE
Particulate matter	Wildfire, prescribed fire, pile burning	Optional	Emissions estimated by fuel models such as CONSUME or FVS-FFE; also called Black Carbon

*) non-methane hydro-carbons

5 PERIODIC REVIEWS

ACR may require revisions to this Methodology to ensure that monitoring, reporting, and verification systems adequately reflect changes in the project's activities. This Methodology may also be periodically updated to reflect regulatory changes, emission factor revisions, or expanded applicability criteria. Before beginning a project, the project proponent should ensure that they are using the latest version of the Methodology.

6 BASELINE DETERMINATION AND ADDITIONALITY

6.1 Baseline determination

The baseline management scenario must be based on silvicultural prescriptions as currently practiced, with a verifiable previous track record. Where documented and approved management plans (including EIS Record of Decisions for federal lands and a Timber Harvest Plan on state and private lands) exist, the baseline identification must incorporate the documented plans. The baseline scenario needs to clearly identify and justify harvesting levels over the crediting period. Excluded parcels within the project area that are part of the fireshed must be included in the modeling framework using a regionally justified management regime based on ownership category.

The ISO 14064-2 principle of conservativeness (ISO, 2006) must be applied for the determination of the baseline scenario. In particular, the conservativeness of the baseline is established with reference to the choice of assumptions, parameters, data sources and key factors so that project emission reductions from the landscape and wood products life cycle assessment (LCA) are more likely to be under-estimated rather than over-estimated, and that reliable results are maintained over a range of probable assumptions. However, using the Conservativeness Principle does not always imply the use of the “most” conservative choice of assumptions or methodologies rather than a reasonable level of conservativeness through e.g. Monte Carlo simulations to account for uncertainty.

6.2 Additionality assessment

Projects must apply a three-prong additionality test to demonstrate that they exceed currently effective and enforced laws and regulations; exceed common practice in the forestry sector and geographic region; and face a financial implementation barrier (ACR, 2018a).

The regulatory surplus test involves existing laws, regulations, statutes, legal rulings, or other regulatory frameworks that directly or indirectly affect GHG emissions associated with a project action or its baseline candidates, and which require technical, performance, or management actions. Voluntary guidelines are not considered in the regulatory surplus test.

The common practice test requires project proponents to evaluate the predominant forest industry technologies and practices in the project’s geographic region. The project proponent must demonstrate that the proposed project activity exceeds the common practice of similar landowners managing similar forests in the region. Projects initially deemed to go beyond common practice are considered to meet the requirement for the duration of their crediting period. If common practice adoption rates of a particular practice change during the crediting period, this may make the project non-additional and thus ineligible for renewal, but does not affect its additionality during the current crediting period.

An implementation barrier represents any factor or consideration that would prevent the adoption of the practice/activity proposed by the project proponent. Financial barriers can include high costs, limited access to capital, or an internal rate of return in the absence of carbon revenues that is lower than the proponent’s established minimum acceptable rate. Financial barriers can also include high risks such as unproven technologies or business models, poor credit rating of project partners, and project failure risk. When applying the financial implementation barrier test, project proponents must include solid quantitative evidence such as net present value and internal rate of return calculations. The project must face capital constraints that carbon revenues can potentially address; or carbon funding is reasonably expected to incentivize the project’s implementation; or carbon revenues must be a key element to maintaining the project action’s ongoing economic viability after its implementation.

7 STRATIFICATION

If the project activity area is not homogeneous, i.e. different fire probability and behavior is expected within the project area due to vegetation type, age, ownership, or topography, stratification must be carried out to improve the precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios in order to achieve optimal accuracy and precision of the estimates of net GHG emissions reductions or GHG removal by sinks. For estimation of baseline carbon stocks, strata must be defined on the basis of parameters that are key variables for estimating changes in managed forest carbon stocks, for example:

a. Management regime.
b. Species or cover types.
c. Size and density class.
d. Site class.
e. Topography.
f. Fire return interval.
g. Weather data.

8 USE OF MODELS FOR ESTIMATING EMISSIONS

Forest growth and yield models and their application are described in section 9.1.1.3. Wildfire related models and their application are described in section 9.1.1.6.

9 QUANTIFICATION OF GHG EMISSIONS REDUCTIONS

9.1 Baseline net GHG emissions

A fixed baseline is employed where the likely baseline carbon stock change must be calculated at five-year intervals for the entire crediting period. The baseline stocking level used for the stock change calculation is derived from the baseline management scenario developed in section 6.1.

9.1.1 Accounting baseline emissions from avoided wildfire emissions

Landscape baseline carbon stocks are calculated according to Equation 1. The sections below describe a stepwise approach how to derive each parameter in the equation.

Equation 1: Baseline GHG accounting.

$$C_{BSL,PROJ} = \left[\left(C_{BSL,AG} + C_{BSL,BG} + C_{BSL,DW}\right) - \sum_{i=1}^{t}(W_{BSL,i} + C_{Redirect,BSL,i}) \times P_{Const}\right] + C_{BSL,WP} - C_{BSL,OPS}$$

Where:

$C_{BSL,PROJ}$ is sum of all carbon stocks in the baseline scenario projection for year t; metric tonnes (MT) CO_2 equivalent (CO_2e)

$C_{BSL,AG}$ is carbon stock in baseline above-ground of live trees for all strata for year t; MT CO_2e (see section 0)

$C_{BSL,BG}$ is carbon stock below-ground portions of live trees for all strata for year t; MT CO_2e (see section 0), optional

$C_{BSL,DW}$ is carbon stock in baseline dead wood pools for all strata for year t; MT CO_2e (see section 0)

$W_{BSL,i}$ is the wildfire emission or carbon stock loss from wildfire combustion for stand i in year t; MT CO_2e (see section 9.1.1.6)

$C_{Redirect,BSL,i}$ is the mean carbon stock loss under the baseline scenario from delayed reforestation based on the % of burned acres that would have been redirected, time t; MT CO_2e (see section 9.1.1.8 and Equation 11)

P_{Const} is the constant annual fire probability based on Equation 10; %

$C_{BSL,WP}$ is carbon stock in baseline wood products pool for year t; MT CO_2e if removals occur in the baseline scenario (see section 9.1.1.4)

$C_{BSL,OPS}$ is the direct fossil fuel GHG emissions associated with the baseline scenario (commercial or non-commercial harvest or prescribed fire treatments for year t; MT CO_2e (see section 9.1.1.4).

9.1.1.1 Project area delineation, selection, and characterization

See section 4.

9.1.1.2 Management scenario development

See section 6.1.

9.1.1.3 Forest carbon (forest growth and sequestration) calculation

Live above ground, live below ground (if included), and dead and down wood -- $C_{BSL,AG}$, $C_{BSL,BG}$, and $C_{BSL,DW}$ (from Equation 1) -- must be estimated for the baseline using models of forest management across the full project term. Modeling of forest growth must be completed with a peer-reviewed forestry model that has been tested for use in the project region. Detail must be provided on what model is being used and what variants have been selected.

Examples of appropriate models include:

- FVS: Forest Vegetation Simulator.
- SPS: Stand Projection System.
- FIBER: USDA, Forest Service.
- California-specific: CRYPTOS and CACTOS (California Conifer Timber Output Simulator).

Models must be:

- Peer-reviewed in a process involving experts in modeling and biology/forestry/ecology.
- Used only in scenarios relevant to the scope for which the model was developed and evaluated.
- Parameterized for the specific conditions of the project.

The output of the models must include projected volume in live aboveground tree biomass, or appropriate unit, by strata in the baseline scenario. Where model projections produce changes in volume over five-year periods, the numbers must be annualized to give a stock change number for each year.

If the output for the tree is a volumetric rather than a weight-based unit, then this must be converted to biomass and carbon using equations in section 0. If processing of alternative data on dead wood is necessary, equations in section 0 may be used.

Above- and belowground live tree carbon

The mean carbon stock in aboveground and belowground tree carbon per unit area, $C_{BSL,AG}$, and $C_{BSL,BG}$, is estimated based on field measurements in sample plots. A sampling plan must be developed that describes the inventory process, including sample size, determination of plot numbers, plot layout and locations, and data collected. Plot data used for biomass calculations may not be older than 10 years. Plots need to be marked permanently for resampling, and they may have a defined boundary or use variable radius sampling methods. Biomass for each tree is calculated from its cubic volume using a component ratio method. The following steps are used to calculate tree biomass:

Step 1: Determine the biomass of each tree based on appropriate volume equations published by USDA Forest Service (if locally derived equations are not available, use regional or national equations as appropriate) and oven-dry tree specific gravity for each species.

Step 2: Determine the biomass of bark, tops and branches, and below-ground biomass as a proportion of the bole biomass based on component proportions from (Chojnacky et al., 2014).

Step 3: Using the sum of the biomass for individual trees, determine the per plot estimate of total tree biomass for each plot.

Step 4: Determine the tree biomass estimate for each stratum by calculating a mean biomass per acre estimate from plot level biomass derived in step 3, multiplied times the number of acres in the stratum.

Step 5: Determine total project carbon by summing the biomass of each stratum for the project area and converting dry biomass to MT CO_2e (Equation 2).

Equation 2: Carbon in live tree biomass.

$C_{AG/BG\ live}$ = total project area above- and belowground MT biomass * 0.5 * 44/12

Where:

$C_{AG/BG\ live}$ is carbon stock in above- and belowground biomass of tree; MT CO_2e for both baseline and project projection

Dead wood calculation

Dead wood included in the methodology, $C_{BSL,DW}$, comprises two components only – standing dead wood and lying dead wood (that is, below-ground dead wood is excluded due to infeasible measurements). Considering the differences in the two components, different sampling and estimation procedures must be used to calculate the changes in dead wood biomass of the two components.

Standing dead wood

Standing dead wood must be measured using most recent FIA protocols (FIA, 2018):

Step 1: Standing dead trees must be measured using the same criteria and monitoring frequency used for measuring live trees.

Step 2: The decomposition class of the dead tree and the diameter at breast height must be recorded, and the standing dead wood is categorized under the following four decomposition classes (FIA 2011, p99):

1. All limbs and branches present.
2. Few limbs, no fine branches.
3. Limb stubs only.
4. Bole only, no branches.

Step 3: Biomass on standing dead trees must be estimated using the component ratio method used for live trees in the decomposition class (FIA, 2018). When the bole is in decomposition classes 2, 3 or 4, the biomass estimate must be limited to the main stem of the tree. If the top of the standing dead tree is missing, then top and branch biomass may be assumed to be zero. For trees broken below minimum merchantability specifications used in the tree biomass equation, existing standing dead tree height must be used to determine tree bole biomass (Woodall et al., 2011).

Step 4: The biomass of dead wood is determined by using the following dead wood density class deductions (Harmon et al., 2011, p. 12):

Softwood: Class 1 – same as live tree biomass; Class 2 – 1.0 of live tree biomass; Class 3 – 0.92 of live tree biomass; Class 4 – 0.55 of live tree biomass.

Hardwood: Class 1 – same as live tree biomass; Class 2 – 0.8 of live tree biomass; Class 3 – 0.54 of live tree biomass; Class 4 – 0.43 of live tree biomass.

Step 5: Determine total project standing dead carbon by summing the biomass of each stratum for the project area and converting dry biomass to MT of carbon using Equation 3.

Equation 3: Carbon in aboveground standing dead biomass.

$C_{AG\ standing\ dead}$ = total project area aboveground MT biomass * 0.5 * 44/12.

Where:

$C_{AG\ stading\ dead}$ is carbon stock in aboveground standing dead in MT CO_2e

Lying Dead Wood

Step 1: Lying dead wood (coarse woody debris; >2.9 inch in diameter) must be sampled using the line transect method (FIA, 2012, p. 4). Three transects are established that originate at the subplot center and extend out 24.0 feet horizontal distance.

Step 2: The dead wood is assigned to one of the five density classes (Harmon et al., 2011, p. 5):

1. Sound, freshly fallen.
2. Sound log sapwood partly soft but can't be pulled apart by hand.
3. Heartwood is still sound with piece supporting its own weight, sapwood can be pulled apart by hand.

4. Heartwood is rotten.
5. There is no remaining structural integrity to the piece with a lack of circular shape.

Step 3. The following dead wood density class deductions must be applied to the three decay classes (Harmon et al., 2011, p. 12):

Softwood: Class 1 – 0.93same as live tree biomass; Class 2 – 0.87 of live tree biomass; Class 3 – 0.7 of live tree biomass; Class 4 – 0.45 of live tree biomass; Class 5 – 0.29 of live tree biomass.

Hardwood: Class 1 – 0.95 of live tree biomass; Class 2 – 0.74 of live tree biomass; Class 3 – 0.51 of live tree biomass; Class 4 – 0.29 of live tree biomass; Class 5 – 0.22 of live tree biomass.

Step 4. The volume of lying dead wood is calculated according to Step 6: Determine total project standing dead carbon by summing the biomass of each stratum for the project area and converting dry biomass to MT of carbon using Equation 6.

Equation 4 (Russell et al., 2015).

Step 5: Volume of lying dead wood must be converted into biomass using Equation 5.

Step 6: Determine total project standing dead carbon by summing the biomass of each stratum for the project area and converting dry biomass to MT of carbon using Equation 6.

Equation 4: Volume of lying dead wood per unit area.

$$V_{LDW} = (\pi^2 \sum DT^2 \div 8L) \times 4046.86L$$

Where:

V_{LDW} is volume of lying dead wood in density class DC per unit area; m^3/acre

DT is Diameter of piece at intersection; cm

L is the length of transect; m

Equation 5: Converting volume of lying dead wood to biomass.

$$B_{\mathrm{LDW}} = A * \sum_{DC=1}^{3} V_{LDW,DC} * WD_{DC}$$

Where:

B_{LDW} is biomass of lying dead wood per unit area; MT CO_2e/ha

A is area; ha

$V_{LDW,DC}$ is volume of lying dead wood in density class DC per unit area; m^3

WD_{DC} is the basic wood density of dead wood in the density class ‐ sound (1), intermediate (2), and rotten (3)

Equation 6: Carbon in aboveground lying dead biomass.

$C_{lying\ dead}$ = total project area aboveground MT biomass * 0.5 * 44/12

Where:

$C_{\text{lying}\ dead}$ is carbon stock in aboveground standing dead; MT CO_2e

9.1.1.4 Forest removals life cycle assessment

Forest wood products -- $C_{BSL,WP}$ (Equation 1) -- must be estimated using models of forest management across the baseline period (see section 9.1.1.3). For $C_{BSL,WP}$, a 100 year LCA GHG emissions profile must be applied towards permanence requirements. Emissions from operations need to be included ($C_{BSL,OPS}$) based on peer-reviewed published research or actual measured operational data. Modeling must be completed with a peer-reviewed forestry model that has been calibrated for use in the project region.

The steps below are used to determine the amount of carbon in harvested wood products:

Step 1: Calculate the annual biomass of the total volume extracted from within the project boundary, with extracted timber volume differentiated into hardwood sawtimber, hardwood pulpwood, softwood sawtimber, or softwood pulpwood and converted to carbon using specific wood densities for each species.

Step 2: Calculate the proportion of extracted timber that remains sequestered after 100 years. Instead of tracking annual emissions through retirement, burning and decomposition, the methodology calculates the proportion of wood products that have not been emitted to the atmosphere 100 years after harvest and assumes that this proportion is therefore permanently sequestered.

Based on Smith et al. (2006)DOE, users must determine the region the project is located in and whether the timber is softwood or hardwood. The average of the proportions defined as “In Use” and “Landfill” 100 years after production must be used.

Alternatively, verifiable case-specific data such as customized and documented industry data (e.g. mill efficiencies, type of wood products manufactured) or peer-reviewed literature (e.g. Skog, 2008) may be used.

Step 3: Calculate the proportion of residues being open pile burned and relevant GHG emission profiles.

Step 4 (Optional): Fossil fuel emission savings realized by using wood products instead of fossil fuel intensive substitutes such as concrete or steel can be accounted for if representative and reliable data are available (e.g. Sathre and O’Connor, 2010; Equation 7).[2] Data must be extensively supported through peer-reviewed literature with regional relevance for the project area.

Equation 7: Carbon emissions avoided through product substitution.

$C_{\mathrm{BSL,WPS}} = C_{\mathrm{WP}} \times DF \times Fs$ total baseline carbon from wood product substitution, MT CO_2e project area aboveground MT biomass * 0.5 * 44/12

Where:

$C_{\mathrm{BSL,WPS}}$ is the total baseline carbon from wood product substitution, MT CO_2e project area aboveground MT biomass * 0.5 * 44/12

C_{WP} is the carbon stored in wood products; MT CO_2e

DF is the displacement factor; MT CO_2e/ MT CO_2e wood

Fs is the percentage of wood products substituting for other materials; %

9.1.1.5 Weather data

Weather data, a critical input to the wildfire models, must be clearly defined and justified.

Fire behavior modeling with FFE-FVS and FlamMap requires values for windspeed and wind direction as well as estimates of fuel moistures for the following fuel size classes: 1-hr, 10-hr, 100-hr, > 100-hr, duff, herbaceous and live woody.

The project proponent needs to use weather data from several weather stations (e.g. RAWS-Remote Automated Weather Stations) to create a realistic weather scenario based on historic patterns. At least two sources of weather data must be used but ideally there would be at least one station per eighth-field watershed. Historical gridded fire weather data is available for areas without nearby RAWS (DRI, 2019). These weather stations must represent the predominant conditions within the project area (elevation, aspect, fuel type). Extreme fire weather is likely to become more common in the near future such that the current (2010-2016) 99th percentile weather conditions could drop to 95th percentile conditions by 2030 (e.g. Mann et al., 2016). The project proponent should analyze weather conditions observed during at least one significant, severe wildfire representing fire behavior that could be expected in or very near the project area. Because the 99th percentile represents an extreme level of fire weather that may be highly unlikely in the near future, and on the other hand the 95th percentile conditions may not reflect future extreme conditions, the project proponent should develop a weather scenario based on 97.5th percentile conditions that best matches the weather observed during the selected recent significant wildfires.

Peak windspeed may have a significant effect on fire behavior, even if these winds are short-lived. If wind gust speed data are not available, the method described by Crosby and Chandler (2004) may be used to convert steady windspeed to wind gust speed.

Software such as FireFamily Plus (FF+; Bradshaw and McCormick, 2000) can be used to summarize the RAWS data. The weather scenario must be vetted by local fire behavior specialists. Specifications (wind speed, wind direction, gust speed, fuel and foliar moisture values) and potential deviations from weather stations due to local particularities need to be described and justified. Peer-reviewed future climate projections can be used to modify weather-related modeling parameters if desired.

Although fuel moisture values are not weather parameters per se, they are the direct product of weather conditions, they are recorded by weather stations (10 hr fuel moisture), and they may be summarized with FireFamily Plus.

9.1.1.6 Wildfire emissions calculation

Acceptable models

Models must be:

- Peer-reviewed in a process involving experts in modeling and fire ecology/forestry/ecology.
- Used only in scenarios relevant to the scope for which the model was developed and evaluated.
- Parameterized for the specific conditions of the project.

Steps to determine baseline wildfire emissions

Wildfire emissions are determined through:

- Simulating wildfire behavior, using a model such as FlamMap (Finney, 2006). Fire behavior models require data on weather, topography, and fuel loads (including elevation, slope, aspect, surface fuel model (FM), canopy cover (CC), canopy height (CH), canopy base height (CBH), and canopy bulk density (CBD)), across the project area landscape.
- Outputs from the wildfire behavior modeling are used by a wildfire emissions model, such as the First Order Fire Effect Model (FOFEM; Lutes, 2016).

The multi-step modeling process involves the following:

Step 1. Define the project area topography, including elevation, slope, and aspect rasters.

Step 2. Define initial stand-level fuel rasters, using a framework such as ArcFuels (Vaillant et al. 2013). ArcFuels is an extension for ArcGIS that facilitates spatial data processing for a number of fire models. This will likely require manually updating the initial stand-level FM, CC, CH, CBH, and CBD rasters produced by ArcFuels to reflect recent disturbances and using local expert knowledge.

Step 3. Create a stand polygon shapefile for ArcFuels. ArcFuels requires a GIS shapefile to associate each unique forest stand with a specific location within the project area. This allows stand-level forest dynamics and wildfire emissions to be modeled aspatially and then integrated later with spatial fire behavior modeling. The specific steps will depend on local data sources.

Step 4. Use the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS), or an acceptable alternative, at each five-year timestep, to simulate forest dynamics, timber harvest, and track carbon stocks, and to provide inputs for wildfire behavior and emissions models (such as FlamMap and FOFEM).

a) FFE-FVS can be inadequate in how it assigns fire behavior fuel models to stands (Collins et al., 2013). A subset of fire behavior fuel models can be used from (Fried et al., 2016) if the outputs from FFE-FVS are not acceptable. Alternatively, a statistical model can be used to assign fuel models based on stand structure, such as that from Collins et al. (2013) or Fried et al. (2016, p. 40).

b) Certain FVS variants such as the Western Sierra variant lack a forest regeneration model leaving the user to input this information. This shortcoming can distort forest stand conditions as they are projected into the future based on user inputs which may be inconsistent or subjective. Depending on the understory conditions, projected canopy base height can increase rapidly, thereby greatly reducing the potential for crown fire initiation (Moody et al. 2016). To counter this effect, a pulse of mixed-conifer regeneration can be applied at every time step, along with a small-tree growth rate multiplier (Collins et al., 2011). These customized FVS parameters should be based on field data.

c) Save FFE-FVS fuel load outputs needed for FOFEM and save carbon inventory data needed for accounting (Equation 1).

Step 5. Format the FFE-FVS outputs for FOFEM. The necessary values are stored in the FVS_Fuels and FVS_PotFire tables of the FVS output database. The FVS fuel load categories do not exactly align with those of FOFEM and will require some adjustment. Likewise, FOFEM requires duff depth as an input but FVS does not track this; ideally duff depth could be derived from field data but expert opinion may be necessary. Values for the percentage of rotten vs. sound fuel in the >= 1000-hr class will also need to be derived or estimated. Once the inputs have been formatted and saved then FOFEM may be run in batch mode to rapidly process thousands of stands. For the non-CO_2 GHG emissions, FOFEM will estimate smoke emissions (in lbs/ac by default) created during the smoldering and flaming phases of combustion for the following species of emissions: particulate matter (PM2.5 and PM10), CH4, CO, CO2, NOx, and SO2. Appendix 2 provides a cross-walk to calculate MT CO_2e for these non-CO_2 GHG emissions.

Step 6. Use ArcFuels to develop and format inputs for FlamMap's Minimum Travel Time (MTT) model (FM, CC, CH, CBH, and CBD rasters). Use FFE-FVS outputs to update all baseline rasters at each time step. Large landscapes (several tens of thousands of hectares) may require the use of FConstMTT instead of FlamMap. FConstMTT (e.g., Barros et al., 2019) is a command-line version of FlamMap's MTT algorithm that uses the same inputs but handles large landscapes better.

Step 7. Use FlamMap or FConstMTT to determine the optimal MTT burn time to ensure sufficient fire spread while limiting computation time. Burn time must be iteratively determined such that every pixel on the landscape burns at least once but not so long that computation times are prohibitive. Burn time is recommended to be at least eight hours. Using the methods of Ager et al. (2010) is recommended.

Step 8. Use FlamMap or FConstMTT to determine the optimal number of MTT random ignitions. A single MTT run simulates many thousands of independently burning random ignitions to remove the effect of ignition location on modeled fire behavior. The use of approximately 0.6 random ignitions per hectare is suggested (see Ager et al., 2010, 2007). However, this will need to be adjusted, along with burn time, so that the entire landscape is covered in the full simulation.

Step 9. Identify random ignition point locations to be used for all FlamMap or FConstMTT simulations. Ignition locations should be randomly selected, but should also be selected so that all portions of the entire landscape will burn. FlamMap and FConstMTT will both create random ignition points that can be saved for subsequent modeling runs.

Step 10. Run FlamMap or FConstMTT runs for each timestep. Save the CBP and FLP rasters, which are used to calculate project emissions (section 9.2.1.6).

Step 11. Run FOFEM for each stand and time step to determine baseline wildfire emissions ($W_{DE,BSL}$). Use Equation 8 to calculate $W_{DE, BSL}$ across all stands. FOFEM requires an estimate of canopy consumption which can be produced by FlamMap. One method of doing this is to use the P-Torch (probability of torching) value as estimated by FFE-FVS for each stand (e.g., Stephens et al. 2012). P-Torch is the probability that torching can occur in a small area of a forest stand and depends in large part on flame length (Rebain et al., 2015). The P-Torch value of each stand may be used without modification as a surrogate for canopy consumption.

Step 12. Compute the average CBP_{BSL} within each forest stand. This will be used for the project wildfire emission calculations (section 4.5.6). CBP is the fraction of simulated wildfires that reach each pixel of the landscape. CBP values range between 0 and 1.

Total baseline wildfire emissions, W_{BSL}, are amortized using the fire probability for a given time period (see section 9.1.1.7).

Equation 8: Baseline wildfire emissions W_{BSL}.

$$W_{BSL} = \sum_{i=1}^{n} W_{BSL,stand}$$

Where:

W_{BSL} are the baseline wildfire emissions at time t; MT CO_2e

$W_{BSL,stand}$ are the baseline wildfire emissions for a given stand i; MT CO_2e

n is total number of stands

Quantifying uncertainty of baseline wildfire emissions

The uncertainty estimate for the baseline wildfire emissions will be quantified using Equation 9.

Equation 9: Uncertainty estimate of project wildfire emissions.

$$U_{BSL,W} = \sqrt{U_{W,BSL}{}^\wedge 2 + U_{FRI}{}^\wedge 2}$$

Where:

$U_{BSL,W}$ is the –combined uncertainty of baseline FRI and baseline wildfire emissions; %

$U_{W,BSL}$ is the uncertainty associated with the GHG emissions of the baseline wildfire emissions based on the 90% confidence interval of all random ignition runs performed

U_{FRI} is the uncertainty of the FRI (see section 9.1.1.7); %

9.1.1.7 Fire ignition probability (fire return interval) assessment

Steps to determine fire ignition probability

Wildfire emissions over the project area are amortized (discounted) by the annual fire ignition probability of occurrence over each separate five-year interval period of the 40-year project term. The annual fire probability of occurrence (P_{const}) is determined from the project area-wide fire return interval (FRI), as shown in Equation 10. The FRI must be selected to represent current contemporary conditions, as opposed to historical pre-suppression conditions. The FRI is assumed to be constant over the 40-year project term but must be updated along with the baseline (see section 10.1). The FRI must represent an average over the entire project area. Table 3 provides an overview on datasets by reference state that have to be used to determine a project-specific fire probability.

Table 3: Applicable fire probability datasets by reference state.

Reference state	Applicable fire probability datasets
All reference states	It is strongly recommended that the FRI be calculated based on the approach outlined in Appendix 1. Alternatively to the reference state-specific datasets, a project area-specific FRI may be i) determined from additional new or updated data using the method of CAL FIRE and Moritz et al., 2009) or ii) from the 'Spatial dataset of probabilistic wildfire risk components for the conterminous United States' developed by Short et al. (2016) and as applied in the Fire SIMulation system (FSIM; Finney et al., 2011).

California	Required inputs can be taken from work by CAL FIRE (2016). CAL FIRE has established contemporary FRI's for the entire state of California on a 1 km x 1 km resolution using the habitat niche modeling techniques of Moritz et al. (2009). Current FRIs may also be selected from the Fire Return Interval Departure (FRID) database (USFS, 2016; see also Safford and Van de Water, 2014) or FSIM.
Colorado	Current FRIs can be selected from the [Modified Fire Return Interval Map of Colorado]

Equation 10: Constant distribution of fire probability for a specific fire return interval.

$$P_{Const} = 1/FRI$$

Where:

P_{Const} is the constant annual fire probability; %

FRI is the fire return interval; years

Quantifying uncertainty of fire ignition probability

FRI uncertainty (U_{FRI}), at a 90% confidence interval of the mean, must be selected for use in uncertainty estimate Equation 9 and Equation 16. It is recommended that at a minimum the FRI uncertainty be set as the higher one of either 25% of the FRI or 10 years. Two primary assumptions drive uncertainty of wildfire emissions on the landscape: 1) fire severity as driven by weather conditions at the time of a wildfire; and 2) fire return interval (see section 9.1.1.7). Project proponents must model the matrix of a range of weather conditions and fire return intervals appropriate to the defined project area to generate a 90% confidence interval as a percentage of the mean expected emissions.

9.1.1.8 Delayed reforestation assessment

Steps to determine baseline emissions from delayed reforestation

The contribution of GHG emissions from delayed reforestation resulting from high-severity wildfire is determined from Equation 11 as the product of:

- Fraction of the burnt area of the baseline that is projected to have delayed reforestation ($P_{TC, BSL}$; see Equation 12). This includes any delayed reforestation that will replace dominant forest vegetation over the project duration of 40 years.
- Change in mean carbon stocks in post-fire type converted land (e.g., shrubland) (C_{tc}) and pre-fire (e.g., forest).

The area of the project that is projected to have delayed reforestation ($P_{tc,b}$) is determined from Equation 12 as the product of:

- High severity fraction of wildfire size ($P_{HS,BSL}$).

- Fraction of high severity wildfire that is landcover type converted (P_{tc}).

The fraction of total acreage burnt under high severity conditions ($P_{HS,BSL}$) is taken from FlamMap modeling results where the fire intensity level (FIL) is 5 or 6 (corresponding to flame lengths of greater than 8'). For FILs of 5 and 6, the aboveground dominant vegetation is consumed or dies as a result of stand-replacing wildfire (e.g., Ansley et al., 2000, p. 5).

The fraction of high severity wildfire that is likely to experience delayed reforestation[5] (P_{tc}) as well as the mean carbon stocking for forest-replacing vegetation (C_{tc})is determined following the methodology described in Appendix 3. Alternatively, regionally relevant peer-reviewed scientific literature can be used as available.

Equation 11: Emissions from delayed reforestation.

$$C_{Redirect,BSL} = \left(C_{P,BSL} - C_{TC}\right) \times P_{TC,BSL}$$

Where:

$C_{Redirect,BSL}$ is is the mean carbon stock loss under the project scenario from delayed reforestation based on the % of burned acres that would have experienced delayed reforestation, time t; MT CO_2e

$C_{P,BSL}$ is the mean carbon stock for vegetation type in the baseline forest prior to wildfire; MT CO_2e

C_{TC} is the mean carbon stock for vegetation type in the redirected baseline scenario high-severity burn; MT CO_2e

$P_{TC,BSL}$ is the proportion of the burned area where delayed reforestation is likely to occur for the baseline scenario (see Equation 12); %

P_{const} is the is the constant probability of fire (see Equation 10); %

Equation 12: Percentage of acreage affected by delayed reforestation.

$$P_{TC,BSL} = P_{TC} \times P_{HS,BSL}$$

Where:

$P_{TC,BSL}$ is the fraction of total acreage burnt that experienced delayed reforestation, time t; %

P_{TC} is the ecological subregion-specific percentage of total acreage burnt by high intensity fires that experienced delayed reforestation; %

$P_{HS,BSL}$ is fraction of the acreage burnt by high intensity fire for the baseline (FIL5, FIL6; see section 9.1.1.6); %

[5] Any delayed reforestation that will replace forest vegetation over the project duration of 40 years can be considered permanent as of ACR permanence requirements of 40 years (see section 9.6).

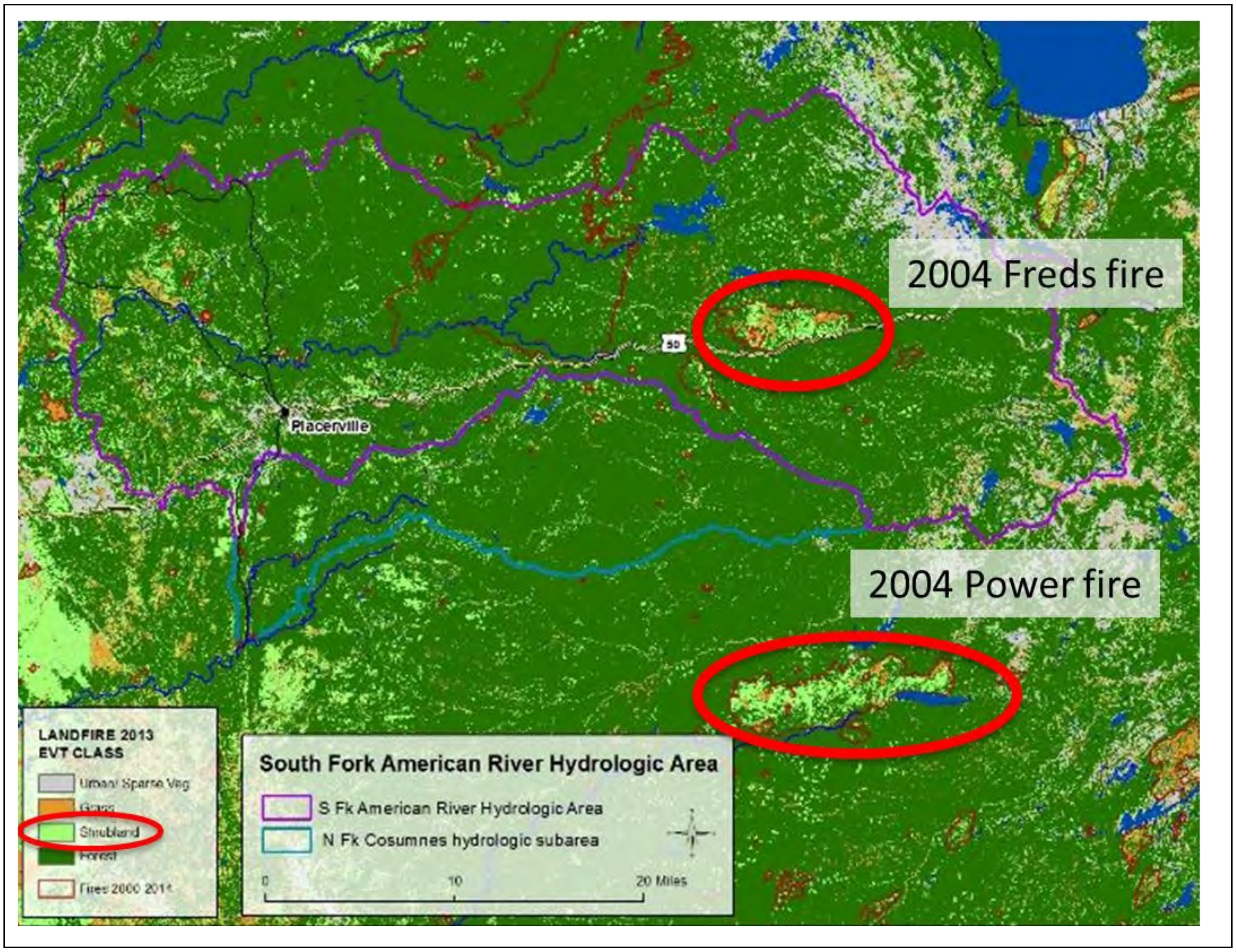
Quantifying uncertainty of baseline scenario delayed reforestation

The uncertainty estimate for the baseline delayed reforestation $U_{BSL,TC}$ is the 90 % confidence interval of all vegetation type occurrences for each high severity fire observed in the region (i.e. delayed reforestation acreage divided by high severity fire acreage for each individual occurrence) and as quantified in the section above.

Box 4: Delayed reforestation.

High severity fires in forests have the potential for high levels of tree mortality and soil impacts that can result in delayed reforestation with temporary or permanent vegetation type conversions from forest to grassland or shrub types. The figure below shows 2013 satellite imagery for the Eldorado National Forest area in California with vegetation cover (dark green = forest; light green = shrub/grass land) and recent forest fire activity (red outline). In some areas, delayed reforestation is apparent as a result of wildfire.

By restricting delayed reforestation assumptions to areas that experienced high intensity fires as reported by USFS Region 5 Burn Severity Database, this approach provides a conservative estimate of related carbon emissions. For conservative GHG emission estimates, areas experiencing less intensive fires followed by delayed reforestation (e.g. Batllori et al., 2015; Gonzalez et al., 2015) will be excluded.



9.1.1.9 Aggregated emissions accounting

GHG losses or savings are aggregated for the entire fireshed on a per-unit-area basis for each five-year increment. Equation 1 and Equation 10 are used to construct the baseline stocking levels over the project term that incorporate projected changes in forest carbon stocks in section 9.1.1.3, wood products calculations described in section 9.1.1.4, and wildfire emissions using models described in section 9.1.1.6.

9.1.2 Estimation of baseline uncertainty

It is assumed that the uncertainties associated with the estimates of the various input data are available, either as default values given in IPCC Guidelines (Eggleston et al., 2006; Penman et al., 2003), or estimates based on sound statistical sampling. Uncertainties arising from the measurement, modeling and monitoring of carbon pools and the changes in carbon pools must always be quantified.

Uncertainty quantification is specified for each carbon pool in the sections above. Indisputably conservative estimates can also be used instead of uncertainties, provided that they are based on verifiable literature sources. In this case the uncertainty is assumed to be zero.

The project proponent must apply one of two approaches for the estimation of combined uncertainties: Approach 1 uses simple error propagation equations, while Approach 2 uses Monte Carlo or similar techniques (Frey et al., 2006).

In Approach 1 (addition and subtraction, Frey et al., 2006), the uncertainty in the baseline scenario should be defined as the square root of the summed errors in each of the measurement pools. The errors in each pool must be weighted by the size of the pool so that projects may reasonably target a lower precision level in pools that only form a small proportion of the total stock (Equation 13).

In Approach 2, the project proponent must employ Monte Carlo simulation procedures as specified by IPCC (2006b) to generate uncertainty-adjusted baseline carbon stocks following four steps:

Step 1: Specify category uncertainties (see sections above; 90% confidence intervals).

Step 2: Select random variables.

Step 3: Estimate emissions and removals (see sections above).

Step 4: Iterate and monitor results.

Equation 13: Uncertainty of baseline carbon stocks and GHGs.

$$Uncertainty_{BSL,t} = \left[\left(C_{BSL,TREE,t} \times U_{BSL,TREE}\right)^2 + \left(C_{BSL,DEAD,t} \times U_{BSL,DEAD}\right)^2 + \left(C_{BSL,WP,t} \times U_{BSL,TREE}\right)^2 + \left(C_{BSL,OP,t} \times U_{BSL,OP}\right)^2 + \left(C_{BSL,WPS,t} \times U_{BSL,WPS}\right)^2 + \left(W_{BSL,t} \times U_{BSL,W}\right)^2 + \left(C_{BSL,Redirect,t} \times U_{BSL,TC}\right)^2 + \right]^{0.5} \div \left(C_{BSL,TREE,t} + C_{BSL,DEAD,t} + C_{BSL,WP,t} + C_{BSL,OP,t} + C_{BSL,WPS,t} + W_{BSL,t} + C_{BSL,Redirect,t}\right)$$

Where:

$Uncertainty_{BSL,t}$ is the uncertainty in the combined carbon stocks in the baseline in year t; %

$C_{BSL,TREE,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$U_{BSL,TREE}$ is the uncertainty expressed as 90% confidence interval percentage of the mean of the carbon stock in above and below ground live trees for the last remeasurement of the inventory prior to year t; %

$C_{BSL,DEAD,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$U_{BSL,DEAD}$ is the uncertainty expressed as 90% confidence interval percentage of the mean of the carbon stock in dead trees for the last remeasurement of the inventory prior to year t; %

$C_{BSL,WP,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$C_{BSL,OP}$ are the emissions from harvest operations and transport in the baseline in year t; $MTCO_2e$

$U_{BSL,OP}$ is the uncertainty of the operation emissions that can be supported by literature; otherwise set to 20 by default; %

$C_{BSL,WPS,t}$ are the avoided emissions from wood product substitution in the baseline year t; $MTCO_2e$

$U_{BSL,WPS}$ is the uncertainty of the wood products substitution emissions that can be supported by literature; otherwise set to 20 by default; %

$W_{BSL,t}$ are the wildfire emissions in the baseline in year t; $MTCO_2e$

$U_{BSL,W}$ is the –combined uncertainty of baseline FRI and wildfire emissions (see section 9.1.1.6); %

$C_{BSL,Redirect,t}$ are the delayed reforestation emissions in the baseline in year t; $MTCO_2e$

U_{TC} is the uncertainty of project vegetation delayed reforestation emissions (see section 9.1.1.8); %

9.2 Project scenario net GHG emissions

9.2.1 Accounting project emissions from avoided wildfire emissions

This section describes the steps required to calculate $C_{P,PROJ}$ (Net carbon stock projected at time *t* under the project scenario; MT CO_2e), which is defined as:

Equation 14: Project GHG accounting.

$$C_{P,PROJ} = \left[\left(C_{P,AG} + C_{P,BG} + C_{P,DW}\right) - \sum_{i=1}^{t}\left(W_{P,i} + C_{Redirect,P,i}\right) \times P_{Const}\right] + C_{P,WP} - C_{P,OPS}$$

Where:

$C_{P,PROJ}$ is sum of all carbon stocks in the project scenario projection for year *t*; MT CO_2e

$C_{P,AG}$ is above-ground carbon stock in the project scenario for trees for all strata for year *t*; MT CO_2e

$C_{P,BG}$ is below-ground carbon for portions of trees in the project scenario for all strata for year *t*; MT CO_2e

$C_{P,DW}$ is carbon stock in project dead wood pools for all strata for year *t*; MT CO_2e

$W_{P,i}$ is the wildfire emissions from combustion in the project scenario for stand i year *t*; MT CO_2e

$C_{Redirect,P,i}$ is the mean carbon stock loss under the project scenario from delayed reforestation based on the % of burned acres that would have been redirected for stand i, time t; MT CO_2e (see Equation 11)

P_{Const} is the constant annual fire probability based on Equation 10; %

$C_{P,WP}$ is carbon stock in project wood products pool for year *t*; MT CO_2e

$C_{P,OPS}$ is the direct fossil fuel emissions associated with fuel treatments (commercial or non-commercial harvest or prescribed fire treatments; optional: may be considered de minimis) for year *t*; MT CO_2e

9.2.1.1 Project area delineation, selection, and characterization.

Identical approach as for baseline scenario (see section 9.1.1.1)

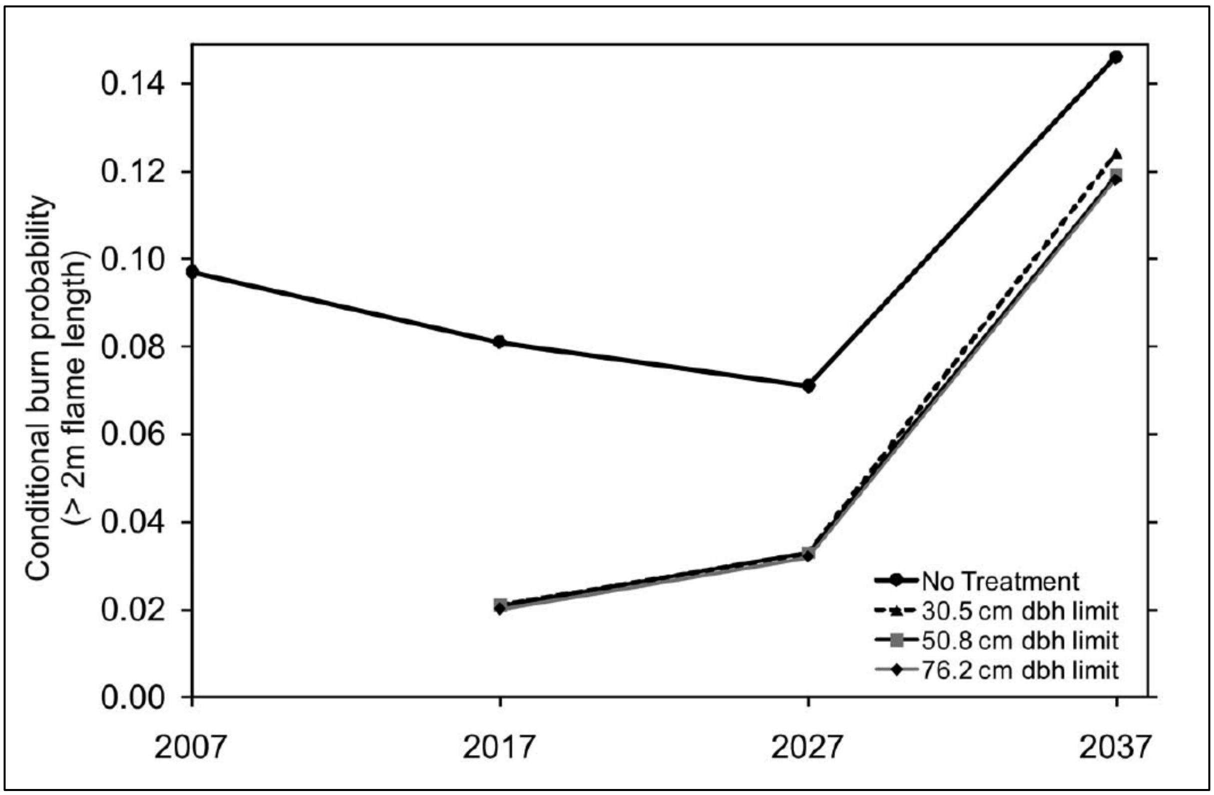
9.2.1.2 Management scenario development and fuel treatment design.

The fuel treatment's long-term ability to mitigate fire behavior within the project area must be assessed. Treatments become less effective over time as forest growth moves treated areas back towards pre-treatment conditions. Fuel treatment effectiveness and longevity depend most importantly on spatial distribution, type of treatment, vegetation growth dynamics, and proportional acreage treated across the fireshed.

To optimize treatment effectiveness, model simulations are required to determine the ‘re-entry interval’ — the point at which over the project term periodic treatments are needed. Fire behavior, vegetation, and weather modeling that must be used for this analysis is detailed in other sections of the protocol.

Box 5: Treatment longevity.

Fuel treatments lose their effectiveness over time. The figure below (Collins et al., 2011) demonstrates conditional burn probability (CBP; a measure of fire hazard) for differing fuel treatment intensities (three different tree removal diameter limits) over time. In this example (1) all fuel treatments provide a considerable (50%) decrease in the initial fire hazard, (2) treatment intensity has little impact on effectiveness or longevity, and (3) effectiveness is completely lost after 20 years for all intensities.



9.2.1.3 Forest carbon (forest growth and sequestration) calculation.

The project proponent must use the same set of equations used in section 9.1.1.3 to calculate carbon stocks in the project scenario.

9.2.1.4 Forest removals life cycle assessment (biofuels, bioenergy, wood products) calculation.

The project proponent must use the same set of equations used in section 9.1.1.4 to calculate carbon stocks in the project scenario.

9.2.1.5 Weather data

Same assumptions and modeling approaches apply as the weather modeling for the baseline scenario (section 9.1.1.5).

9.2.1.6 Wildfire emissions calculation

Steps to determine project wildfire emissions

Procedures identical to those of section 9.1.1.6 for baseline wildfire emissions are used to calculate unadjusted project wildfire emissions, $W_{p,stand}$. However, project wildfire emissions differ from baseline wildfire emissions since fuel treatments change fire severity as well as conditional burn probability (CBP), i.e. the probability of a given point burning assuming a fire occurs. Fuel treatments reduce wildfire emissions within the treated areas themselves (through decreased fire severity) as well as outside of the fuel treatments in fire shadows. A fire shadow is an untreated area that may or may not burn but is indirectly affected by nearby fuel treatments (Box 6). A fire shadow has a reduced CBP and reduced expected fire severity because of neighboring fuel treatments, despite being untreated itself. Two variables are required to fully capture the effect of fuel treatments on fire shadows: fire severity and CBP. Changes in fire severity are captured the same way whether inside or outside of fire shadows — through canopy consumption – and are calculated identically for both baseline and project wildfire emissions. The following steps describe how to adjust project wildfire emissions accounting for a fuel treatment-induced change in CBP.

Step 1: Produce CBP raster map. One raster map of CBPs is produced for the baseline scenario and another for the project scenario. The two rasters can then be divided (CBP_P/CBP_{BSL}); areas where the ratio is 1 have no change in CBP (and are neither a fuel treatment nor a fire shadow) and areas where the ratio is less than 1 is either a fuel treatment or a fire shadow.

Step 2: Correct for CBP ratio anomalies if necessary. FlamMap-MTT and FConstMTT should produce identical maps of CBP for identical inputs. As long as the only differences in inputs (including ignition points) are related to fuels treatments, any differences in outputs will solely reflect the effects of those fuels treatments. Nonetheless, a basic sanity check is recommended to ensure that CBP values only differ where expected and if necessary, minor differences may need to be filtered out as noise so they do not incorrectly present a legitimate change in CBP.

Step 3: The ratio of the project and baseline CBPs are then used to account for the fuel treatment impact on burn probability. Project wildfire emissions, W_P , are calculated according to Equation 15.

Equation 15: Project wildfire emissions W_P.

$$W_P = \sum_{i=1}^{n} \left(W_{P,stand} \times \frac{CBP_{P,stand}}{CBP_{BSL,stand}}\right)$$

Where:

W_P are the project wildfire emissions at time t; MT CO_2e

$W_{P,stand}$ are the unadjusted project wildfire emissions for a given stand i; MT CO_2e

$CBP_{P,stand}$ is the conditional burn probability for a given stand i under project conditions; %

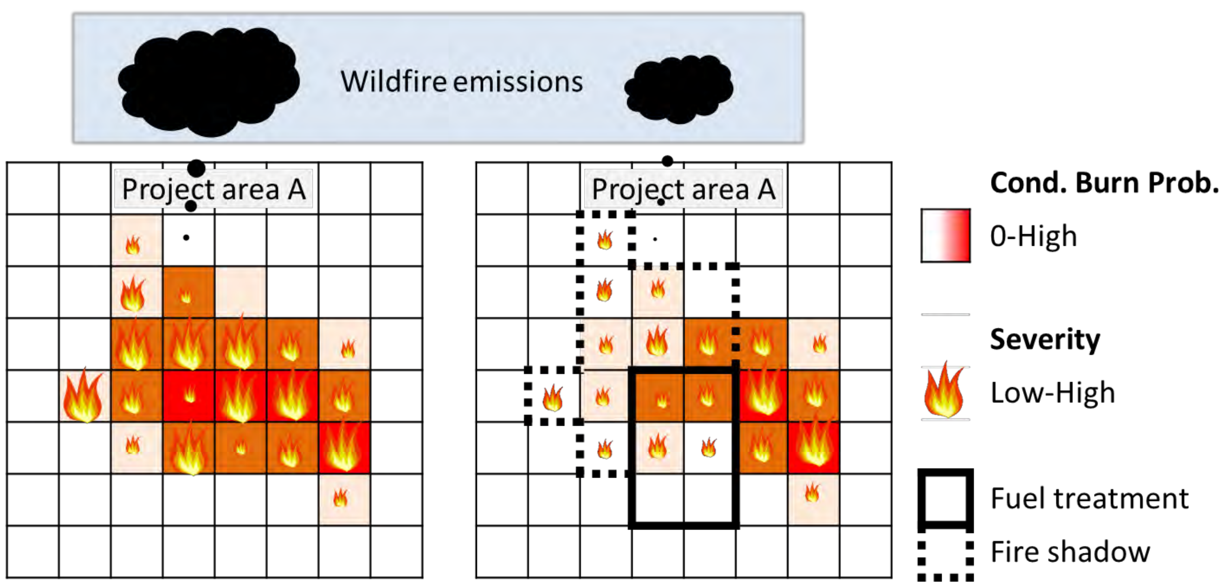
$CBP_{BSL,stand}$ is the conditional burn probability for a given stand i under baseline conditions; %

Box 6: Calculating baseline and project wildfire emissions.

Wildfire emissions reductions occur within the fuel treatment area as well as in the treatment shadow in adjacent untreated areas because of changes in fire severity and reductions in fire size induced by the fuel treatments. Because FlamMap-MTT (or alternatively, FconstMTT) is a deterministic model and the baseline and project runs utilize similar (but not necessarily identical) ignition points, any difference in the conditional burn probability (CBP) between the two scenarios- after correcting for noise- is an indication of fuel treatment effectiveness. (The alternative model FlamMap is capable of reusing the same ignition points but it does not handle large landscape as well.) Changes in expected fire severity due to fuel treatments (whether inside or outside of fuel treatments) are captured by including an estimate of canopy consumption in the emissions modeling (section 0, step 11). Changes in burn probability are captured by multiplying each stand's expected emissions by the ratio of project CBP to baseline CBP. This term cancels to a value of 1 for stands that are not affected in burn characteristics by the project but in fuel treatments and wildfire shadows it will be less than 1.

The below figure graphically demonstrates the direct and shadow wildfire emissions when comparing the baseline and fuel treatment scenarios:

- **Baseline.** For the baseline untreated fireshed on the left, the fire footprint area is shown in red color.
- **Fuel treatment.** For the fuel treatment fireshed shown on the right, fire will be directly limited in severity on the treated stand acres, represented by the orange colored Rx (treated) area. The shadow benefit results from the overall fire size and severity reduction, the difference in the red colored areas.



Quantifying uncertainty of baseline wildfire emissions

The uncertainty estimate for the project wildfire emissions $U_{P,W}$ will be quantified using an project-specific equivalent to Equation 9.

9.2.1.7 Fire ignition probability (fire return interval) assessment

The same fire return Interval assumptions are used as for the baseline scenario in section 9.1.1.7.

9.2.1.8 Aggregated emissions accounting

All GHG losses or savings are summarized for the entire fireshed on a per-unit-area (acre) basis. For each treatment scenario at each time step, the project proponent must examine net GHG storage loss from treatment, offset by GHG benefits realized from merchantable and non-merchantable wood removal life cycles. The Equation 14 and Equation 10 are used to construct the with-project stocking levels over the project term that incorporate projected changes in forest carbon stocks in Equation 14, Wood Products calculations described in section 9.2.1.4, and wildfire emissions using models described in section 9.2.1.6.

For aggregate emissions accounting, the project proponent must use the latest version of the "GHG offset protocol: Avoided wildfire emissions" Microsoft Excel template.

9.2.2 Estimation of emissions due to leakage

Project activity by definition will typically increase products outputs over the baseline and leakage will be 0.

9.2.3 Estimation of with-project uncertainty

It is assumed that the uncertainties associated with the estimates of the various input data are available, either as default values given in IPCC Guidelines (Frey et al., 2006; Penman et al., 2003), or estimates based on sound statistical sampling. Uncertainties arising from the measurement, modeling and monitoring of carbon pools and the changes in carbon pools must always be quantified.

Uncertainty quantification is specified for each carbon pool in the sections above. Indisputably conservative estimates can also be used instead of uncertainties, provided that they are based on verifiable literature sources. In this case the uncertainty is assumed to be zero.

The project proponent must apply one of two approaches for the estimation of combined uncertainties: Approach 1 uses simple error propagation equations, while Approach 2 uses Monte Carlo or similar techniques (Frey et al., 2006).

In Approach 1 (addition and subtraction, Frey et al., 2006), the uncertainty in the baseline scenario should be defined as the square root of the summed errors in each of the measurement pools. The errors in each pool must be weighted by the size of the pool so that projects may reasonably target a lower precision level in pools that only form a small proportion of the total stock (Equation 16).

In Approach 2, the project proponent must employ a Monte Carlo simulation procedure as specified by IPCC (2006b) to generate uncertainty-adjusted baseline carbon stocks following four steps:

Step 1: Specify category uncertainties (see sections above; 90% confidence intervals).

Step 2: Select random variables.

Step 3: Estimate emissions and removals (see sections above).

Step 4: Iterate and monitor results.

Equation 16: Uncertainty of with-project carbon stocks and GHGs.

$$Uncertainty_{P,t} = \left[\left(C_{P,TREE,t} \times U_{P,TREE}\right)^2 + \left(C_{P,DEAD,t} \times U_{P,DEAD}\right)^2 + \left(C_{P,WP,t} \times U_{P,TREE}\right)^2 + \left(C_{P,OP,t} \times U_{P,OP}\right)^2 + \left(C_{P,WPS,t} \times U_{P,WPS}\right)^2 + \left(C_{P,W,t} \times U_{P,W}\right)^2\right]^{0.5} \div \left(C_{P,TREE,t} + C_{P,DEAD,t} + C_{P,WP,t} + C_{P,OP,t} + C_{P,WPS,t} + C_{P,W,t}\right)$$

Where:

$Uncertainty_{P,t}$ is the uncertainty in the combined carbon stocks in the baseline in year t; %

$C_{P,TREE,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$U_{P,TREE}$ is the uncertainty expressed as 90% confidence interval percentage of the mean of the carbon stock in above and below ground live trees for the last remeasurement of the inventory prior to year t; %

$C_{P,DEAD,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$U_{P,DEAD}$ is the uncertainty expressed as 90% confidence interval percentage of the mean of the carbon stock in dead trees for the last remeasurement of the inventory prior to year t; %

$C_{P,WP,t}$ is carbon stock in the baseline stored in above and below ground live trees in year t; $MTCO_2e$

$C_{P,OP}$ are the emissions from harvest operations and transport in the baseline in year t; $MTCO_2e$

$U_{P,OP}$ is the uncertainty of the operation emissions that can be supported by literature; otherwise set to 20 by default; %

$C_{P,WPS,t}$ are the avoided emissions from wood product substitution in the baseline year t; $MTCO_2e$

$U_{P,WPS}$ is the uncertainty of the wood products substitution emissions that can be supported by literature; otherwise set to 20 by default; %

$W_{P,t}$ are the wildfire emissions in the baseline in year t; $MTCO_2e$

$U_{P,W}$ is the –combined uncertainty of baseline FRI and wildfire emissions; %

9.3 Leakage

9.3.1 Description of leakage

Leakage from market or activity shifting effects does not apply since wood product supply is expected to increase in a project scenario more than under the baseline scenario (Table 4).

Table 4: Leakage sources.

Leakage Source	Product type	Included / Optional / Excluded	Justification / Explanation of choice
Activity-Shifting	Timber Harvesting	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
	Fuelwood	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
Market Effects	Timber	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
	Fuelwood	Excluded	Project scenario will have typically greater timber harvesting activity than baseline

9.3.2 Quantification of leakage deduction

Not applicable – see section 9.3.1.

9.4 Net GHG emissions

ERTs will be calculated based on Equation 17 and Equation 18. ERTs will be calculated on an ex-ante basis only (independent of wildfire presence, see section 1.1). ERTs will be issued once the implementation of fuel treatments specified in the project scenario can be documented, i.e. over a time period for which a valid verification report has been filed with ACR. A timely implementation of fuel treatments as specified assures issuance of credits on an annual basis following the Annual Attestation Statement and verified every five years (see section 9.6).

Equation 17: Total net GHG emission reductions.

$$C_t = (C_P - C_{BSL} - C_{LK}) * (1 - UNC)$$

Where:

C_t is the total net GHG emission reductions at time *t* (MT CO_2e)

C_P is the sum of the carbon stock changes and GHG emissions under the project scenario up to time *t,* in MT CO_2e (section Equation 14)

C_{BSL} is the sum of the carbon stock changes and GHG emissions under the baseline scenario up to time *t,* in MT CO_2e (section Equation 1)

C_{LK} is the sum of the carbon stock changes and GHG emissions due to leakage up to time *t,* in MT CO_2e (section 10.4)

UNC is the total project uncertainty, in % (Equation 19). *UNC* will be set to zero if the project meets the precision requirement of within 10% of the mean with 90% confidence of forest pool carbon stocks. If the project does not meet this precision target, *UNC* must be the half-width of the confidence interval of calculated net GHG emission reductions.

Equation 18: Number of emissions reduction units.

$$ERT_t = \left(C_{t_2} - C_{t_1}\right) * \left(1 - BUF\right)$$

Where:

ERT_t is the number of Emission Reduction Tonnes between time $t = t_2 - t_1$

C_{t2} is the cumulative total net GHG emissions reductions up to time t_2

C_{t1} is the cumulative total net GHG emissions reductions up to time t_1

BUF is the non-permanence buffer deduction as calculated by the ACR Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination (*BUF* will be set to zero if an approved insurance product is used); fraction

Box 7: Issuance of Emission Reduction Tonnes (ERTs).

ERTs are calculated as the net CO_2e (the difference between baseline and fuel treatment project emissions) for each five-year period, incorporating all included and optional pools, climate relevant non CO_2 emissions converted to CO_2e, and uncertainty and buffer pool reductions.

The below tabulation shows emissions results (in MT CO_2e/acre, where negative numbers are emissions reductions and positive number are liabilities) for an example fuel treatment project, broken into the following sub-categories:

Forest carbon stock and growth
Wood products
Wood product substitution
Wildfire emissions

For this example, in the first ten-year period, ERTs of 2.8 MT CO_2e/acre would be issued.

The remaining 20 years to year 40, the full project term, need to be considered to fulfill permanence requirements. In this example, since the total accumulated credits after year 40 (the end of the project term) are negative, the project is considered permanent. If the total accumulated credits would have been positive at the end of the project term, the project would be considered a reversal and would not be eligible. A follow-up round of fuel treatments at a later point in time might remediate that condition.

	Project year								
Category	0	5	10	15	20	25	30	35	40
Forest carbon stock and growth	2.0	8.2	8.5	13.1	18.3	24.1	29.8	35.3	36.9
Wood products	-	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)
Wood product substitution	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	(2.0)	2.0
Wildfire emissions	-	(3.8)	(8.2)	(13.0)	(18.8)	(24.8)	(30.6)	(37.4)	(43.8)
ERTs	-	1.3	(2.8)	(3.0)	(3.6)	(3.8)	(3.9)	(5.2)	(6.0)

This example assumes that ERTs reductions due to uncertainty and buffer pool contributions are already accounted for.

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9.5 Uncertainty

The following equation must be applied:

Equation 19: Total project uncertainty.

$$\boldsymbol{UNC} = \sqrt{\boldsymbol{UNC_{BSL}}^{2} + \boldsymbol{UNC_{WP}}^{2}}$$

Where:

UNC is the total project Uncertainty, in %

UNC_{BSL} is the baseline uncertainty, in % (Section 9.1.2)

UNC_{WP} is the with-project uncertainty, in % (Section 9.2.3)

UNC will be set to zero if the project achieves a precision requirement of within 10% of the mean with 90% confidence.

9.6 Permanence and reversal risk

9.6.1 Assessment of reversal risk

Project proponents commit to a minimum project term of 40 years. Projects must have effective risk mitigation measures in place to compensate fully for any loss of sequestered carbon, whether this occurs through an unforeseen natural disturbance or through a project proponent or landowners' choice to discontinue forest carbon project activities.

9.6.2 Mitigation of reversal risk

Mitigation measures can include contributions to the buffer pool, insurance, or other risk mitigation measures approved by ACR. If using a buffer contribution to mitigate reversals, the project proponent must conduct a risk assessment addressing both general and project specific risk factors. General risk factors include risks such as financial failure, technical failure, management failure, rising land opportunity costs, regulatory and social instability, and natural disturbances. Project specific risk factors vary by project type, but can include land tenure, technical capability and experience of the project developer, fire potential, risks of insect/disease, flooding and extreme weather events, illegal logging potential, and others. If they are using an alternate ACR - approved risk mitigation product, they will not do this risk assessment.

9.6.3 Buffer pool contributions

Project proponents must conduct their risk assessment using the ACR Tool for Risk Analysis and Buffer Determination. The output of this tool is an overall risk category, expressed as a fraction, for the project translating into the buffer deduction that must be applied in the calculation of net Emission Reduction

Tonnes (ERTs, section 9.4). This deduction must be applied unless the project proponent uses another ACR - approved risk mitigation product.

10 MONITORING AND DATA COLLECTION

Project proponent must present an ex-ante stratification of the project area or justify the lack of it. The number and boundaries of the strata defined ex-ante may change during the crediting period (ex-post).

The ex-post stratification must be updated due to the following reasons:

- Unexpected disturbances occurring during the crediting period (e.g. due to fire, pests or disease outbreaks), affecting differently various parts of an originally homogeneous stratum.
- Forest management activities (e.g. cleaning, planting, thinning, harvesting, coppicing, replanting) may be implemented in a way that affects the existing stratification.
- Established strata may be merged if reason for their establishment has disappeared.

10.1 Parameters

At a minimum, the data parameters specified in Table 5 must be monitored. The 90% statistical confidence interval (CI) of sampling can be no more than +/- 10% of the mean estimated amount of the combined carbon stock at the project level. For calculating pooled CI of carbon pools across strata, see equations in Shiver (1995). If the project cannot meet the targeted +/- 10% of the mean at 90% confidence, then the reportable amount must be the lower bound of the 90% confidence interval.

Table 5: Parameters to be monitored.

Acronym	Unit	Parameter	Potential Evidence	Source	Baseline or project	Frequency of monitoring
Project area	acre	Total project area	GIS shapefiles	GIS analytics	Both	Five years
Sample plot area	acre	Size of sample plots	Inventory design documents	Inventory design documents	Both	Five years
Tree species	N/A	Tree species present	Inventory outputs	Inventory statistics	Both	Five years
Tree biomass	MT CO_2e	Total tree biomass	Growth and yield output database	Inventory statistics	Both	Five years

Wood products volume	MT CO_2e	Total volume of wood products in-use	Growth and yield output database	Growth and yield models	Both	Five years
Dead wood pool	MT CO_2e	Total dead wood biomass	Growth and yield output database	Inventory statistics	Both	Five years
Fuel treatment implementation	acre, ft^2/acre, trees/acre, etc.	Treated acreage, basal area, stand density index, tree density, fuel load treatment incl. residues, etc.	Site-visit	Management plan	Project	Five years

Box 8: The role of monitoring carbon stocks for avoided wildfire emissions offsets.

Periodic inventories must be conducted every five years over the complete project term to show: (1) impact of unavoidable and unplanned reversals such as disease or wildfires, (2) status of avoidable reversals such as deviations from the harvest plan, (3) accuracy and true-up of forest growth modeling and delayed reforestation assumptions.

The project proponent must make an ex-ante calculation of all net anthropogenic GHG removals and emissions for all included sinks and sources for the entire project crediting period. Project proponent must provide estimates of the values of those parameters that are not available before the start of monitoring activities. The project proponent must retain a conservative approach in making these estimates.

Uncertainties arising from, for example, biomass expansion factors or wood density, could result in unreliable estimates of both baseline net GHG removals by sinks and the actual net GHG removals by sinks, especially when global default values are used. Project proponents must identify key parameters that would significantly influence the accuracy of estimates. Local values that are specific to the project circumstances must then be obtained for these key parameters, whenever possible. These values must be based on:

- Data from peer-reviewed literature or other well-established published sources; or
- National inventory data or default data from IPCC literature that has, whenever possible and necessary, been checked for consistency against available local data specific to the project circumstances; or
- In the absence of the above sources of information, expert opinion may be used to assist with data selection. Experts will often provide a range of data, as well as a most probable value for the data. The rationale for selecting a particular data value must be noted. For any data provided by experts, record the expert's name, affiliation, and principal qualification as an expert– plus inclusion of a 1-page summary CV for each expert consulted, included in an annex.

When choosing key parameters based on information that is not specific to the project circumstances, such as in use of default data, project proponents must select values that will lead to an accurate estimation of net GHG removals by sinks, considering uncertainties. If uncertainty is significant, the project proponent must choose data such that it tends to under-estimate, rather than over-estimate, net GHG removals by sinks (CDM, 2010).

10.2 Monitoring requirements for baseline renewal

A project's crediting period is the finite length of time for which the baseline scenario is valid and during which a project can generate offsets against its baseline. Considering the rapidly changing patterns of fire weather, a 10-year recalculation of the baseline is required to account for additional change (ACR, 2018b).[6]

A project proponent may apply to renew the crediting period by:

- Re-submitting application in compliance with then-current GHG Program standards and criteria.
- Re-evaluating of the project baseline, in particular if new science becomes available to refine estimates of fire return intervals.
- Demonstrating additionality against then-current regulations, common practice and implementation barriers.
- Using GHG Program-approved baseline methods, emission factors, and tools in effect at the time of crediting period renewal.
- Undergoing verification by an approved verifier.

10.3 Monitoring project implementation

Information must be provided and recorded to establish that:

- The geographic position of the project boundary is recorded for all areas of land.

[6] Identical to requirements for unplanned deforestation or degradation REDD projects through ACR.

- The geographic coordinates of the project boundary (and any stratification inside the boundary) are established, recorded and archived. This can be achieved by field mapping (e.g. using GPS), or by using georeferenced spatial data (e.g. maps, GIS datasets, orthorectified aerial photography or georeferenced remote sensing images).
- Professionally accepted principles of forest inventory and management are implemented.
- Standard operating procedures (SOPs) and quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management must be applied. Use or adaptation of SOPs already applied in national forest monitoring, or available from published handbooks, or from Penman et al. (2003), is recommended.
- The forest management plan, together with a record of the plan as actually implemented during the project, must be available for certification and verification.

10.4 Monitoring of leakage

As per the applicability conditions, leakage does not need to be considered since project activities exceed baseline levels of commercial and non-commercial removal of biomass. If leakage from activity shifting is discovered, project proponents must estimate the associated leakage amount and deduct ERTs to fully compensate for emissions resulting from activity shifting leakage.

11 VALIDATION AND VERIFICATION

ACR validation and verification standards apply. The ACR-specific mandatory field visit every five years for forest carbon projects applies (ACR, 2018a). A verifier must provide a reasonable level of assurance that the GHG assertion is without material discrepancy; thereby providing evidence of permanence, i.e. absence of reversals. The implementation of the forest management plan, most notably the fuel treatments as modeled for the project scenario have to be verified along with forest inventory assumptions for a given year (see section 10).

Project proponents must consider all relevant information that may affect the accounting and quantification of GHG reductions/removals, including estimating and accounting for any decreases in carbon pools and/or increases in GHG emission sources. This methodology sets a de minimis threshold of 3% of the final calculation of emission reductions. For the purpose of completeness, any decreases in carbon pools and/or increases in GHG emission sources must be included if they exceed the de minimis threshold. Any exclusion using the de minimis principle must be justified using fully documented ex-ante calculations.

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DEFINITIONS

Elements of the glossary below have been adapted from CAR's Forest Project Protocol Version 3.3 2012.

Additionality	A criterion for project eligibility. A forest project is "additional" if it would not have been implemented without incentives provided by the carbon offset market, including the incentives created through the credit issuing entity's program. Under this protocol, forest projects meet the additionality criterion by demonstrating that they pass a legal requirement test and a performance test, as described in section 0, and by achieving GHG reductions and removals quantified against an approved baseline, determined according to the requirements in section 7.
Annual Attestation Statement	The statement that a project proponent provides annually to ACR relating to the continuance, ownership, and community and environmental impacts of a project. The Attestation is required in order to continue crediting.
Baseline	The level of GHG emissions, removals, and/or carbon stocks at sources, sinks or reservoirs affected by a forest project that would have occurred under a common practice scenario. For the purposes of this protocol, a project's baseline must be estimated following standard procedures in Section 7.
Baseline Renewal	Changes to the baseline when applying to renew the crediting period.
Baseline Scenario	The project baseline is a counterfactual scenario that forecasts the likely stream of emissions or removals to occur if the project proponent does not implement the project, i.e., the common practice case.
Baseline Uncertainty	Uncertainties associated with baseline assumptions.
Belowground Biomass Carbon	All organic carbon stored belowground.
Biomass	The total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass.[7]
Black Carbon	See Particulate Matter.

[7] B. Metz, O. Davidson, R. Swart, J. Pan, Climate Change 2001: Mitigation (Cambridge Univ. Press, Cambridge, 2001), 656 pp.

Buffer Pool	The buffer pool is a holding account for forest project ERTs administered by the credit issuing entity (e.g. CAR, VCS, ACR). It is used as a general insurance mechanism against Unavoidable Reversals for all forest projects registered with the credit issuing entity. If a forest project experiences an Unavoidable Reversal of GHG reductions and removals (as defined in Section 9.6), the credit issuing entity will retire a number of ERTs from the buffer pool equal to the total amount of carbon that was reversed (measured in MT of CO_2-equivalent).
Carbon Pool	A reservoir that has the ability to accumulate and store carbon or release carbon. In the case of forests, a carbon pool is the forest biomass, which can be subdivided into smaller pools. These pools may include aboveground or belowground biomass or harvested wood products, among others.
CO_2e	Carbon Dioxide equivalent. The amount of CO_2 that would have the same global warming potential (GWP) as other GHGs over a 100-year lifetime using SAR - 100 GWP values from the IPCC's fourth assessment report.
Common Practice	The activities, and associated GHG reductions and removals that would have occurred in the project area in the absence of incentives provided by a carbon offset market. Methodologies for determining these activities and/or for approximating carbon stock levels that would have resulted from these activities – are provided in Section 6 of this protocol for each type of forest project.
Conditional Burn Probability	The probability of a pixel burning during a specified duration, given that a fire ignites in the analysis area—not annual burn probability.
Conservativeness Principle	Projects are only required to account for increased emissions or decreases in sequestration.
Crediting Period	The period in which a project can receive credits from the issuing entity. To apply permanence requirements, the project term might be considerably longer than the crediting period.
Crowning Idex	The open wind speed above which an active crown fire is possible for the specified fire environment.
De Minimis	Too minor to merit consideration.

Delayed reforestation	Reducing the occurrence of high severity fires prevents the (temporary or permanent) shifting of ecosystem composition from high carbon dense types to low carbon dense types (forest to grasslands and/or shrublands).
Wildfire Emissions	Same as aboveground carbon stock change from a wildfire.
Emission Reduction Tonne (ERT)	The unit of offset credits used by ACR. Each ERT represents one metric ton (2204.6 lbs) of CO_2 equivalent reduced or removed from the atmosphere.
Ex-ante	Prior to an event, i.e. the project certification. Ex-ante refers mostly to modeling work done in preparation for project submission to ACR.
Ex-post	After the event, a measure of past performance.
FIA	USDA Forest Service Forest Inventory and Analysis program. FIA is managed by the Research and Development organization within the USDA Forest Service in cooperation with State and Private Forestry and National Forest Systems. FIA has been in operation under various names (Forest Survey, Forest Inventory and Analysis) for 70 years.
Fire Hazard	The difficulty of controlling potential wildfire.
Fire Intensity Level	Categories for fire intensity on a given stand that are defined by probable flame length.
Fire Probability	The probability of ignition, or the probability of a given point on the landscape igniting over the course of the study period. Fire Return Interval (FRI) is used as the base metric for fire probability.
Fire Regime	Pattern, frequency, severity, and intensity of the bushfires and wildfires that prevail in an area.
Fire Return Interval	See Fire Probability.
Fireshed	Firesheds are large (thousands of acres) landscapes, delineated based on Fire Regime, condition class, fire history, Fire Hazard and probability, and potential wildland fire behavior.
Flame Length Probability	The expected net value change within an area calculated as the product of (1) the probabilities that the area represented by the pixel will burn for user-defined flame length classes (low, medium, high, very high) given a random ignition within the project area, and (2) the resulting change in

	financial or ecological value (response function) if the area represented by the pixel burns for each user-defined flame length class.
Forest Carbon	The carbon found in Forestland resulting from photosynthesis in trees and associated vegetation, historically and in the present. Forest Carbon is found in soils, litter and duff, plants and trees, both dead and alive.
Forest Cover Type	Name for a specific composition of tree community.
Forest Floor	See Litter
Forest Management	The commercial or noncommercial growing and harvesting of forests.
Forest Owner	A corporation or other legally constituted entity, city, county, state agency, individual(s), or a combination thereof, that has legal control (described in Section 2.2) of any amount of forest carbon within the project area.
Forest Project	A planned set of activities designed to increase removals of CO_2 from the atmosphere, or reduce or prevent emissions of CO_2 to the atmosphere, through increasing and/or conserving forest carbon stocks.
Forestland	Land that supports, or can support, at least ten percent tree canopy cover and that allows for management of one or more forest resources, including timber, fish and wildlife, biodiversity, water quality, recreation, aesthetics, and other public benefits.
Fuel (Reduction) Treatment	Treatments designed to modify fire behavior such that severity, intensity, and size are reduced compared to the baseline of no fuel treatment activity. This can be achieved through thinning or prescribed fire.
GHG Project Plan	A GHG project plan is a document that describes the project activity, satisfies eligibility requirements, identifies sources and sinks of GHG emissions, establishes project boundaries, describes the baseline scenario, defines how GHG quantification will be done and what methodologies, assumptions and data will be used, and provides details on the project's monitoring, reporting and verification procedures.
Greenhouse Gases (GHG)	Gases that contribute to global warming and climate change. For the purposes of this Forest Project Protocol, GHGs are the six gases identified in the Kyoto Protocol: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Harvested Wood Products	All wood products including pulp and paper derived from roundwood.
High Severity Fire	Canopy trees killed and charred organic matter to several cm in depth.
Implementation Barrier	Any factor or consideration that would prevent the adoption of the practice/activity proposed by the project proponent.
Improved Forest Management Project	A type of forest project involving management activities that increase carbon stocks on forested land relative to baseline levels of carbon stocks.
Ladder Fuel	Low-level branches and vegetation providing opportunities for ground fires to climb up on trees.
Leakage	Leakage refers to a decrease in sequestration or increase in emissions outside project boundaries as a result of project implementation. Leakage may be caused by shifting of the activities of people present in the project area, or by market effects whereby emission reductions are countered by emissions created by shifts in supply of and demand for the products and services affected by the project.
Litter	Or Forest Floor; any piece(s) of dead woody material from a tree, e.g. dead boles, limbs, and large root masses, on the ground in forest stands that is smaller than material identified as lying dead wood.
Lying Dead Wood	Any piece(s) of dead woody material from a tree, e.g. dead boles, limbs, and large root masses, on the ground in forest stands. Lying dead wood is all dead tree material with a minimum average diameter of five inches and a minimum length of eight feet. Anything not meeting the measurement criteria for lying dead wood will be considered litter. Stumps are not considered lying dead wood.
Market Effect	Impact of (wood product) markets on harvest decisions.
Minimum Travel Time	A unit generated by FlamMap that searches for the set of pathways with minimum spread times from a ignition source, keeping environmental (fuel moistures and winds) conditions constant for the duration of the simulation.
Native Forest	For the purposes of this protocol native forests must be defined as those occurring naturally in an area, as neither a direct nor indirect consequence of human activity postdating European settlement.

Natural Forest Management	Forest management practices that promote and maintain native forests comprised of multiple ages and mixed native species at multiple landscape scales. The application of this definition, its principles, detailed definition, and implementation are discussed further in Section 3.11.2.
Oven-Dry	Containing 0 % moisture.
Overstocked Canopy	Forest canopy characterized by severe competition for light and at high risk of spreading high-severity crown fires
Particulate Matter	Also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution, which can be associated with global warming, is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.
Permanence	The requirement that GHGs must be permanently reduced or removed from the atmosphere to be credited as carbon offsets. For forest projects, this requirement is met by ensuring that the landscape carbon associated with credited GHG reductions and removals remains stored over the project term and a 100-year carbon flux documentation for wood products.
Primary Effects	The forest project's intended changes in carbon stocks, GHG emissions or removals.
Project Area	The area inscribed by the geographic boundaries of a forest project, as defined following the requirements in section 2 of this protocol.
Project Crediting Period	See Crediting Period.
Project Proponent	A Forest Owner responsible for undertaking a forest project and registering it with the credit issuing entity as described in Section 2.
Project Scenario	Scenario described with fuel treatments in place.
Project Term	Refers to the duration of a forest project and its associated monitoring and verification activities.
Reduction	The avoidance or prevention of an emission of CO_2 (or other GHG). Reductions are calculated as gains in carbon stocks over time relative to a forest project's baseline (also see Removal).

Registered	A forest project becomes registered when it has been verified by a an approved and ISO accredited verification body, all required documentation has been submitted by the project proponent to the crediting issuing entity (e.g. CAR, VCS, ACR) for final approval, and the credit issuing entity approves the project.
Removal	Sequestration ("removal") of CO_2 from the atmosphere caused by a forest project. Removals are calculated as gains in carbon stocks over time relative to a forest project's baseline (also see Reduction).
Reservoir	Physical unit or component of the biosphere, geosphere or hydrosphere with the capacity to store or accumulate carbon removed from the atmosphere by a sink, or captured from a source.
Retire	To retire an ERT means to transfer it to a retirement account in the credit issuing entity's system. Retirement accounts are permanent and locked, so that a retired ERT cannot be transferred or retired again.
Reversal	A reversal is a decrease in the stored carbon stocks associated with quantified GHG reductions and removals that occurs before the end of the project term.
Sequestration	The process of increasing the carbon (or other GHGs) stored in a reservoir. Biological approaches to sequestration include direct removal of CO_2 from the atmosphere through land-use changes and changes in forest management.
Shadow Effect	See Treatment Shadow Effect.
Sink	Physical unit or process that removes a GHG from the atmosphere.
Soil Organic Carbon	Carbon stored belowground and originating from biomass
Source	Physical unit or process that releases a GHG into the atmosphere.
Stocks (or Carbon Stocks)	The quantity of carbon contained in identified carbon pools.
Torching Index	The open wind speed at which some kind of crown fire is expected to initiate.
Treatment Shadow Effect	Treating even a small portion of the landscape can result in a decrease in probability of areas outside those treated areas being burned.
Tree	A perennial woody plant with a diameter at breast

	height (4.5’) greater than or equal to 1” and a height of greater than 4.5’
Unavoidable Reversal	An Unavoidable Reversal is any reversal not due to the project proponent’s negligence, gross negligence or willful intent, including wildfires or disease that are not the result of the project proponent's negligence, gross negligence or willful intent.
Verification	The process of reviewing and assessing all of a forest project’s reported data and information by an ISO accredited and credit issuing entity verification body, to confirm that the project proponent has adhered to the requirements of this protocol.
Wood Products	See Harvested Wood Products.

APPENDIX

Appendix 1: Modern Mean Fire Return Interval (MFRI) mapping for the western US

Appendix 2: Non-CO2 GHG emissions accounting

Appendix 3: Quantifying occurrence and carbon emissions from delayed reforestation in Californian forests following high-severity wildfire

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Concept note:

Avoided wildfire emissions due to fuel treatments: Accounting for non-CO2 greenhouse gas (GHG) emissions

Project:

Quantifying ecosystem service benefits of reduced occurrence of significant wildfires (2015-2019); Task 3: ‘Ensure versatility and robustness in the carbon accounting framework’

Prepared on behalf of SIG by:

Thomas Buchholz (tbuchholz@sig-gis.com), David Schmidt, David Saah

Summary

- Non-CO2 GHG emissions provide a substantial contribution to overall wildfire emissions;
- Some elements of non-CO2 wildfire GHG emissions are difficult to quantify in terms of their global warming potential (GWP);
- This concept note provides a crosswalk from non-CO2 GHG emissions model results (e.g. FOFEM) to a GWP estimate;
- Suggestions for improvements are provided and hinge on more data becoming available especially for black (BC) and brown carbon estimates (BrC), both potent climate forcing agents.

Date:

March 28 2019

1 RATIONALE

Wildfires can contribute substantial non-CO_2 GHG emissions such as particulate matter ($PM_{2.5}$), CH_4, CO, NO_x, and SO_2 (McClure & Jaffe, 2018; Urbanski, Reeves, Corley, Silverstein, & Hao, 2018). Changing low-frequency high-severity wildfire patterns to higher-frequency lower-intensity wildfires can reduce non-CO_2 GHG emissions including particulate matter, i.e. smoke (Pierce, Martin, & Heald, 2017; Schweizer, Preisler, & Cisneros, 2018). These non-CO_2 GHG emissions can be estimated for wildfire scenarios with standard models such as FOFEM (Lutes, 2016).

However, as a standard default output, all of these non-CO_2 GHG wildfire emissions are provided in pounds (lbs) per acre affected by wildfire. To estimate the accumulated global warming impact of a wildfire, these non-CO_2 GHG emissions have to be converted to an aggregated metric of their global warming potential (GWP) expressed in CO_2 equivalents (CO_2e). While there is ample scientific literature providing GWP lookup numbers for CH4 (28; (Mythe et al., 2013, Table 8.a.1) and CO (1.8; (Mythe et al., 2013, Table 8.a.4), the other wildfire-relevant non-CO_2 GHG emissions are less well documented. This concept note provides a wildfire-relevant crosswalk to calculate the GWP in CO_2e for particulate matter (PM), non-methane volatile organic compounds (NMVOC), and NO_x. The GWP of PM is calculated a crosswalk utilizing a fraction of PM referred to as black carbon (BC) which is a light-absorbing aerosol in the infrared spectrum (Aurell & Gullett, 2013). While brown carbon (BrC) containing light-absorbing absorbing organic compounds from smoldering biomass (Aurell & Gullett, 2013; Gustafsson & Ramanathan, 2016; Jacobson, 2014; Liu et al., 2017; Ottmar, 2014) can also have global warming impact, no model currently exists to estimate BrC emissions, the fraction of BrC that has a climate impact, or cross-walk BrC to a GWP. Hence, a GWP estimate for BrC is not included in this concept note.

2 NON-CO2 GHG EMISSIONS CROSS-WALKS

2.1 NMVOC

In the absence of NMVOC specific GWP estimates, we assume a GWP of 5 for NMVOC based on VOC estimates for North America with a 100 year time horizon. (Mythe et al., 2013; Table 8.a.5).

2.2 NO_x

While N_2O is emitted during wildfires (Urbanski, Hao, & Baker, 2009) and has a GWP of over 260 (Mythe et al., 2013; Table 8.7), the global warming impact of all NO_x combined and released during wildfires is fraught with considerable uncertainty due to its multiple short and long-lived atmospheric interactions but overall believed to be climate beneficial due to its cooling effects (influencing ozone built-up, providing a fertilization effect, etc). Mythe et al. (2013; Table 8.a.3) estimate a GWP of -8.2 for all NO_x combined in the context of North America. It should be noted that these assumptions are based mostly on fossil fuel emissions in the transport sector (air, sea, land). In the context of estimating the climate impact of wildfires, the negative, i.e. climate beneficial, impact of NO_x also provides an additional safeguard to not overestimate the benefits of fuel treatments. A conservative, lower overall GHG emission profile of wildfires serves attributes therefore fewer climate benefits to fuel treatments and should be included as an additional uncertainty buffer to avoided wildfire emissions calculations when analyzing the effects of fuel treatments.

2.3 Black carbon (BC)

While the GWP for BC can be defined (Table 1), there is no model linking BC emissions to specific wildfire events. Therefore, a crosswalk has to be generated utilizing PM emissions which can be modeled (e.g. FOFEM). Since

In the context of defining the GWP of BC, BC is equated here with a fraction of $PM_{2.5}$ emissions (e.g. Aurell & Gullett, 2013). Liu et al. (2017) and May et al. (2014) provide extensive current wildfire specific estimates of BC and PM are provided by and outlined in Table 1. Cross-referencing their data on a BC emission factor as well as PM_1 emissions provides a GWP of 9 for PM_1 emissions. FOFEM provides only $PM_{2.5}$ (flaming) estimates of which only a fraction are PM_1 emissions (~3%). Therefore, equating the GWP of PM_1 emissions with a GWP for $PM_{2.5}$ emissions is a conservative wildfire GHG estimate. This conservative estimate is further supported by results provided by Aurell & Gullett (2013) who suggest slightly higher mass balances for $PM_{2.5}$/BC (4-9%). A GWP of 345 for BC is a low estimate (Mythe et al., 2013; Table 8.a.6) as the average across multiple studies and regions could be as high as 830 if including radiation interactions and albedo on a global scale. However, these estimates are fraught with high uncertainties varying frequently by over 50%.

Table 1: GWP cross-walk from PM to BC emissions.

VARIABLE	METRIC	VALUE	SOURCE	COMMENT
BC emission factor (EF)	g/kg fuel	0.59	May et al., 2014; Table 4	Aircraft average 'Montane'
PM_1 EF wildfire (WF)	g/kg fuel	12.1	May et al., 2014; Table 4	Aircraft average 'Montane'
PM_1 EF prescribed burns (PB)	g/kg fuel	26.0	Liu et al., 2017; Table 3	Submicron aerosol, study average
Ratio PB/WF		25%	Estimate	
PM_1/BC mass balance		2.6%	Calculation output	
GWP BC	MT CO_2e/MT BC	345	Mythe et al., 2013; Table 8.a.6	Lowest estimate for 100y time horizon to account for uncertainty
GWP PM2.5	MT CO_2e/MT $PM_{2.5}$	9	Calculation output	

3 SUGGESTED NEXT STEPS

As new data and models becomes available, BrC could be incorporated into the non-CO2 GHG emissions calculations for avoided wildfire emissions. Furthermore, BC emissions could be further improved once $PM_{2.5}$ specific GWPs become available. Since current calculation methods are conservative, both measures would increase baseline wildfire GHG emissions. Consequently, more GHG benefits would be attributed with fuel treatments.

NMVOC and NO_x emissions can be also further refined once more wildfire-specific data and models become available.

4 ACKNOWLEDGEMENTS

Shawn Urbanski from the Forest Service Missoula Fire Sciences Laboratory provided very helpful feedback on some elements of the cross-walk for BC. The authors of this concept note accept full responsibility for its content.

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Attachment 2
Fire Return Interval Evaluation

(Protocol Appendix 1)

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Concept note:

Modern Mean Fire Return Interval (MFRI) mapping for the western US

Project:

Quantifying ecosystem service benefits of reduced occurrence of significant wildfires (2015-2019); Task 3: 'Ensure versatility and robustness in the carbon accounting framework'

Prepared on behalf of SIG by:

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Summary

- Fire probability is a crucial metric when analyzing avoided wildfire emissions from fuel treatments;
- Modern MFRI mapping efforts are difficult to establish and/or exist only for specific regions within the western US;
- Building on previous research, we present a method to calculate absolute fire probability for the western US at a 300 m resolution based on observed recent fire history from 1996-2015 and including anthropogenic factors;
- Regional variances are considered by distinguishing fire history by vegetation type as well as ecological supersection;
- Compared to datasets and methods that do not include most recent fire history, results suggest a regional increase in fire probabilities.

Date:

March 14 2019

1 RATIONALE

Mean fire return intervals (MFRI) express the average time measured in years that pass between wildfires for a given area[1]. While empirical datasets on pre-European settlement MFRI abound; there is a significant departure of historically observed MFRI's over the last decades based on multiple factors such as climate change, fuel composition and recent fire suppression history, and human population density (Mann et al., 2016). MFRIs are a crucial input metric to estimate avoided emissions from wildfires for a given study area. However, such spatial data is not available in a consistent format and methodology for regions as large as the western US (e.g. Mann et al., 2016) and/or does not contain the latest wildfire history (e.g. CAL FIRE, 2016). To create applicable FRI input metrics for case study areas across a large multi-state region in the US, it is crucial to apply i) consistent methodology, at ii) an appropriate resolution which considers iii) latest fire history to provide maps that reflect modern or contemporary fire regimes in contrast to historic/pre-European settlement MFRIs.

In this concept note we present i) a MFRI mapping methodology that covers the entire western US at a 300m resolution and ii) discuss results in the context of quantifying avoided wildfire emissions through the implementation of fuel reduction measures. This method consists of a method that builds on previous relevant studies (most notably Mann et al., 2016; Moritz et al., 2012; Parisien et al., 2012; Saah et al., 2010). As a result, we present absolute fire probabilities by merging contemporary relative fire probabilities provided by Parisien et al. (2012) with recent fire perimeter data from the Monitoring Trends in Burn Severity (MTBS) database for each forest type of the 44 ecological supersections in the western US.

[1] MFRI can also be expressed as the inverse of the mean annual fire probability; i.e. MFRI= 1/mean annual fire probability.

2 MATERIALS AND METHODS

2.1 Data retrieval: recent fire history, ecozones, dominant vegetation, and relative fire probability

We retrieved spatially explicit modern-day fire history data from 1996 to 2015 from the Monitoring Trends in Burn Severity program (MTBS; USGS, 2018). Besides providing fire perimeter data for fires covering more than 1,000 acres, we retrieved information from MTBS on the year of the fire. To provide ecology specific analysis, we obtained spatial data on the 44 Ecological Supersections covering the western US from the CA Air Resources Board (CA ARB, 2015) as well as Existing Vegetation Type (EVT) data from Landfire (2015) at a 30 m resolution. Relative fire probability data, i.e. the probability of one pixel to burn in comparison to other pixels ignoring a temporal scale, was retrieved from a publicly available dataset[2] that built on previous efforts using machine-learning Maxent algorithms and described in papers that look at modern fire history using climate and vegetation type datasets including anthropogenic impacts (Parisien, Parks, Krawchuk, et al., 2011; Parisien, Parks, Miller, et al., 2011; Parisien et al., 2012; Parisien & Moritz, 2009) at a 30 m resolution. However, this dataset does not provide an absolute fire risk in a sense of a fire probability or fire return interval.

2.2 Spatial data processing

To create a consistent raster-based dataset in terms of resolution as well as to keep the overall dataset at a workable size, we created a vector-based ‘fishnet' at a 300 m resolution for the target area. In a second step we applied zonal statistics to both the EVT Landfire data and the Parisien et al. probability data. Since the Landfire is a qualitative dataset, the majority vegetation type for each pixel of the fishnet was determined. The quantitative nature of the Parisian et al. data allowed for the mean probability for each pixel to be determined. The resulting dataset contained unique raster IDs for the entire western US at a 300 m resolution containing the following raster-specific information:

- Relative fire probability; annual burn probability in % (source: Parisien et al., 2012 ‘full model' including anthropogenic impacts);
- Recent fire history; area burnt in m^2 (source: USGS, 2018);
- Forest type; Landfire EVT classification (source: Landfire, 2015);
- Ecological supersection; CA ARB classification (source: CA ARB, 2015).

2.3 Adding raster-specific absolute fire probability to the spatial dataset

We calculated average annual burn probability over the last 20 years for each vegetation type within a given ecological supersection (Equation 1). In a second step, we calculated the mean

[2] Supplementary information to Parisien et al., (2012): http://www.publish.csiro.au/?act=view_file&file_id=WF11044_AC.zip

relative fire probability for each vegetation type within a given ecological supersection (Equation 2). In a last step, we multiplied the raster-specific relative fire probability with the respective vegetation type and ecological supersection specific mean annual fire probability to derive the raster-specific absolute fire probability (Equation 3).

Equation 1: Vegetation type and ecological supersection specific (mean) annual absolute fire probability 1996-2015.

$$Ap_{ESS,EVT,t} = \frac{\sum B_{ESS,EVT,t}}{\sum S_{ESS,EVT}} /t$$

Where:

$Ap_{ESS,EVT,t}$ is the vegetation type specific mean absolute annual fire probability for a given ecological supersection over a given timeline; %

$B_{ESS,EVT,t}$ is the vegetation type specific area that burnt for a given ecological supersection over a given timeline; m^2

$S_{ESS,EVT,t}$ is the total area covered by a specific vegetation type for a given ecological supersection; m^2

t is the timeframe covered by the burn dataset from 1996-2015; 20

Equation 2: Vegetation type and ecological supersection specific (mean) annual relative fire probability.

$$Rp_{ESS,EVT} = \frac{\sum R_{ESS,EVT,i}}{N}$$

Where:

$Rp_{ESS,EVT}$ is the vegetation type specific average mean annual relative fire probability for a given ecological supersection; %

$Rp_{ESS,EVT,i}$ is the vegetation type specific annual relative fire probability for an unique raster pixel within a given ecological supersection; %

N is the total number of raster pixels within a vegetation type and ecological supersection; N

Equation 3: Pixel specific absolute annual fire probability.

$$Ap_{ESS,EVT,i} = \frac{Rp_{ESS,EVT,i}}{Rp_{ESS,EVT}} \times Ap_{ESS,EVT,t}$$

Where:

$Ap_{ESS,EVT,i}$ is the vegetation type specific annual absolute fire probability for an unique raster pixel within a given ecological supersection; %

$Rp_{ESS,EVT,i}$ is the vegetation type specific annual relative fire probability for an unique raster pixel within a given ecological supersection; %

$Rp_{ESS,EVT}$ is the vegetation type specific average mean annual relative fire probability for a given ecological supersection; % (Equation 2)

$Ap_{ESS,EVT,t}$ is the vegetation type specific mean absolute annual fire probability for a given ecological supersection over a given timeline; % (Equation 1)

3 RESULTS AND DISCUSSION

3.1 MFRI mapping results

Results show absolute annual fire probability variation within reasonable limits (e.g. Figure 1). The eastern quarter of the case study area is within the 'Sierra Nevada foothills' ecological supersection while reminder is located in the 'Sierra Nevada' ecological supersection. We normalized color-coding for results across ecological supersections, i.e. an identical absolute fire probability across different ecological supersections would receive the same color. The distinct borderline between these two ecological supersections in Figure 1 suggests that differences across ecological supersections exist, since pixels located in the 'Sierra Nevada foothills' supersection tend to receive lower probabilities than pixels located in the directly adjacent 'Sierra Nevada' ecological supersection. This observation confirms the importance of the distributional aspects of using this dataset. When researching a representative MFRI for a given project area, it is important to use the full width of statistical outputs (mean, median, standard deviations, percentiles) to identify a representative (set of) MFRI(s).

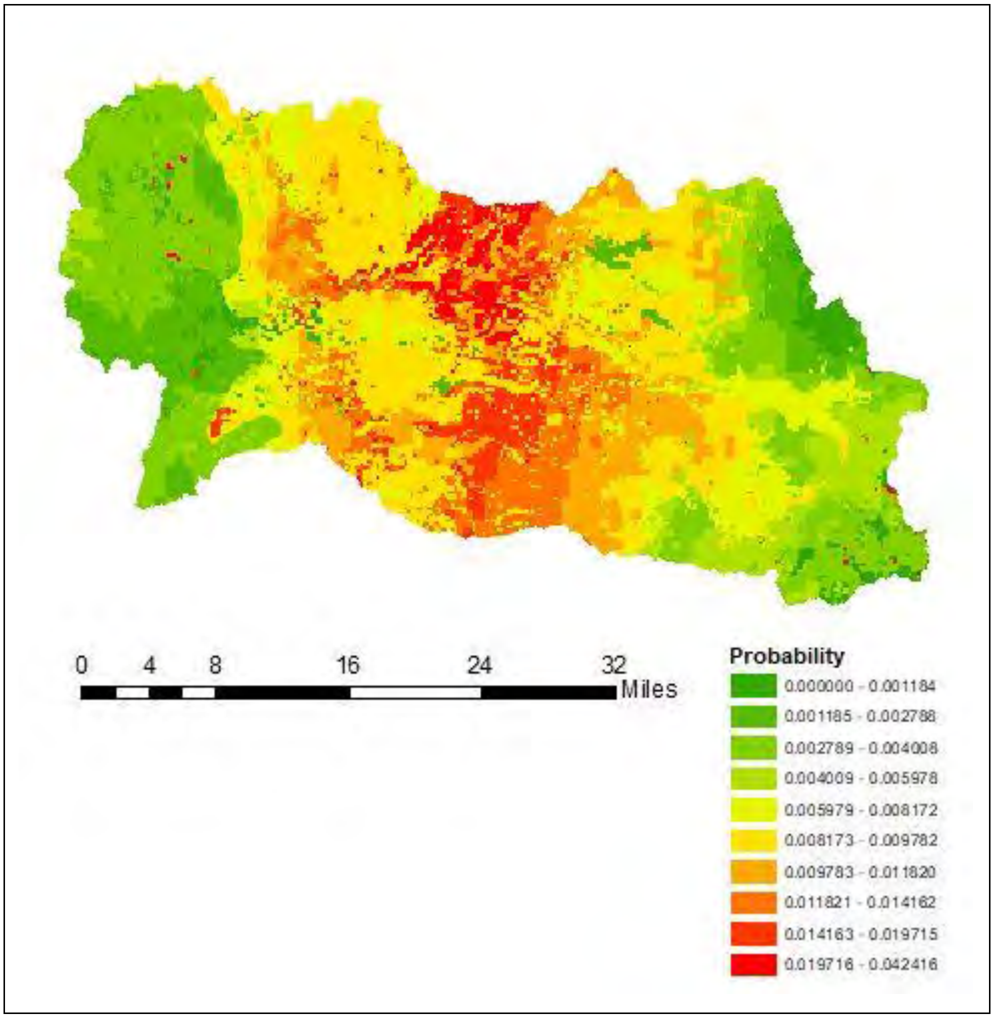

Figure 1: MFRI ‘heatmap’ for a 650k acre case study area in the Eldorado National Forest (Ecological supersection ‘Sierra Nevada’ and ‘Sierra Nevada foothills’) based on 20-year fire history across all relevant ecological supersections. The contrast-rich boundary between the two supersections in the eastern quarter of the case study area is derived from an overall lower fire risk in the Sierra Nevada foothills and underlines the importance of using probability distributions rather than a representative mean fire probability for a case study area.

3.2 Sensitivity analysis – fire history data

Since fire probabilities have been shifting over the last decades, i.e. burnt acreage is increasing, picking an appropriate fire history interval is an important first step for this analysis. We explored the impact of changing the length of the fire history on MFRI (Figure 2) for a 250k acre study area in the ‘Sierra Nevada’ ecological supersection. The distribution of annual fire probabilities within the study area overlapped significantly. While results suggest that annually burnt acreage is increasing in more recent years (the probability distribution is shifting upwards), shortening the fire history period increases uncertainty (the distribution is ‘flattening). However, most importantly, there is no sweeping difference in the distribution of pixel-specific mean annual fire probabilities across different timelines. For instance, the mean annual fire probability when considering only the most recent 15 years (2001-2015) is still within one standard deviation from the mean for a dataset covering fire history over the last 20 years (1996-2015). Therefore, it could be argued that any value within the 15-year mean +/1 standard deviation would be a reasonable representative value for the given study area.

Also, it should be noted that the MTBS database does not include smaller fires that cover less than 1,000 acres. Therefore, results presented in this database can be considered conservative, i.e. potentially underestimating annual fire probabilities.

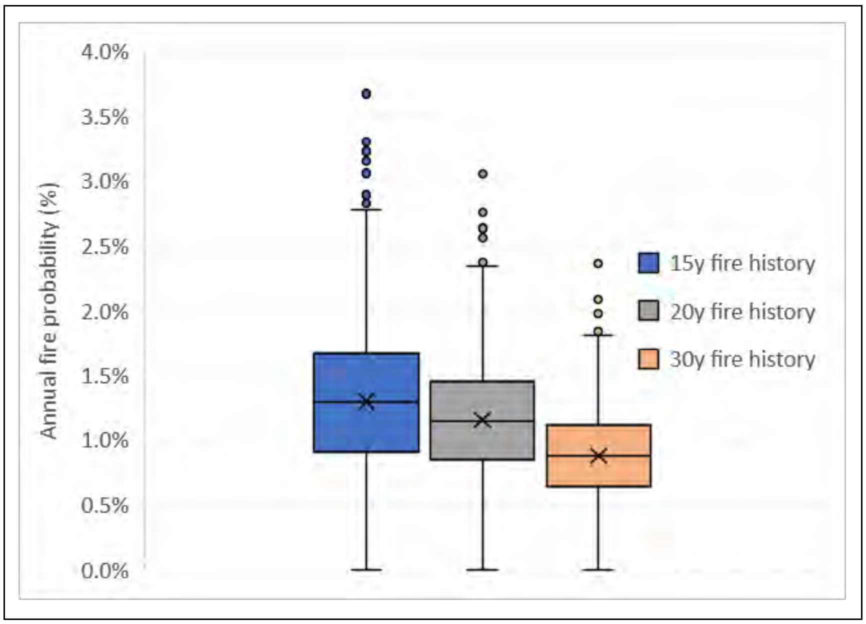

Figure 2: MFRI distribution for a 250k acre case study area in the Eldorado National Forest using different lengths of fire histories in the relevant ecological supersections. This analysis suggests that i) annually burnt acreage is increasing, while at the same time ii) there is no drastic difference in the distribution of pixel-specific mean annual fire probabilities across different timelines. For instance, the mean annual fire probability when considering only the most recent 15 years (2001-2015) is still within one standard deviation from the mean for a dataset covering fire history over the last 20 years (1996-2015).

4 SUGGESTED NEXT STEPS

The approach outlined above can be fine-tuned towards higher spatial resolutions, more recent fire history and scaled across the western US.

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Attachment 4
Delayed Reforestation Evaluation

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(Protocol Appendix 3)

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Concept note:

Quantifying occurrence and carbon emissions from delayed reforestation in Californian forests following high-severity wildfire

Project:

Quantifying ecosystem service benefits of reduced occurrence of significant wildfires (2015-2019); Task 6: 'Avoided wildfires: accounting for ecological co-benefits'

Prepared on behalf of SIG by:

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Summary

- Delayed reforestation following high severity wildfire is occurring across multiple forest types in California at a high rate;
- Delayed reforestation is defined here if no tree-dominated vegetation cover re-establishes at least 20 years post high-severity burns;
- We analyzed FVeg data to identify high severity burns (MTBS class 4) that occurred prior to 1994 and examined what fraction of the acreage was not associated with tree cover by 2015 (FVeg);
- Results are presented by forest type and percentage of acreage affected by delayed reforestation;
- We reviewed literature to identify non-tree vegetation types commonly occurring on sites that experienced high-severity wildfires;
- Carbon stocking estimates for shrubland including potential stocks are provided by ecoregion for the Western US;
- To account for potentially undetected tree carbon in shrublands (due to tree height >1m) at year 20 post high-severity wildfire, we generated tree carbon stocking estimates up to year 40 for the Sierra Nevada range.

Date:

March 14 2019

1 RATIONALE

High severity fires in forests, particularly uncharacteristically severe active and passive crown fires, can cause high levels of tree mortality and soil impacts. High severity fires can result in the delayed regeneration of forest cover and a dominant vegetation of grassland or shrub types over extended periods of time (Collins & Roller, 2013; Coppoletta et al., 2016; Roccaforte et al., 2012; Rother & Veblen, 2016; Tubbesing et al., 2019; van Wagtendonk et al., 2012; Welch et al., 2016). Fuel treatments can reduce the amount of forest that is affected by delayed reforestation compared to the baseline, through moderating fire size and severity.

The goal of the analysis presented here was to provide an implementable procedure to quantify carbon loss due to delayed reforestation in California following high-severity wildfires. The research objectives were to i) quantify the risk of delayed reforestation due to high-severity fire by forest type and ii) quantify the average carbon stocking of non-forest vegetation types following high-severity wildfires.

In the context of a carbon offset protocol, this concept note provides a methodology to quantify carbon emissions from delayed reforestation over a 40-year timeline following high-severity wildfires, i.e. carbon stocks and fluxes for e.g. a forestry project have to be accounted for over 40-year time frame. Permanence is therefore restricted to a 40-year timeframe. Therefore, in the context of delayed reforestation, we equate delayed reforestation with evidence that no forest cover has reestablished after 40 years.

2 METHOD

2.1 Quantifying acreage affected by delayed reforestation using FVeg data

Step 1: Identify pre-1994 forest cover

Figure 1 outlines the three-step process identified to generate occurrence estimates of and carbon stock estimates for shrub-dominated landscapes following high-severity wildfires. For step 1, we used 1977 CALVEG to identify vegetation type classification layers (the best approximation prior to 1984) for pre-1994 forest cover in California. We used CA-GAP data to subtract non-forest tree cover such as urban parks (USGS, 2011).

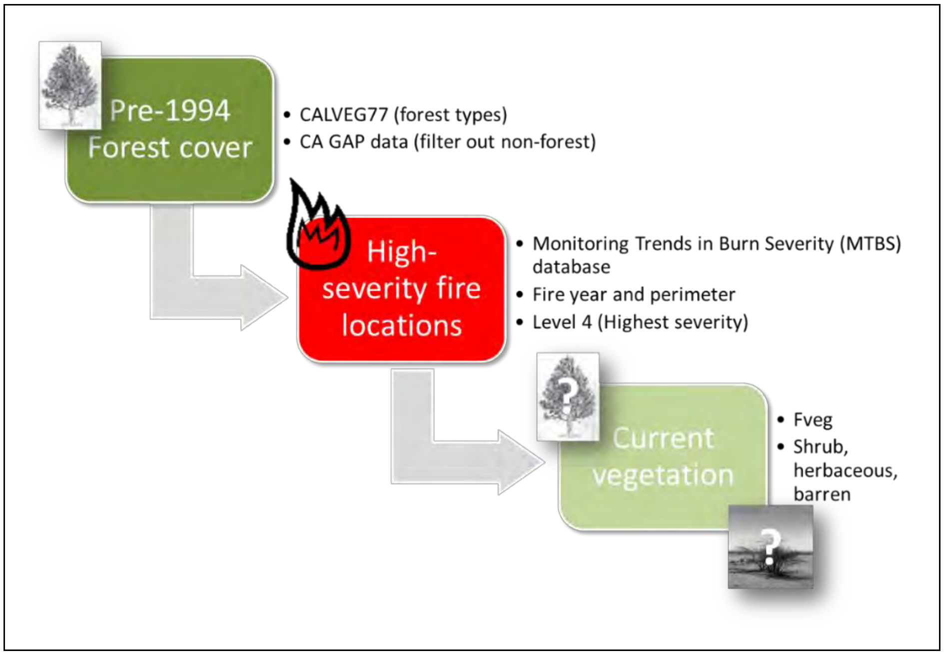

Figure 1: Steps to quantify acreage affected by delayed reforestation following high-severity wildfires.

Step 2: Identify high-severity areas

We used the 'USFS Region 5 Burn Severity Database-1984-present' (USFS, 2017) to identify the area of all wildfires since 1984 that were high severity (Burn Severity 4; i.e. lethal to the tree, Brewer et al. 2005) within California. Areas that experienced less severe fires followed by delayed regeneration (e.g. Batllori *et al.*, 2015; Gonzalez *et al.*, 2015) were therefore excluded resulting in a conservative estimate of delayed reforestation following wildfires.

Step 3: Identify delayed reforestation occurrence using FVeg data

We used 2015 FVeg data (CAL FIRE, 2015) to identify existing vegetation types as of today on the areas that burnt at high severity between 1984 and 1994 (Figure 1). The restriction to wildfires prior to 1995 should allow for a sufficient buffer of 20 years to exclude misclassification of vegetation type (i.e. absence of trees) due to ongoing natural or artificial regeneration. As a proxy for delayed reforestation, we therefore assumed that if no regeneration is detectable at least 20 years after a fire, an enduring delay in reforestation has occurred and the landscape is dominated by shrub or grassland vegetation types at least over the medium term (20-40 years).

FVeg 2015 data provides the data layer Life Form containing the following categories: Barren/Other, Conifer, Hardwood, Herbaceous, Shrub. We excluded acreage classified as Barren/Other from our analysis since lost forest cover could be caused by other drivers than wildfire severity (e.g. land use conversion towards development). Delayed reforestation (DR) as evidenced under the Life Form FVeg 2015 layer would defined as in Equation 1.

Equation 1: Percentage of delayed reforestation by forest type following high-severity wildfire in California using FVeg.

$$DR_{LifeForm} = (Herbaceous + Shrub) / (Conifer + Hardwood + Herbaceous + Shrub)$$

Where:

$DR_{LifeForm}$ Fraction of acreage affected by delayed regeneration following high-severity wildfire; percent of total acreage affected by high-severity wildfire (%)

$Herbaceous$ FVeg Lifeform typology for herbaceous-dominated ecosystems; acre (acre)

$Shrub$ FVeg Lifeform typology for shrub-dominated ecosystems; acre (acre)

$Conifer$ FVeg Lifeform typology for conifer-dominated ecosystems; acre (acre)

$Hardwood$ FVeg Lifeform typology for hardwood-dominated ecosystems; acre (acre).

2.2 Carbon stocking of non-forest vegetation types following high-severity wildfires

Shrub carbon pools

We reviewed the scientific literature on delayed reforestation relevant data for both typical non-forest vegetation types following high-severity wildfires and related carbon stocking in the Western US. A full list of the reviewed literature is attached as Appendix 1.

Tree carbon pools

Since we were only able to confirm shrub-dominated landscapes up to 20 years following a high-severity wildfire, there is a possibility that natural tree regeneration was not detected due to similar shrub and tree heights of around 1m at the end of a 20-year period. Since permanency in ACR is defined over a 40-year time horizon, it would be important to also consider potential average tree carbon stocks from year 20 to year 40 due to undetected tree growth. We used the Western FVS Variant to estimate maximum total stand carbon stock for a variety of stand types 20 years after establishment.

Soil carbon pools

Besides the life and dead carbon pool, the soil carbon pool can be significant but is relatively unaffected by fuel treatments and is excluded (Boerner et al., 2009; Kashian et al., 2006; Woodbury et al., 2007). This conservatively underestimates fuel treatment project benefits as reducing fire severity increases carbon soil through reducing erosion, reducing soil carbon vaporization, and decreasing soil respiration. For consistency, shrub vegetation-specific soil carbon estimates were therefore omitted since they are not accounted for under ACR protocol requirements. Screening the literature for a further break-down of carbon stocking by genera provided no further options to refine results.

Estimating total average carbon stocks following high-severity wildfire on shrub dominated landscapes

The maximum total stand carbon for a shrub dominated stand with tree saplings (undetected at year 20 due to limited height) between year 0 and year 40 following a high-severity wildfire would be the average total stand carbon over those 40 years and can be calculated using Equation 2.

Equation 2: Total carbon stock of shrubland including potential tree regeneration.

$$SC_{total} = (SC * 40 + TC * 20) / 40$$

Where:

SC_{total} Average total stand carbon for a shrub dominated landscape with tree regeneration between year 0 and 40 following high severity wildfire; metric tonnes (MT) CO_2 equivalent (CO_2/acre)

SC Total stand carbon of shrub dominated landscape (Table 2); metric tonnes (MT) CO_2 equivalent (CO_2/acre)

TC Total stand carbon of tree dominated landscape starting with 1 m saplings year 20-40 (Table 3); metric tonnes (MT) CO_2 equivalent (CO_2/acre).

3 RESULTS AND DISCUSSION

3.1 Acreage affected by delayed reforestation

Results suggest that delayed reforestation, i.e. the absence of a tree-dominated vegetation cover after 20 or more years after a high-severity wildfire, is pervasive across most forest vegetation types in California (Table 1). The dominant forest types in the Sierra Nevada range such as Sierran Mixed Conifer, showed delayed reforestation on 43% of the high severity burns. Of the 202,127 acres forested at the time of a wildfire and experiencing a high-severity burn, 55% experienced delayed reforestation. While results for less abundant forest types might be affected by higher uncertainties (e.g. lodgepole pine on 124 acres), results for other prominent forest types such as the Sierran Mixed Conifer, representing 20% of total acreage analyzed, can be considered robust and show a high risk of delayed reforestation following high-severity wildfires.

Table 1: Delayed reforestation as evidenced by FVeg 2015 Life Form. Forest types ordered by acreage affected by MTBS burn severity 4 between 1984 and 1994. A high percentage indicates a high fraction of the high-severity burn is not under tree cover as of 2015.

Forest type (CALVEG77 WHRNAME)	Acres burnt at high severity	Delayed reforestation (% of acreage)
Sierran Mixed Conifer	40,706	43%
Chamise-Redshank Chaparral	25,404	87%
Montane Hardwood-Conifer	15,385	45%
Douglas-Fir	15,028	34%
Coastal Oak Woodland	14,559	61%
Montane Hardwood	14,073	44%
Jeffrey Pine	13,047	78%
Klamath Mixed Conifer	12,846	52%
Ponderosa Pine	11,579	50%
Mixed Chaparral	10,075	62%
Blue Oak Woodland	8,710	50%
Eastside Pine	8,475	9%
Red Fir	4,562	79%
Pinyon-Juniper	2,057	86%
Montane Chaparral	1,846	66%
White Fir	1,512	82%
Valley Oak Woodland	1,395	77%
Juniper	648	94%
Lodgepole Pine	124	21%
Subalpine Conifer	55	5%
Redwood	43	18%
Grand Total	202,127	55%

Results could be considered to be conservative. While our methodology identified 55% of all high-severity burns being affected by delayed reforestation, Welch et al. (Welch et al., 2016) suggests a similar percentage for all burnt acreage including low- and medium-severity wildfires by stating that “In 54 percent of the areas burned this century, the research suggests too few trees grew back to ensure a full forest recovery.” Meanwhile, Shive et al. ((Shive et al., 2018) stress once more the causal relationship between high-severity burns and delayed reforestation with their research suggesting that “Annual precipitation and continuous burn severity (IA) had the largest effect on the odds of regeneration, […]”.

Our conceptual approach to identifying the risk of delayed reforestation following high-severity fires is further corroborated by California-specific Forest Service data on the ‘Threat of Deforested conditions in CA National Forests’ (USFS, 2015). This effort identifies high-severity burn patches and provides replanting recommendations based on Landfire-derived tree survival rates. The resulting maps and datasets suggest that a large fraction of stands that experienced high-severity burns should be actively replanted to ensure continuous forest cover. However, only a fraction of this acreage in need of reforestation is replanted annually. For instance, only 6% of the acreage in need of reforestation in 2015 was replanted. The corresponding average from 1986-2015 is 20%. The ‘buildup’ of the reforestation need-accomplishment gap 1986-2015 results in substantial lost carbon sequestration capacity which this concept note attempts to quantify.

3.2 Post high-severity wildfire shrub vegetation types and carbon stocking

Shrub carbon pools

Most of the identified literature focused on tree reestablishment following high-severity wildfire. Since this element of delayed reforestation was covered with the remote sensing and GIS based analysis presented above, it had less relevance for this effort. In general, the publications had only a secondary focus on the type of non-tree vegetation types. However, all studies that identified non-tree vegetation types following high-severity wildfires were consistent in reporting i) shrub rather than grass dominated vegetation types and ii) identifying Ceanothus and Arctostaphylos genera as the most common shrub types due to their fire-resilient seed banks (Collins & Roller, 2013; Goforth & Minnich, 2008; Nagel & Taylor, 2005; Zald et al., 2008). There is very limited literature Concerning carbon stocking of shrub vegetation. Zhu & Reed (2012) provided life and dead carbon stocking estimates for shrub vegetation types in the Western US as a whole as well as by ecoregion (Table 2). Battles et al. (2014) provide estimates for shrubland averaging over 1m in height in California of 13.2 Mg CO_2e/acre for above and belowground life carbon pools. In the context of a carbon estimate over a 40-year timeframe, assuming an average shrub height over 1m for shrublands of 0-40 years in age was deemed to be reasonable. Since the dead carbon pool is not quantified, this is considered to be a conservative estimate. Furthermore, the numbers provided in Table 2 assume a fully established shrubland. However, post high-severity fire shrubland establishment will accumulate carbon over time, maturing at a later stage. Accounting for shrubland carbon by using the inputs from Table 2, i.e. using a high shrubland carbon estimate instead of an average carbon estimate reflecting carbon accumulation from shrubland initiation to maturation over a 40-year timeframe, is therefore adding to a conservative carbon emission estimate of high-severity wildfires.

Table 2: Average life and dead carbon stocking (above- and belowground) of shrublands/grasslands by ecoregion in the Western US (Zhu & Reed, 2012, p. 115) based on minimum and maximum projections. Soil carbon estimates are omitted since they are not accounted for under ACR protocol requirements.

Ecoregion	Area (acres)	Live biomass (Mg CO_2e/acre)	Dead biomass (Mg CO_2e/acre)	Live & dead biomass (Mg CO_2e/acre)
Western Cordillera	678,368	5.9	7.5	13.4
Marine West Coast Forest	10,737	0.2	0.2	0.4
Cold Deserts	1,962,647	15.6	14.5	30.1
Warm Deserts	981,358	7.6	5.7	13.3
Mediterranean California	161,736	1.8	2.2	4.0
Western US	3,794,846	5.6	5.4	11.0

Tree carbon pools

In the context of a typical Eldorado area Sierra mixed conifer stand starting with 1m tall saplings and assuming at a site index of 100, the Western FVS Variant yields a maximum total stand carbon stock (above and belowground) of 36.6 Mg CO_2e/acre (black oak at 250 trees per acre) after 20 years (Table 3).

Table 3: Western FVS variant generated total stand carbon stocking estimates (CO_2e/acre) for a typical range of species and tree densities at year 20 following a sapling stage.

Saplings per acre	Black Oak	Incense Cedar	Ponderosa Pine	White Fir
10	30.9	17.4	22.6	3.1
50	26.7	30.1	24.5	28.2
100	33.3	35.3	32.1	34.4
150	7.0	11.2	4.9	9.1
200	21.7	25.4	19.6	23.7
250	36.3	27.1	31.6	13.4

Total average carbon stocks following high-severity wildfire on shrub dominated landscapes

Using input data from Table 2and Table 3 in Equation 2, the maximum average total carbon stock on shrubland post high-severity wildfire over 40 years is SC_{total}= (13.4 MT CO_2e/acre *40+36.6 MT CO_2e/acre *20) / 40 = 24.8 MT CO_2e/acre.

4 NEXT STEPS

The methodology described and tested above is promising in quantifying i) the occurrence of delayed reforestation and ii) stand carbon stocks post high-severity wildfires. If applied to areas outside of California, it would be important to use pre- and post-wildfire landcover datasets that are based on similar landcover type detection methodologies. For instance, comparing pre-wildfire CALVEG77 data with post-wildfire Landfire data instead of FVeg data entails the risk of classification mismatches. To further corroborate and refine results, we suggest the following steps:

- Individual 2015 FVeg inputs have a variety of vintage years. The current dataset could be further filtered for high-severity wildfire affected areas that star a FVeg data entry with a vintage year less than 20 years post-wildfire occurrence;
- Spot checking spatial datasets that suggest post high-severity wildfire delayed reforestation could further rule out misinterpretations;
- Extend this California-focused analysis and provide datasets by ecological supersection covering the entire western US.

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APPENDIX 1: FULL LIST OF REVIEWED LITERATURE ON DELAYED REFORESTATION IN THE WESTERN US.

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ATTACHMENT 1

Avoided Wildfire Emissions Methodology Submission

Carbon Offset Market Study for Avoided Wildfire Emissions Projects in California

MARKET ANALYSIS

1.1 Resource assessment

There is a significant and urgent need for forest fuel treatments (hazardous fuels reduction) in California and other states in the western United States. Almost 20 million acres of California forest land are at extreme risk for catastrophic wildfire and will benefit from fuels treatments, as shown in Table 1 below. This is the result of decades of fire suppression, timber management, and grazing policy. Much of the at-risk forest land is Sierra Nevada conifers where less than 20% of the critically needed fuel treatments are getting accomplished. There is a need to increase fuel treatment by approximately 450,000 acres per year, from the current baseline business as usual of 130,000 acres/year.

Table 1. Forest fuel treatments in California (California Air Resources Board 2018, Forest Climate Action Team 2018, Christofk 2013).

Land Owner	Forest at Extreme Fire Risk (acres)	Fuel Treatment (acres/year)	
		Current Baseline Business as Usual	Desired
Public			
USFS	9,000,000	100,000	500,000
BLM	2,000,000	10,000	20,000
Private	7,000,000	20,000	60,000
Total	18,000,000	130,000	580,000

1.2 Economics

Fuel treatments are not getting done in many situations because the cost to conduct the fuel treatment operations is higher than potential project revenues. Fuel treatment costs can be up to $3,000/acre – where costs are particularly high on lands where slopes are steep and contain riparian and other ecologically sensitive zones. Potential project revenues are constrained by limitations on harvested tree diameter size and wood products operations proximity. Funding fuels treatments is very difficult (usually requiring subsidies), and funds to support the work are critically needed.

We very conservatively estimate that fuel treatment greenhouse gas (GHG) offset projects could generate at least 225,000 metric tonnes of CO_2 equivalent (MT CO_2e) per year at an approximate market value of $2,250,000/year in California alone, based on support of 10% of the desired fuel treatment increases (45,000 acres), a net GHG project benefit of 5 MT CO_2e/acre, and an offset credit value of $10/MT CO_2e.

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ATTACHMENT 2

Avoided Wildfire Emissions Methodology Submission

Sample Project

Avoided wildfire related greenhouse gas (GHG) emissions from implementing forest fuel treatments in the Sierra Nevada / Eldorado region

Sample project submitted to:

American Carbon Registry (ACR) as part of the first step towards a carbon offset protocol review

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Date:

October 16, 2018

Contents

1 PROJECT SUMMARY

1.1 Scope

The Avoided Wildfire Emissions Methodology (AWE Methodology) quantifies greenhouse gas (GHG) emissions from implementing fuel treatments in forests that are at risk for wildfire from fire-suppression and past harvesting history. The methodology is applicable in the following states (referred to in the following as "the reference states"): California and Colorado. Fuel treatments qualifying for this protocol include fuel reduction thinning and prescribed fire. Fuel treatments modify fire behavior such that severity[1] and individual fire size are reduced compared to the baseline of no fuel treatment activity (Fulé et al., 2003; Liang et al., 2018; Moghaddas et al., 2010; Moghaddas & Craggs, 2007; Peterson et al., 2005; Safford et al., 2009, 2009; Stephens et al., 2012; Stephens, Moghaddas, Edminster, et al., 2009; Stephens, Moghaddas, Hartsough, et al., 2009). While identifying climate benefits of fuel treatments can be challenging (Campbell et al., 2012; Mitchell et al., 2009), this methodology seeks to identify ecological conditions and fuel treatment approaches that verifiably provide climate benefits.

Fuel treatments provide GHG emissions reductions through considering (see also Box 1):

- Forest carbon. Increase in stored carbon on the designated landscape (project area) over time, particularly in larger, more fire-resistant trees (Hurteau & North, 2010; Stephens, Moghaddas, Hartsough, et al., 2009). This results from reducing individual wildfire size and severity on both the directly treated areas as well as untreated areas through fuel limitation (Collins et al., 2008). Treating even a small portion of the landscape can result in a decrease in probability of areas outside those treated areas being burned severely, referred to as the "treatment shadow effect" (Finney et al., 2007; Moghaddas et al., 2010). The thinned forest may also grow at an enhanced rate compared with the untreated forest due to a reduction in competition for water, nutrients, and light.
- Wood products and renewable energy. Utilization of fuel treatment byproducts as: (1) long-lived wood products that sequester carbon and displace fossil fuel intensive alternatives to wood products, such as concrete and steel[2]; and (2) renewable energy[3] production that displaces fossil fuel energy alternatives (Buchholz et al., 2016).
- Fossil fuel emissions required for harvesting and processing of wood. This also requires accounting for fossil fuel emissions associated with harvest and processing of wood products.

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[1] While recognizing that fire *intensity* (a physical parameter of the fire) and fire *severity* (describing the ecological effect of that fire) are different concepts, we generally use *severity* throughout to avoid confusion because in many forests the two concepts are closely related (e.g., a high intensity fire will result in high severity effects).

[2] Climate benefits from wood product substitution are included as an optional part of this protocol as representative and reliable data are obtained.

[3] Offsets derived from the electricity and fossil fuel sector are covered by other offset markets than the forestry sector. The *Biomass Waste for Energy Greenhouse Gas Offset Protocol* (Springsteen et al., 2011), approved in the CAPCOA GHG Registry, can be used to determine the GHG benefits of bioenergy from fuel treatment byproducts.

- Preservation of forest. High intensity fires in forests, particularly uncharacteristically severe active and passive crown fires, can cause high levels of tree mortality and soil impacts that result in delayed reforestation and at least a temporary vegetation type change from forest to grassland or shrub types lasting from several decades to permanent change (Collins & Roller, 2013; Coppoletta et al., 2016; Roccaforte et al., 2012; Rother & Veblen, 2016; van Wagtendonk et al., 2012; Welch et al., 2016). Fuel treatments can reduce the amount of forest that is redirected compared to the baseline, through moderating fire size and severity. This protocol provides a methodology to quantify delayed reforestation related GHG emissions.

Applicability of this methodology is restricted to forest ecosystems in the reference states where fire is a key ecological process (Safford & Van de Water, 2014) and therefore depends on the site-specific landscape and ecosystem context, particularly the fire return interval.

The methodology uses the latest science in wildfire dynamics. It employs probability-based wildfire models to calculate GHG emissions in the absence (baseline scenario) and presence (project scenario) of fuel treatments that are additional to current practice (Box 2).

Using field data, modeling, and probabilistic functions, the ERT quantification approach is fundamentally different from improved forest management (IFM) methodologies where landscape carbon stock changes are solely identified using measured data. Emission credits are calculated prior to the project start ("ex-ante") and following the fuel treatment implementation. Credits are distributed in five-year intervals over the crediting period of the project. Credits are refined and verified based on subsequent project area measurement assessments to confirm stand growth response to initial fuel treatments.

Uncertainties about emissions reductions are captured by carbon pool-specific uncertainty deductions (section 3.2), an appropriate buffer pool contribution (section 3.3), and conservative emission savings estimates.

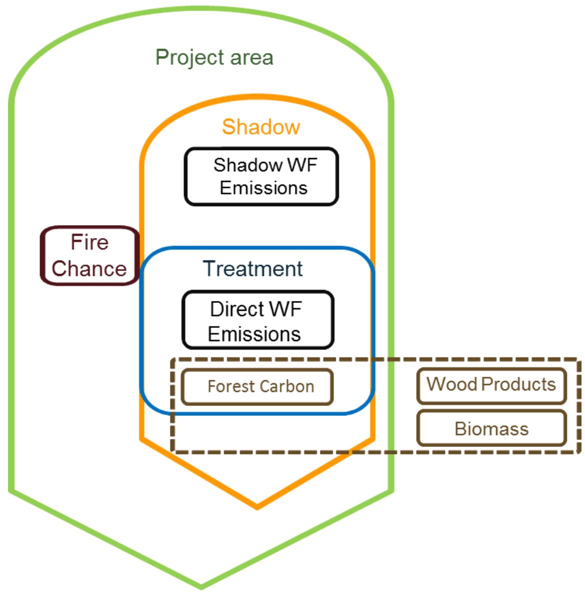
The methodology is applicable to private, public, or tribal forestland eligible for management that are at risk for wildfire and that exhibit no recent history of fuel treatments or a significant change in fuel treatment activity between the baseline and project scenario.

Leakage effects through activity shifting or market effects are not considered in the protocol because the fuel treatment project activity will include greater removal of forest products than the baseline (Table 2), based on application of the conservativeness principle.

Many elements of this methodology have been adapted from the current ACR IFM carbon offset protocol (ACR, 2018); most notably eligibility requirements, validation, verification, monitoring, and reporting rules, as well as reversal risk assessments and buffer pool contributions.

Box 1: Avoided wildfire emissions accounting steps.

To quantify fuel treatment impacts on reducing emissions from wildfires, all relevant carbon pools -- forest carbon, wood products, and biomass -- are accounted for across the entire project area. This requires an ecologically relevant integration of wildfire probability (fire chance), wildfire behavior, and forest carbon accounting. Treatments to reduce high severity fires will impact fire behavior within their direct footprint, and indirectly beyond their direct footprint ("treatment shadow effect"). Emission savings from delayed reforestation are also considered in this methodology.



1.2 Methodology summary

The AWE methodology quantifies the GHG benefits from fuel treatments (fuel reduction thinning, prescribed fire) that restore forest to desired ecological conditions and fire regimes (North 2012). Fuel treatments reduce wildfire size and severity in forests that are at risk for wildfire from a fire-suppression and harvesting history.

The methodology involves the following steps, for both the baseline and project scenarios, as shown in Box 1 and Box 2:

1. Project area. Define the geographic boundary of the project. Quantify the forest condition - including tree stands, tree list, species, height, and diameter, and surface fuels - in the project area existing at the start of the project through site characterization measurements.
2. Management scenario development. Define the details of the fuel treatment - including fuel reduction harvesting levels, procedures, location, timing, and fate of residuals.
3. Forest carbon. Project the growth of the forested land over the project term (40 years) at five-year intervals.
4. Forest removals life cycle assessment. Determine sequestration in wood products, and avoided/displaced fossil fuels from wood products and bioenergy.[2,3]
5. Fire ignition probability. Determine the project area's expected fire return interval. Use the fire return interval to determine statistical fire probability over the project term.
6. Weather data. Define weather conditions under which to simulate fire over the project term.
7. Wildfire emissions. Determine emissions from wildfire that burns the entire project area, at five-year intervals over the project term. Amortize the emissions by the statistical fire probability (fire return interval).

8. Delayed reforestation. Quantify the area and emissions associated with project land temporarily or permanently over the project term converted from forestland to grass or shrubland following high severity fire.
9. Aggregated emissions accounting. Determine the difference between the baseline and project scenario GHG emissions, for each five-year interval period over the project term.

These assessment steps are followed by two post-implementation steps:

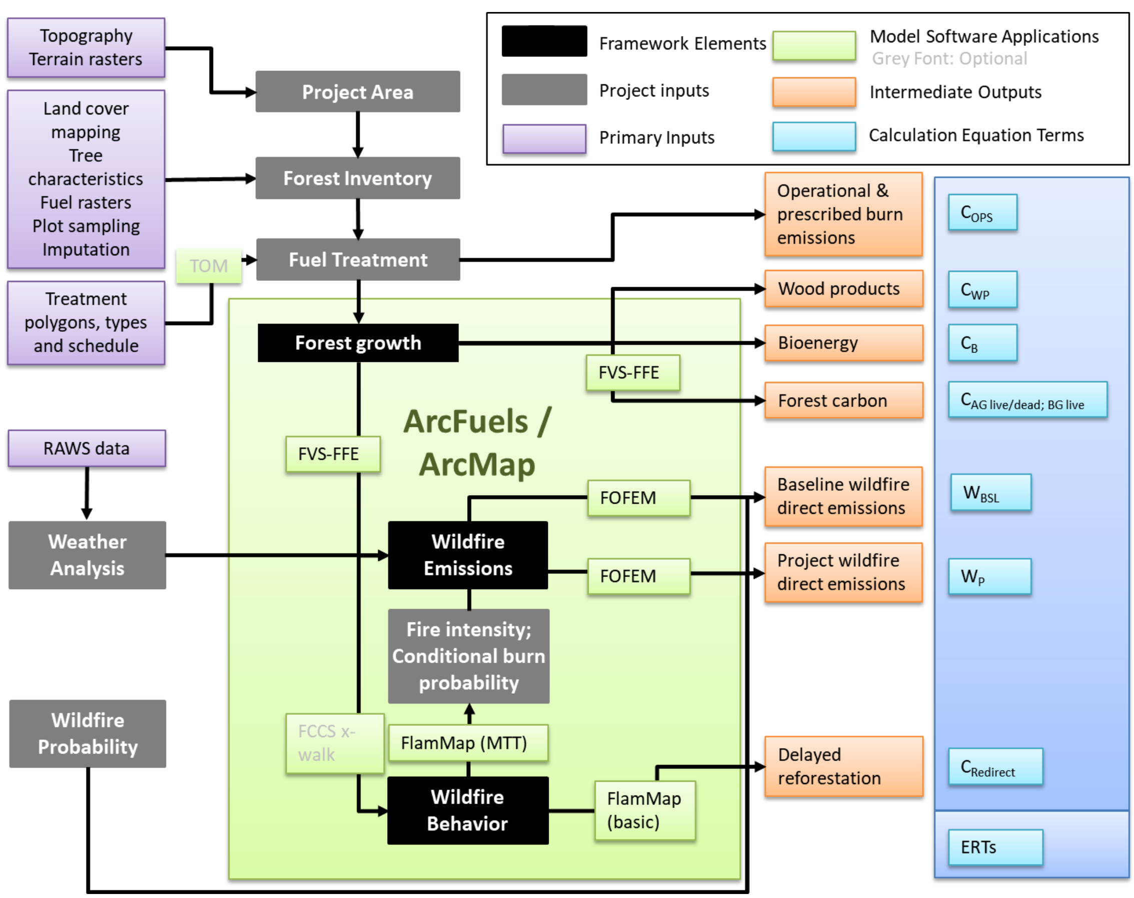
10. Fuel treatment project measurements. Over the project term, measure and document all applicable operational parameters, including fossil fuel engine usage, tree and brush removal rates, wood products generation, bioenergy [3], prescribed fire, and open pile burning. Use these to refine/adjust the aggregate emissions.
11. Project site inventory. At ten-year intervals, perform site measurements to characterize on-the-ground carbon. Use these to refine/adjust the aggregate emissions.

Leakage, both through activity shifting and market effects, will not occur because harvesting under the project scenario is greater than that in the baseline scenario.

Box 2. Modeling GHG emissions from fuel treatment projects.

Using coupled vegetation and wildfire models, the methodology calculates GHG emissions for wildfire occurrences over the project term timeframe for both the baseline and fuel treatment project scenarios:

- **Inventory and growth and yield modeling.** Using inventory and treatment data, vegetation models, such as the Forest Vegetation Simulator (FVS), are used to project carbon stock changes.
- **Fire probability.** Fire probability is based on determination of the fire return interval.
- **Wildfire emissions.** Inventory and growth data are used with fuel consumption models, such as First Order Fire Effects Model (FOFEM), to project emissions from wildfire burning through the entire project area.
- **Overall averaged wildfire emissions.** Wildfire emissions are amortized by the fire probability to obtain emissions during the project term.
- **Wood products and biomass life cycle.** Wood product, fossil fuel, and bioenergy[3] emissions are accounted for.
- **Credit issuance.** Offsets credits are determined based on initial inventory data, model projections, fuel treatment implementation, and ongoing periodic on-the-ground measurements. Issued credits are independent of actual wildfire activity on the project area during the project term.



1.3 Sample project summary

The sample project covers about 215,986 forested acres in the north-central Sierra Nevada mountains (Figure 1). It consists of the central areas of the South Fork American River Hydrologic Area and the North Fork Cosumnes Hydrologic Subarea. Both watersheds consist of about 650,000 forested acres, with over one third burnt over the last 100 years. This region is characterized by high productivity, a watershed at high risk for wildfire, relatively short fire return intervals, and a mix of industrial timberland (Figure 1a; mostly Sierra Pacific Industries), non-industrial private timberland, and public forests (mostly the Eldorado National Forest).

Besides the availability of on-the-ground inventory data for key factors when assessing avoided wildfire emissions, this project area was chosen to provide a challenging case study area for an avoided wildfire emissions project in several respects: a high crown-fire risk (Figure 1b); the ownership mix challenges; the type (mechanical treatments vs. prescribed burns) and the placement (only in the national forest) of fuel treatments; abundant wildlife habitat restrictions (spotted owl); and a topography that limits options to implement mechanical fuel treatments. Therefore, the project's net GHG benefits presented here are likely conservative. Projects located in areas where, for instance, large-scale prescribed burns can be implemented regularly (e.g. Liang et al., 2018) will yield substantially larger GHG emission benefits.

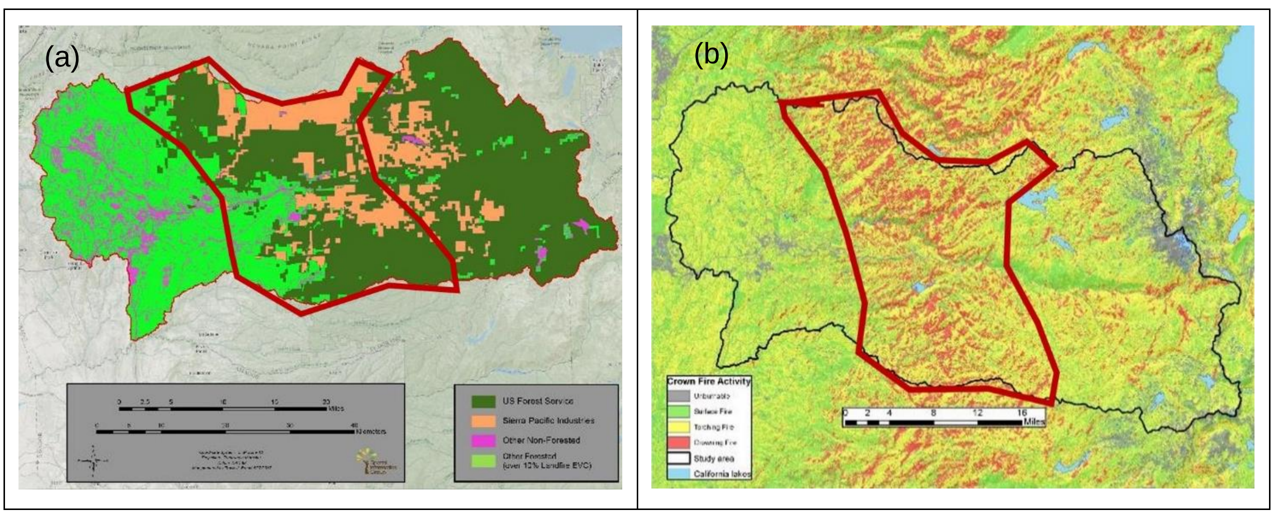


Figure 1: Sample project area (red boundary) and ownership types (a) and potential crown fire activity (b) at a 95th percentile weather condition (pre-2014 King fire forest inventory data).

The sample project site has a Mediterranean climate, receiving precipitation averaging about 1,200 mm/year over the period of record (1990–2008), predominantly in the form of snow. Vegetation is typical of west-slope Sierra Nevada forests, composed primarily of mixed conifer forest dominated by white fir (Abies concolor (Gord. & Glend.) Lindl. ex Hildebr. var. lowiana (Gord.) Lemmon), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii), and incense-cedar (Calocedrus decurrens (Torr.) Florin) with sugar pine (Pinus lambertiana Dougl.), and ponderosa pine (Pinus ponderosa var. ponderosa Dougl.). California black oak (Quercus kelloggii Newb.) appears as a co-dominant at variable densities throughout, with stands of montane chaparral interspersed throughout the area as well. Since Euro-American settlement, the sample project area has been influenced by a range of activities, including railroad logging in the early 20th century (Beesley, 1996), changing climates (Miller et al., 2009), intensive forest management through the 20th century (Beesley, 1996), and fire exclusion ((McKelvey et al., 1996), similar to much of the west-slope of the Sierra Nevada. Studies of similar forest types in nearby areas suggest pre-historic fire return intervals of 5-15 years (Stephens et al., 2004).

This sample project demonstrates the technical and financial feasibility of avoided wildfire related GHG emissions through the implementation of fuel treatments in the project area. The basic difference in the baseline and project scenario pertains to the implementation of additional fuel treatments in the Eldorado National Forest sections of the project area. All other forest ownership types (industrial and non-industrial private timberlands) do not receive alternative treatments but benefit from adjacent treatments through treatment shadow effects (Box 1). While industrial timberland in the region is already managed for a reduction in wildfire risk, non-industrial timberland is considered unmanaged in both the baseline and project scenario due to the highly parcellated ownership structure – resulting in significant fuel treatment implementation barriers. To validate treatment effects, we used pre-summer 2014 forest inventory data, therefore predating the 2014 King fire that affected a large section in the northern quadrant of the project area. Project scenario treatments in the Eldorado National Forest were characterized by:

- All treatments (baseline and project) would exclude treatments on slopes >40%;
- Doubling treatment acreage on National Forest land from currently 20% to 40%. The currently treated 20% of National Forest land was modeled based on current treatment practice:
  - 90% of brush removed (mastication) with leave pockets left in the case of early thinnings and wildlife areas 90% of brush removed;
  - Thin from below <30" Diameter at Breast Height (DBH);
  - Snags >15" and hardwoods >4" are not removed;
  - 80% of 4-10" trees removed;
  - Target 100-140 trees per acre, maintain canopy closure of at least 40%;
  - Follow-up prescribed burn immediately after treatment. Repeat prescribed burn in 10 years, repeat mechanical treatment in 20 years.
- Focusing treatments on stands with high carbon stocks including stands that are categorized as Home Range Core Area (HRCA) for spotted owl but avoiding Protected Activity Centers (PAC);
- For the project treatment design, we used a Stand Density Index (SDI) target of 200. Using an SDI instead of a tree density, basal area, or diameter on breast height (DBH) limit allows for a more stand-specific treatment design. Using SDI as a metric to measure a stand's capacity to reduce fire severity is based on evidence that SDI based treatments reduce stand susceptibility to stand-replacing wildfire and beetle kill (Oester et al., 2005) events as well as drought (Landram, 2004). The treatment type and schedule was as follows:
  - 90% of brush removed (mastication) with leave pockets left in the case of early thinnings and wildlife areas (unchanged from current Forest Service Practice);

- Target an average residual Stand Density Index (SDI) of 200 (no longer specifying a target residual trees per acre) with 100% efficiency using a thin from below of live softwoods within the 4-30” DBH range;
- Follow-up prescribed burn immediately after treatment. Repeat prescribed burn in 10 years, repeat mechanical treatment in 20 years.

2 ELIGIBILITY CHECKLIST

To qualify as a legitimate offset project, the following conditions must be met:

1. The U.S. Forest Service Forest Inventory & Analysis (FIA) Program definition must be used to demonstrate the project area meets the definition of forestland conditions. Forest land is defined as land at least 10 percent stocked by trees of any size, or land formerly having such tree cover, and not currently developed for non-forest uses.
2. This methodology applies to privately owned and public (state and federal) timberlands in the reference states able to document: 1) clear land title or timber rights, and 2) offsets title.
3. The methodology applies to lands eligible for commercial timber harvesting, non-commercial harvesting, and/or prescribed fire, held by entities owning or controlling management rights across the project area. Projects must also meet all other requirements of the governing program (e.g. ACR) such as sustainable harvesting and natural forest management practices.
4. Size, location, and geography correspond to the definition of a coherent project area that allows the ecologically relevant integration of wildfire probability, wildfire behavior, and forest carbon accounting. Participating ownership groups within the project area need to jointly apply and adhere to project agreements. Where exclusion parcels within the project area exist, they must be spatially identified.
5. The fuel treatments that are part of the project must exceed the pace or scale, or both, of previously planned or implemented fuel treatment practices.
6. Documentation must show that potential revenue from a planned forest management project is not sufficient to cover the cost of fuel treatment necessary to adequately reduce wildfire hazard.
7. The average forest carbon stocking at the start the project must be documented to exceed the regional average using site-specific FIA Assessment Area Data (CAR, 2010) or the historic range of natural variability for the project area forest cover type -- considering structural characteristics that include high surface and ladder fuels, size distribution skewed towards many small diameter trees, and contemporary fire regimes outside of the pre-suppression range of natural variability.
8. Evidence must be provided on scientifically justified contemporary fire return intervals.
9. Use of non-native species is prohibited where adequately stocked native stands were converted for forestry or other land uses after 1997.
10. Draining or flooding of wetlands is prohibited.

The sample project case study meets all of these conditions because: (1) all of the project area is forest; (2) the forest is overstocked with hazardous fuel levels; (3) the project fuel treatments are not economically feasible and are at a scale and scope that is beyond current baseline fuel treatment activities of the land owners; and (4) land ownership is well established and distinguished.

3 ERTS QUANTIFICATION

3.1 ERTs contributions by accounting element

3.1.1 Accounting procedures

Wildfire emissions on treated stands

Wildfire emissions are determined through:

- Simulating wildfire behavior, using a model such as Randig/FlamMap (Finney et al., 2007). Fire behavior models require data on weather, topography, and fuel loads (including elevation, slope, aspect, surface fuel model (FM), canopy cover (CC), canopy height (CH), canopy base height (CBH), and canopy bulk density (CBD)), across the project area landscape.
- Outputs from the wildfire behavior modeling are used by a wildfire emissions model, such as the First Order Fire Effect Model (FOFEM) (Lutes, 2016).

The multi-step modeling process involves the following:

Step 1. Define the project area topography, including elevation, slope, and aspect rasters.

Step 2. Define initial stand-level fuel rasters, using a framework such as ArcFuels (Vaillant et al. 2013). ArcFuels is an extension for ArcGIS that facilitates spatial data processing for a number of fire models. This will likely require manually updating the initial stand-level FM, CC, CH, CBH, and CBD rasters produced by ArcFuels to reflect recent disturbances and using local expert knowledge.

Step 3. Create a stand polygon shapefile for ArcFuels. ArcFuels requires a GIS shapefile to associate each unique forest stand with a specific location within the project area. This allows stand-level forest dynamics and wildfire emissions to be modeled aspatially and then integrated later with spatial fire behavior modeling. The specific steps will depend on local data sources.

Step 4. Use the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS), or an acceptable alternative, at each five-year timestep, to simulate forest dynamics, timber harvest, and track carbon stocks, and to provide inputs for wildfire behavior and emissions models (such as FlamMap and FOFEM).

a) FFE-FVS can be inadequate in how it assigns fire behavior fuel models to stands (Collins et al., 2013). A subset of fire behavior fuel models can be used from Fried et al. (2016, p. 38) if the outputs from FFE-FVS are not acceptable. Alternatively, a statistical model can be used to assign fuel models based on stand structure, such as that from Collins et al. (2013).
b) Certain FVS variants such as the Western Sierra variant lack a forest regeneration model leaving the user to input this information. This shortcoming can distort forest stand conditions as they are projected into the future based on user inputs which may

be inconsistent or subjective. Depending on the understory conditions, projected canopy base height can increase rapidly, thereby greatly reducing the potential for crown fire initiation (Moody et al., 2016). To counter this effect, a pulse of mixed-conifer regeneration can be applied at every time step, along with a small-tree growth rate multiplier (Collins et al., 2011). These customized FVS parameters should be based on field data.

c) Save FFE-FVS fuel load outputs needed for FOFEM and save carbon inventory data needed for accounting.

Step 5. Format the FFE-FVS outputs for FOFEM. The necessary values are stored in the FVS_Fuels and FVS_PotFire tables of the FVS output database. The FVS fuel load categories do not exactly align with those of FOFEM and will require some adjustment. Likewise, FOFEM requires duff depth as an input but FVS does not track this; ideally duff depth could be derived from field data but expert opinion may be necessary. Values for the percentage of rotten vs. sound fuel in the >= 1000-hr class will also need to be derived or estimated. Once the inputs have been formatted and saved then FOFEM may be run in batch mode to rapidly process thousands of stands. FOFEM will estimate smoke emissions (in lb/ac by default) created during the smoldering and flaming phases of combustion for the following species of emissions: particulate matter (PM2.5 and PM10), CH_4, CO, CO_2, NO_x, and SO_2.

Step 6. Use ArcFuels to develop and format inputs for FlamMap's Minimum Travel Time (MTT) model (FM, CC, CH, CBH, and CBD rasters). Use FFE-FVS outputs to update all baseline rasters at each time step.

Step 7. Use FlamMap to determine the optimal MTT burn time to ensure sufficient fire spread while limiting computation time. Burn time must be iteratively determined such that every pixel on the landscape burns at least once but not so long that computation times are prohibitive. Burn time is recommended to be at least eight hours. Using the methods of Ager et al. (2010) is recommended.

Step 8. Use FlamMap to determine the optimal number of MTT random ignitions. A single MTT run simulates many thousands of independently burning random ignitions to remove the effect of ignition location on modeled fire behavior. The use of approximately 0.6 random ignitions per hectare is suggested (see Ager et al., 2007, 2010). However, this will need to be adjusted, along with burn time, so that the entire landscape is covered in the full simulation.

Step 9. Identify random ignition point locations to be used for all FlamMap simulations. Ignition locations should be randomly selected, but should also be selected so that all portions of the entire landscape will burn.

Step 10. Run FlamMap MTT run for each timestep. Save CBP and FLP rasters, which are used to calculate project emissions.

Step 11. Run FOFEM for each stand and time step to determine baseline wildfire emissions ($W_{DE,BSL}$). Calculate $W_{DE, BSL}$ across all stands. FOFEM requires an estimate of canopy consumption which can be produced by FlamMap. One method of doing this is to use the P-Torch (probability of torching) value as estimated by FFE-FVS for each stand (e.g., Stephens et al., 2012). P-Torch is the probability that torching can occur in a small area of a forest stand and depends in large part on flame length (Rebain et al., 2015). The

P-Torch value of each stand may be used without modification as a surrogate for canopy consumption.

Step 12. Compute the average CBP_{BSL} within each forest stand. This will be used for the shadow wildfire emission calculations. CBP is the fraction of simulated wildfires that reach each pixel of the landscape. CBP values range between 0 and 1.

Wildfire emissions over the project area are amortized (discounted) by the annual fire ignition probability of occurrence over each separate five-year interval period of the 40-year project term. The annual fire probability of occurrence (P_{const}) is determined from the project area-wide fire return interval (FRI). The FRI must be selected to represent current contemporary conditions, as opposed to historical pre-suppression conditions. The FRI is assumed to be constant over the 40-year project term but must be updated along with the baseline. FRI is determined from an evaluation of fire perimeter data using a methodology recently developed by Mann et al. (2016) and Parisien et al. (2012).

Wildfire emissions on untreated stands (shadow effect)

Wildfire emissions reductions occur within the fuel treatment area as well as in the treatment shadow in adjacent untreated areas because of changes in fire severity and reductions in fire size induced by the fuel treatments. Because Randig is a deterministic model and the baseline and project runs utilize similar (but not necessarily identical) ignition points, any difference in the conditional burn probability (CBP) between the two scenarios -- after correcting for noise -- is an indication of fuel treatment effectiveness. (The alternative model FlamMap is capable of reusing the same ignition points but it does not handle large landscape as well.) Changes in expected fire severity due to fuel treatments (whether inside or outside of fuel treatments) are captured by including an estimate of canopy consumption in the emissions modeling. Changes in burn probability are captured by multiplying each stand's expected emissions by the ratio of project CBP to baseline CBP. This term cancels to a value of 1 for stands that are not affected in burn characteristics by the project, but in fuel treatments and wildfire shadows it will be less than 1.

Figure 2 graphically demonstrates the direct and shadow wildfire emissions when comparing the baseline and fuel treatment scenarios:

- Baseline. For the baseline untreated fireshed on the left, the fire footprint area is shown in red color.
- Fuel treatment. For the fuel treatment fireshed shown on the right, fire will be directly limited in severity on the treated stand acres, represented by the orange colored Rx (treated) area. The shadow benefit results from the overall fire size and severity reduction, represented as the difference in the red colored areas.

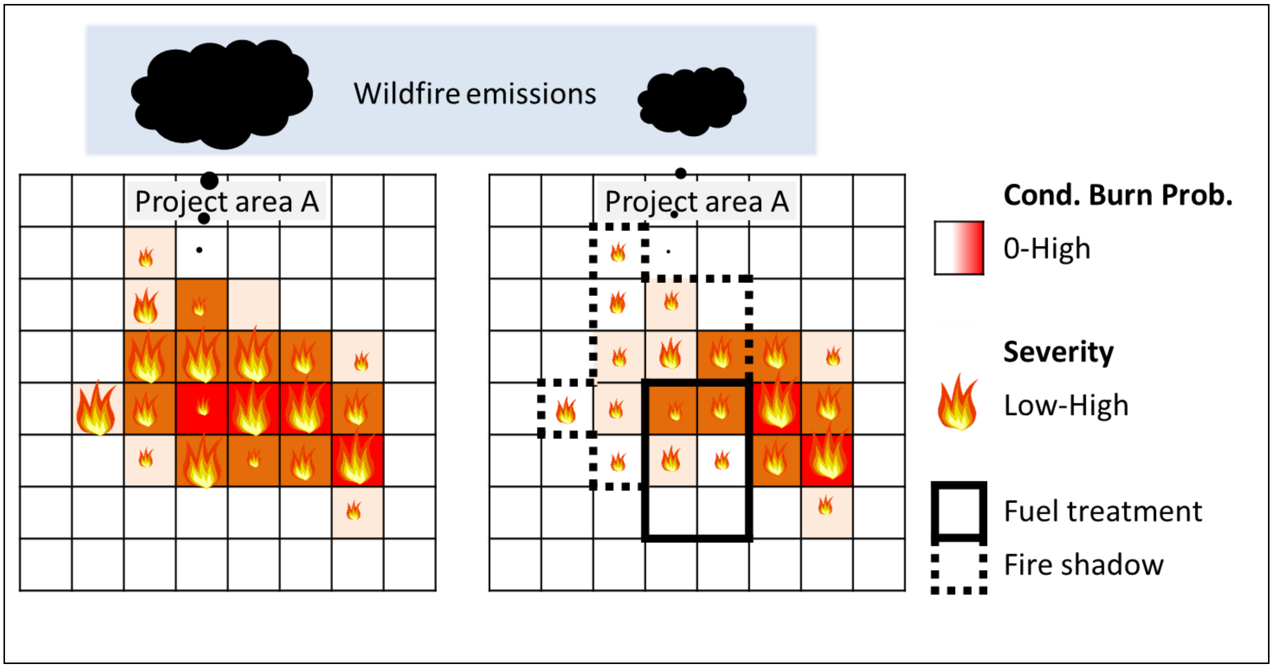


Figure 2: Avoided wildfire emissions through the reduction of fire size and severity on treated and adjacent stands.

Delayed reforestation

The three-step process described below, and outlined in Figure 3, provides a methodology to quantify carbon emissions from delayed reforestation over a 40-year timeline following high-severity wildfires (carbon stocks and fluxes for a forestry project are accounted for over a 40-year time frame).

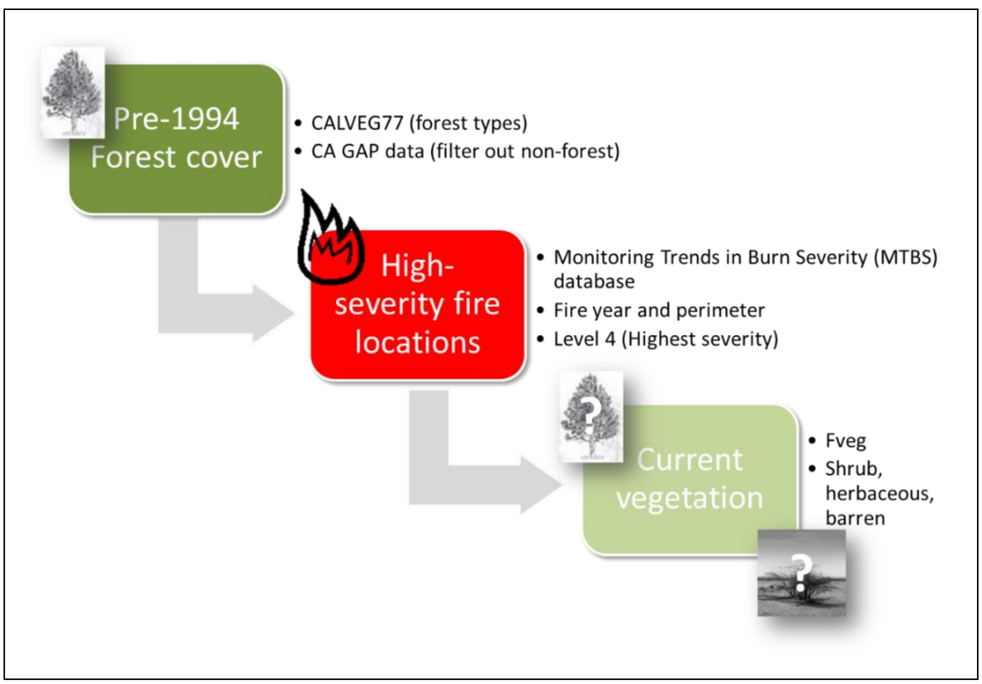


Figure 3: Steps to quantify acreage affected by delayed reforestation following high-severity wildfires.

Step 1: Identify pre-1994 forest cover

For step 1, we used 1977 CALVEG to identify vegetation type classification layers (the best approximation prior to 1984) for pre-1994 forest cover in California. We used CA-GAP data to subtract non-forest tree cover such as urban parks (USGS, 2011).

Step 2: Identify high-severity areas

We used the "USFS Region 5 Burn Severity Database-1984-present" (USFS, 2017) to identify the area of all wildfires since 1984 that were high severity (Burn Severity 4; i.e. lethal to the tree, Brewer et al. 2005) within California. Areas that experienced less severe fires followed by delayed forest regeneration (e.g. Batllori et al., 2015; Gonzalez et al., 2015) were therefore excluded resulting in a conservative estimate of delayed reforestation following wildfires.

Step 3: Identify delayed reforestation occurrence using FVeg data

We used 2015 FVeg data (CAL FIRE, 2015) to identify existing vegetation types as of today on the areas that burnt at high severity between 1984 and 1994 (Figure 3). The restriction to wildfires prior to 1995 should allow for a sufficient buffer of 20 years to exclude misclassification of vegetation type (i.e. absence of trees) due to ongoing natural or artificial regeneration. As a proxy for delayed reforestation, we therefore assumed that if no regeneration is detectable at least 20 years after a fire, an enduring delay in reforestation has occurred and the landscape is dominated by shrub or grassland vegetation types at least over the medium term (20-40 years).

3.1.2 Accounting results

ERTs are calculated based on the procedures and models outlined in section 1.2 and Box 2. The initial C stock reduction on the project area due to fuel treatments (Figure 4, light green columns) is eventually offset by GHG emission savings mostly associated with avoided delayed reforestation, reduced C emissions from treated and untreated (shadow effect) stands, as well as reduced non-CO_2 GHG emissions. Due to its outsized effect on overall ERTs contributions and novelty compared to the current ACR IFM protocol, we highlight the calculation procedures for avoided wildfire C emissions on treated and non-treated stands as well from avoided delayed reforestation. The total accumulated ERTs over the 40-year project term equal 4.9 ERTs/acre before accounting for leakage, uncertainty, and buffer pool contributions. Table 1 provides a detailed accounting of the results summarized in Figure 4.

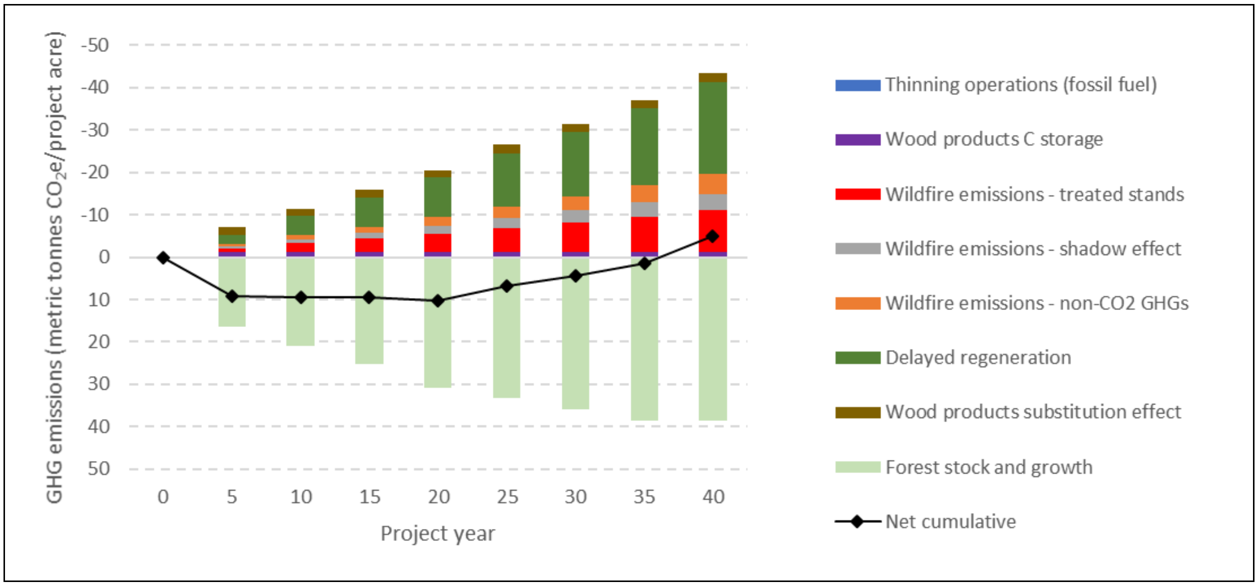


Figure 4: ERTs contributions by accounting element per project acre. Net cumulative GHG emissions savings over the 40-year project term equal 4.9 ERTs per acre (pre-uncertainty accounting and buffer pool contributions). This example is considered a conservative scenario in terms of avoided wildfire emissions benefit (see section 1.3).

Note that for the delayed reforestation analysis, in context of the sample project area, this methodology suggests that 43% of the Sierran Mixed Conifer forest type that burnt at high-severity did not show forest cover twenty years post-wildfire. Based on average shrub carbon stocks in the western Cordillera (13.4 Mg CO_2e/acre; Zhu & Reed, 2012), this methodology suggests a maximum carbon stock of 24.8 MG CO_2e/acre over a 40 year time period on post high-severity wildfire patches, including potential re-established tree cover.

Table 1: AWE Calculation template (pre-uncertainty, pre-buffer pool contributions, pre-leakage).

Parameter	MT CO_2e/acre fire shed								
	Time (yrs)								
	0	5	10	15	20	25	30	35	40
Baseline									
Forest stock and growth	(318.7)	(338.8)	(354.2)	(374.4)	(389.7)	(408.3)	(423.2)	(440.4)	(453.8)
Constant (annual) probability of fire		1.60%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Periodic (5-year) probability of fire		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Wildfire		39.7	42.2	42.7	45.6	47.1	49.0	49.9	53.5
Non-CO2 GHGs		33.6	34.6	35.5	36.6	37.5	38.5	39.5	40.8
Weighted 5 year interval		5.9	6.2	6.3	6.6	6.8	7.0	7.2	7.6
Weighted cumulative		5.9	12.0	18.3	24.9	31.7	38.7	45.9	53.5
Total cumulative	(318.7)	(332.9)	(342.2)	(356.1)	(364.8)	(376.6)	(384.5)	(394.5)	(400.4)
(Fuel treatment) Project									
Forest stock and growth	(318.7)	(322.6)	(333.3)	(349.1)	(359.0)	(375.1)	(387.5)	(402.0)	(415.4)
Wildfire		20.8	21.9	23.7	25.2	25.5	26.6	26.8	28.4
Non-CO2 GHGs		28.7	29.1	28.9	29.1	29.7	30.2	30.5	32.3
Weighted 5 yr interval		4.0	4.1	4.2	4.4	4.4	4.6	4.6	4.9
Weighted cumulative		4.0	8.1	12.3	16.6	21.1	25.6	30.2	35.1
Net slash removed (zero for ACR)									
Net slash diverted to bioenergy LCA		-	-	-	-	-	-	-	-
Net merchantable removed		2.55				0.22			
Wood products produced		(1.72)	-	-	-	(0.15)	-	-	-
Wood products in use or landfill (%)		43%	43%	43%	43%	43%	43%	43%	43%
Harv. & trsp. incl. presc. burn emissions		0.1	-	-	-	0.0	-	-	-
Wood products LCA		(1.0)	(1.0)	(1.0)	(1.0)	(1.1)	(1.1)	(1.1)	(1.1)
Net mill waste fate		(0.8)	-	-	-	(0.1)	-	-	-
Mill waste bioenergy LCA (zero for ACR)									
Mill waste fate non-bioenergy in-use (%)	100%	40%	10%	5%	0%	0%	0%	0%	0%
Mill wastefate non-bioenergy LCA		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Net wood product substitution LCA		(1.8)	(1.8)	(1.8)	(1.8)	(2.0)	(2.0)	(2.0)	(2.0)
Avoided delayed reforestation									
Delayed reforestation baseline (%)		27%	30%	30%	32%	30%	33%	32%	34%
Delayed reforestation project (%)		19%	23%	23%	26%	21%	28%	25%	25%
Weighted 5 yr interval LCA		(2.3)	(2.3)	(2.3)	(2.5)	(3.4)	(2.4)	(3.0)	(3.6)
Cumulative LCA		(2.3)	(4.6)	(6.8)	(9.3)	(12.7)	(15.1)	(18.1)	(21.8)
Total cumulative (pre UNC, L, B)	(318.7)	(323.8)	(332.7)	(346.6)	(354.6)	(370.0)	(380.2)	(393.1)	(405.3)
Net cumulative (pre UNC, L, B)	-	9.2	9.4	9.5	10.2	6.6	4.3	1.4	(4.9)
Net periodic (pre UNC, L, B)	-	9.16	0.25	0.05	0.72	(3.55)	(2.29)	(2.95)	(6.32)

3.2 Accounting for uncertainty

It is assumed that the uncertainties associated with the estimates of the various input data are available, either as default values given in IPCC Guidelines (Frey et al., 2006; Penman et al., 2003) or estimates based on sound statistical sampling. Uncertainties arising from the measurement, modeling and monitoring of carbon pools and the changes in carbon pools must always be quantified.

Uncertainty quantification is specified for each carbon pool in the sections above. Indisputably conservative estimates can also be used instead of uncertainties, provided that they are based on verifiable literature sources. In this case the uncertainty is assumed to be zero.

The project proponent must apply one of two approaches for the estimation of combined uncertainties: Approach 1 uses simple error propagation equations, while Approach 2 uses Monte Carlo or similar techniques (Frey et al., 2006).

In Approach 1 (addition and subtraction; Frey et al., 2006), the uncertainty in the baseline scenario should be defined as the square root of the summed errors in each of the measurement pools. The errors in each pool must be weighted by the size of the pool so that projects may reasonably target a lower precision level in pools that only form a small proportion of the total stock (Equation 13).

In Approach 2, the project proponent must employ a Monte Carlo simulation procedures as specified by IPCC (Frey et al., 2006) to generate uncertainty-adjusted baseline carbon stocks following four steps:

Step 1: Specify category uncertainties (see sections above; 90% confidence intervals).

Step 2: Select random variables.

Step 3: Estimate emissions and removals (see sections above).

Step 4: Iterate and monitor results.

If following Approach 1 for the sample project, each accounting element (aboveground and belowground C stocks, C fluxes from operations and transport of harvested material, wood product substitution, wildfire emissions and delayed reforestation can be based on 90% confidence interval of the mean for each C or non-CO_2 GHG pool/flux. In case of the sample project, if the uncertainty deduction derived from the calculation outlined above would reduce the C pool contribution of each accounting element by 20%, the cumulative ERTs over the project term would equal 4.9 ERTs/ project acre. We strongly assume that this is a “worst-case” scenario where a full uncertainty accounting under Approach 1 would yield a reduced uncertainty deduction, while Approach 2 would most likely be even more beneficial from a ERTs point of view since uncertainty deductions by accounting element would not be compounded.

3.3 Buffer pool contributions

Project proponents must conduct their risk assessment/ buffer pool contributions using the ACR Tool for Risk Analysis and Buffer Determination (ACR, 2010). The output of this tool is an overall risk category, expressed as a fraction, for the project translating into the buffer deduction that must be applied in the calculation of net ERTs. This deduction must be applied unless the project proponent uses another ACR - approved risk mitigation product.

For the sample project, the buffer pool contribution is calculated as follows:

> ***Total Risk score =*** *[4% (default value for financial risk) + 4% (default value for management risk) + 2% (default value for social/policy risk) + -2% (default value for conservation easement deduction)] + [4% (high fire risk region) + 4% (default value for diseases and pest) + 0% (no wetland project) + 2% (default value for other natural disaster events)] =* ***18%***

Total cumulative ERTs generated over the project term including uncertainty subtractions (see example in section 3.2) and buffer pool contributions would be 3.4 ERTs/project acre.

3.4 Leakage components

Leakage from market or activity shifting effects does not apply since wood product supply is expected to increase in a project scenario more than under the baseline scenario (Table 2).

Table 2: Leakage sources.

Leakage Source	Product type	Included / Optional / Excluded	Justification / Explanation of choice
Activity-Shifting	Timber Harvesting	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
	Fuelwood	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
Market Effects	Timber	Excluded	Project scenario will typically have greater timber harvesting activity than baseline
	Fuelwood	Excluded	Project scenario will have typically greater timber harvesting activity than baseline

4 ERTS TIMING AND VOLUMES

The sample project would result in a credit generation of 726,000 ERTs (3.4 ERTs/project acre; see section 3.3; Table 3). Comparable to ERTs issued based on project activities above and beyond common practice in the ACR IFM protocol, ERTs issuance would be following the initial project verification. Periodic mandatory monitoring, reporting, and verification (MRV) efforts would ensure implementation of fuel treatments on which ERTs depend or, if fuel treatments were not implemented, result in a voluntary reversal.

Table 3: Sample project revenues and costs in 2018 $. ERTs payout would be contingent on implementation of two rounds of fuel treatments in project year 0-5 and again in 20-25.

Year	Unit	0	5	10	15	20	25	30	35	40	Total
Credits	1,000 ERTs	726	-	-	-	-	-	-	-	-	
Price projections	$/ERTs	9.01	12.06	16.14	21.59	28.90	38.67	51.75	69.25	92.67	
Gross revenue	$1,000	**6,538**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6,538**
Inventory (every 5 yrs)	$1,000	150	150	150	150	150	150	150	150	150	
Project management	$1,000	80	-	-	-	-	-	-	-	-	
Third party verification (every 5 yrs)	$1,000	60	60	60	60	60	60	60	60	60	
Annual MRV	$1,000	-	60	60	60	60	60	60	60	60	
Brokerage and registry fees	$1,000	109	-	-	-	-	-	-	-	-	
Total Direct Third-Party Costs	$1,000	**399**	**270**	**270**	**270**	**270**	**270**	**270**	**270**	**270**	**2,559**
Total net revenue	$1,000	**6,139**	**(270)**	**(270)**	**(270)**	**(270)**	**(270)**	**(270)**	**(270)**	**(270)**	**3,979**

5 COSTS AND TIMING OF COSTS

5.1 Project activity

Initial project activity costs are expected to be comparable to large-scale (>20,000 acres) carbon offset projects under ACR IFM standards with inventory costs in the range of $150,000, and registry/transfer fees on a per-ERTs basis for the initial project year. ERTs generation is tied to the implementation of fuel treatments and is based on probability statistics regarding wildfire occurrence. The sample project resulted in 51,000 acres treated within the first five-year project period with follow up treatments occurring 20 years later. A total of 102,000 acres would be treated under the project scenario over the project term in addition to baseline assumptions.

5.2 Project development

Project development costs are expected to be comparable to large-scale (>20,000 acres) carbon offset projects under ACR IFM standards totaling about $80,000. These costs would include project management, coordinate verifiers, inventory contractor, pre-assessment eligibility, growth and yield modeling and registry quantification, baseline optimization; non-conformity report (NCR) response; and onsite verification guidance. Registry fees would be calculated on a per-ERTs basis for each issuance year.

5.3 Initial validation and verification

Initial validation and verification project costs are expected to be comparable to large-scale (>20,000 acres) carbon offset projects under IFM standards. Initial third-party verification costs would be about $60,000.

5.4 Revenues

Total project gross revenues would be about $6.5 million over the project term. Project costs would total about $2.6 million, resulting in net revenues in the range of $4.0 million. This estimate is expected to be conservative for a project of this size due to the challenging constraints in the project area (see section 1.3).

5.5 Monitoring, Reporting, Verification

Ongoing Monitoring, Reporting, Verification (MRV) costs are expected to be comparable to large-scale (>20,000 acres) carbon offset projects under ACR IFM standards. Reoccurring management costs within every five-year period would be about $12,000 for management, $150,000 for inventory costs, and $60,000 for third-party verification costs. Costs associated with verification field visits every five years would be in the range of $150,000 for inventory costs and $60,000 for third-party verification costs.

6 DESCRIPTION AND QUANTIFICATION OF REVERSAL SCENARIOS

6.1 Assessment of reversal risk

Reversal scenarios for an Avoided Wildfire Emissions project would be identical to IFM reversal scenarios. Project proponents commit to a minimum project term of 40 years. Projects must have effective risk mitigation measures in place to compensate fully for any loss of sequestered carbon, whether this occurs through an unforeseen natural disturbance or through a project proponent or landowners' choice to discontinue forest carbon project activities.

6.2 Mitigation of reversal risk

Mitigation measures can include contributions to the buffer pool, insurance, or other risk mitigation measures approved by ACR. If using a buffer contribution to mitigate reversals, the project proponent must conduct a risk assessment addressing both general and project specific risk factors. General risk factors include risks such as financial failure, technical failure, management failure, rising land opportunity costs, regulatory and social instability, and natural disturbances. Project specific risk factors vary by project type, but can include land tenure, technical capability and experience of the project developer, fire potential, risks of insect/disease, flooding and extreme weather events, illegal logging potential, and others. If they are using an alternate ACR - approved risk mitigation product, they will not do this risk assessment.

7 OTHER INFORMATION

Not applicable

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ATTACHMENT 3

Avoided Wildfire Emissions Methodology Submission
Quantifying Ecosystem Service Benefits of Reduced Occurrence of Significant Wildfires
Project Team List

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ATTACHMENT 3

Avoided Wildfire Emissions Methodology Submission
Quantifying Ecosystem Service Benefits of Reduced Occurrence of Significant Wildfires
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Bruce Springsteen	Placer County Air Pollution Control District
Jeff Ravage	Coalition of the Upper South Platte

ATTACHMENT 4
Avoided Wildfire Emissions Methodology Submission
Avoided Emissions Calculation Spreadsheet

GHG offset protocol: Avoided emissions from significant wildfires
Calculation template v 8/15/2018
Example: Eldorado case study (2015-2018 QUEBROW project)

MT CO_2e/acre fire shed

Parameter	0	5	10	15	20	25	30	35	40	Calculation	Notes
	Time (yrs)										Input cells
Baseline											
Forest stock and growth	(318.7)	(338.8)	(354.2)	(374.4)	(389.7)	(408.3)	(423.2)	(440.4)	(453.8)	$C_{BSL,\ AG/BG\ live/dead}$	above grnd, below grnd, dead
Constant (annual) probability of fire		1.60%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%		Constant fire probability
Periodic (5-year) probability of fire		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	ΔP_{Const}	
Wildfire		39.7	42.2	42.7	45.6	47.1	49.0	49.9	53.5	W_{BSL}	
Non-CO2 GHGs		33.6	34.6	35.5	36.6	37.5	38.5	39.5	40.8		
Weighted 5 year interval		5.9	6.2	6.3	6.6	6.8	7.0	7.2	7.6	$W_{BSL,\ w}=W_{DEb}*\Delta P_{const}$	
Weighted cumulative		5.9	12.0	18.3	24.9	31.7	38.7	45.9	53.5		
Total cumulative	(318.7)	(332.9)	(342.2)	(356.1)	(364.8)	(376.6)	(384.5)	(394.5)	(400.4)	$C_b=C_{BSL,\ AG/BG\ live/dead}+W_{DE,w}$	
(Fuel treatment) Project											
Forest stock and growth	(318.7)	(322.6)	(333.3)	(349.1)	(359.0)	(375.1)	(387.5)	(402.0)	(415.4)	$C_{P,\ AG/BG\ live/dead}$	above grnd, below grnd, dead
Wildfire		20.8	21.9	23.7	25.2	25.5	26.6	26.8	28.4	W_P	
Non-CO2 GHGs		28.7	29.1	28.9	29.1	29.7	30.2	30.5	32.3		
Weighted 5 yr interval		4.0	4.1	4.2	4.4	4.4	4.6	4.6	4.9	$W_{P,w}=\Sigma W_{d,p}*\Delta P_{const}$	
Weighted cumulative		4.0	8.1	12.3	16.6	21.1	25.6	30.2	35.1		
Net slash removed (zero for ACR)										ΔC_S	Delta slash BSL - slash P
Net slash diverted to bioenergy LCA		-	-	-	-	-	-	-	-	$C_s=\Delta C_S*P_b*(1-LCA_{sb})$	P_b(slash utilized for bioenergy) 95% LCA_{sb} (emission 20% MT CO2e sav 0.48
Net merchantable removed		2.55				0.22				ΔC_M	Delta merch BSL - merch P 0
Wood products produced		(1.72)	-	-	-	(0.15)	-	-	-	$C_{WP}=C_M*E_m$	E_m(mill efficiency) 67.5%
Wood products in use or landfill (%)		43%	43%	43%	43%	43%	43%	43%	43%	F_{wp}	100 year average DOE 1605(B) Table 6
Harv. & trsp. incl. presc. burn emissions		0.1	-	-	-	0.0	-	-	-	C_{OPS}	
Wood products LCA		(1.0)	(1.0)	(1.0)	(1.0)	(1.1)	(1.1)	(1.1)	(1.1)	$C_{WP,perm}=C_{wp}*F_{wp}$	
Net mill waste fate		(0.8)	-	-	-	(0.1)	-	-	-	$C_{MW}=\Delta C_m-C_{WP}$	Delta sawmill waste BSL
Mill waste bioenergy LCA (zero for ACR)										$C_{w,b}=C_w*F_{merb}*(1-LCA_{mb})$	F_{merb} (zero for ACR) 75% LCA_{mb} (emission 20%
Mill waste fate non-bioenergy in-use (%)	100%	40%	10%	5%	0%	0%	0%	0%	0%	LCA_{mnb}	
Mill wastefate non-bioenergy LCA		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	$C_{w,nb}=C_w*(1-F_{merb})*LCA_{mnb}$	
Net wood product substitution LCA		(1.8)	(1.8)	(1.8)	(1.8)	(2.0)	(2.0)	(2.0)	(2.0)	$C_{WPS}=C_{WP}*DF*F_s$	DF (MT CO2e/MT CO2e wood) 2.1 Fs (% of wood 50%
Avoided delayed reforestation											
Delayed reforestation baseline (%)		27%	30%	30%	32%	30%	33%	32%	34%	$P_{TC,BSL}$	Proportion of land experiencing type conversion
Delayed reforestation project (%)		19%	23%	23%	26%	21%	28%	25%	25%	$P_{TC,P}$	Proportion of land experiencing type conversion
Weighted 5 yr interval LCA		(2.3)	(2.3)	(2.3)	(2.5)	(3.4)	(2.4)	(3.0)	(3.6)	$C_{redirect}=[(C_{BSL}-C_{TC})*P_{TC,\ BSL}-(C_P-C_{TC})*P_{TC,P}]*\Delta P_{Const}$	C_{tc} (MT CO2e/acre) 24.8 $D_{Redirect}$ (discou 100%
Cumulative LCA		(2.3)	(4.6)	(6.8)	(9.3)	(12.7)	(15.1)	(18.1)	(21.8)		
Total cumulative (pre UNC, L, B)	(318.7)	(323.8)	(332.7)	(346.6)	(354.6)	(370.0)	(380.2)	(393.1)	(405.3)	$C_{total}=C_P+W_{DE,P,w}+W_{id,w}+C_s+C_{WP,perm}+W_{BSL}+W_P+C_{WPS}+C_{redirect,cum}$	
Net cumulative (pre UNC, L, B)	-	9.2	9.4	9.5	10.2	6.6	4.3	1.4	(4.9)	$ERT=C_{total}-C_b$	
Net periodic (pre UNC, L, B)	-	9.16	0.25	0.05	0.72	(3.55)	(2.29)	(2.95)	(6.32)	$ERT_P=ERT-ERT_{t-1}$	

Leakage, buffer, uncertainty calculations - IPCC (2006) Approach 1: error propagation

	0	5	10	15	20	25	30	35	40	Calculation
Leakage deduction	0%	0%	0%	0%	0%	0%	0%	0%	0%	LK
Buffer deduction	18%	18%	18%	18%	18%	18%	18%	18%	18%	BUF
Uncertainty AG&BG	20%	20%	20%	20%	20%	20%	20%	20%	20%	$U_{AGBG}=[(C_{TREE}*U_{TREE})\text{^}2+(C_{DEAD}*U_{DEAD})\text{^}2]\text{^}0.5/(C_{TREE}+C_{DEAD})\text{^}2$
Uncertainty operations and trsp.	20%	20%	20%	20%	20%	20%	20%	20%	20%	U_{OP}
Uncertainty wood prod. subst.	20%	20%	20%	20%	20%	20%	20%	20%	20%	U_{WPS}
Uncertainty FRI	20%	20%	20%	20%	20%	20%	20%	20%	20%	U_{FRI}
Uncertainty (C) wildfire BSL	20%	20%	20%	20%	20%	20%	20%	20%	20%	$U_{C,W,BSL}$
Uncertainty wildfire BSL	28%	28%	28%	28%	28%	28%	28%	28%	28%	$U_{W,BSL}=[(U_{FRI})\text{^}2+(U_{CW,BSL})\text{^}2]\text{^}0.5$
Uncertainty (C) wildfire P	20%	20%	20%	20%	20%	20%	20%	20%	20%	$U_{C,W,P}$
Uncertainty wildfire P	28%	28%	28%	28%	28%	28%	28%	28%	28%	$U_{W,P}=[(U_{FRI})\text{^}2+(U_{C,W,P})\text{^}2]\text{^}0.5$
Uncertainty delayed reforestation	20%	20%	20%	20%	20%	20%	20%	20%	20%	U_{TC}
Uncertainty	20%	17%	17%	17%	17%	17%	17%	17%	17%	U_{TOTAL}
Total cumulative	(209.1)	(220.3)	(226.5)	(235.8)	(241.4)	(251.8)	(258.7)	(267.4)	(275.9)	$C_{total}=C_P+W_{P,w}+C_s+C_{WP,perm}+W_{BSL}+W_P+C_{WPS}+C_{redirect,cum}$
Net cumulative	-	6.2	6.4	6.4	6.9	4.5	2.9	0.9	(3.4)	$ERT=C_{total}-C_b$
Net periodic	-	6.2	0.2	0.0	0.5	(2.4)	(1.6)	(2.0)	(4.3)	$ERT_P=ERT-ERT_{t-1}$

Forest Management Task Force:

Rural Economic Development Steering Committee/ Wood Utilization Work Group

Removing Barriers Team

Statewide Feedstock Availability Literature Review

By California Law Empowering Renewable Energy (CLERE Inc.)

CLERE Inc.
California Law Empowering Renewable Energy

Funded by Placer County Air Pollution Control District

Forest-based Feedstock Availability Literature Review

Summary of Results

Studies that attempt to estimate statewide forest-based feedstock availability are difficult to conduct due to the inaccessible fine-grain data needed to create conclusive numbers. Through a literature review of five of the major reports on statewide biomass availability produced in the last five years, this document has been developed to compare results related to forest-based biomass volume and density within the state. Results from each publication provide a unique perspective to biomass availability, and when combined, can provide a general understanding of forestry-based biomass estimates. Based on forest health and fire reduction biomass removal projects, High Hazard Zone (HHZ)-incentivized biomass removal, tree mortality, and private land forest operations, the studies find there is an abundant amount of biomass to support existing power facilities, and support the development of a range of new wood based businesses through the North Coast and Sierra-Cascade Mountain Range.

The most recent models indicate a significant increase in statewide biomass availability with estimates falling around 12.4 million BDT per year available in High Hazard Zones (HHZ) and 24 million BDT per year available statewide across forest management, sawmill, and shrubs and chaparral feedstock sources as calculated by the Lawrence Livermore National Laboratory (LLNL). Older models estimate 10 million BDT per year being available through forest management sources alone. In comparison, the LLNL estimates 15 million BDT per year available only through forest management sources when modeling the Forest Carbon Plan's 1 million acre per year restoration goal. There are mixed results on the amount of financially and technically available feedstock from mortality, but research out of UC Berkeley indicates there is the potential to generate between 1.7-6.4 Terawatts from mortality numbers sourced from the 2012-2017 drought. The California Biomass Collaborative (CBC) and Spatial Informatics Group (SIG) applied their feedstock numbers into biorefinery siting models to assess financial viability and viable feedstock supply chains. The CBC found the potential to develop over 10 facilities in the North Coast and upper Sierra Nevada while SIG found the need for 30 existing or new facilities across the North Coast and all of the Sierra Nevada to normalize carbon credit prices through sustainable forestry practices.

Overview of Literature Reviewed

1. ***Potential for Biofuel Production from Forestry Woody Biomass (2015)[1]:*** A collaboration between UC Davis and UC Berkeley, this report was conducted for the California Energy Commission to assess biofuel potential from forest residue – ie. thinning and fuel reduction operations. The team utilized UC Berkeley's research on optimal forest dynamics to define limits to forestry operations and applied data from the Forest Inventory and Analysis' (FIA) and the BioSUM model[2] into UC Davis' Geospatial Biorefinery System Model (GBSM) in order to define a few scenarios of siting new biofuel facilities in California. The first model scenario showed only operations that generate *positive net*

[1] Katherine A. Mitchell, et. al; *Potential for Biofuel Production from Forestry Woody Biomass.* California Biomass Collaborative. 2015

[2] The Bioregional Inventory Origination Summarization Model (BioSUM) is a model developed by Jeremy Fried that considers the cost and effectiveness of forest health restoration, yields of timber and feedstock for existing forest biomass facilities and most promising locations for building biomass-to-energy facilities.

revenue[3] when looking at harvesting scenarios. A second model scenario went beyond economics and simulated what biomass availability would look like if statewide policy prioritized forest management to reduce wildfire risk. They analyzed availability for biofuels over a 40-year period.

2. ***Forest Biomass Utilization Project Integration Report (2016)[4]:*** Spatial Informatics Group was commissioned under the CEC's Alternative and Renewable Fuel and Vehicle Technology (ARFVT) Program to comprehensively evaluate the sustainability of potential extraction of forest biomass to generate transportation fuels in California. By integrating different elements of various forestry management practices over a 40-year timeline, the report investigates ecological disturbance regimes and financial policies that would be impacted by expanding the biomass utilization market. In two subtasks of the project they developed different methodologies of estimating statewide biomass availability. In the first method, they used Fire and Fuel Extension program of the Forest Vegetation Simulator (FFE-FVS), FIA data and the BioSum v5.0 model to evaluate the sustainability of 25 silvicultural prescriptions. In a separate subtask they used a similar methodology before applying it to three different policy credit price scenarios to evaluate their influence on feedstock availability. The resulting feedstock estimates were then applied to GBSM to identify the optimal number of facilities, their locations, sizes, gross revenues and total throughput to sustainably support the biomass utilization market through biofuels. This study was showcased in the state's Forest Carbon Plan (FCP), which is the leading policy guidance relating to forest health in California.[5]

3. ***High Hazard Fuel Availability Study (2019)[6]:*** A team of consultants prepared this report for the High Hazard Fuel Study Committee and PGE. The objective is to assess the current and future demand for and supply of biomass fuel that meets BioRAM requirements, in addition to identifying barriers to increase forest biomass fuel production. Consequently, the geographic region as outlined by BioRAM requirements limits the assessment to High Hazard Zones (HHZ) to roughly half of the forestland of California. The report also provides an analysis of feedstock competition between all existing facilities and includes merchantable timber allocation and a gamut of other economic considerations within their research. The study did take into account standing dead tree mortality, and was updated with tree mortality information from FIA and Aerial Surveys. The team employed Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) modeling sourced from 2012 FIA data over a 20-year period. They used Forest Vegetation Simulator (FVS) to model forest growth date to 2017 which also adjusted for harvest and mortality from 2012-2017.

4. ***Characterization of the Woody Biomass Feedstock Potential Resulting from California's Drought (2020)[7]:*** Written by a team of UC Berkeley researchers, this paper combines USFS aerial survey data between 2012-2017 with forest structure maps to estimate the hard-to-calculate standing dead

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[3] Positive Net Revenue is used here as a modeling input that optimizes maximum industry profit, meaning that feedstock was not accounted for if the cost of removal was higher than the end, value-added product

[4] Saah, David, Gunn, John, Moghaddas, Jason. (Spatial Informatics Group). *Forest Biomass Utilization Project Integration Report*. California Energy Commission. Publication Number: CEC-600-10-006. 2016

[5] Forest Carbon Plan, Page 134

[6] Mason, Bruce and Girard, The Beck Group; *High Hazard Fuel Availability Study*. Prepared for the High Hazard Fuel Study Committee and PGE. Natural Resource Management Contract #C9333. 2019

[7] Carmen L Tubbesing, Jose Daniel Lara, et. al; *Characterization of the Woody Biomass Feedstock Potential Resulting from California's Drought.* Scientific Reports, Nature Research. 2020

biomass from five years of drought-stricken tree mortality. The aerial data is combined with LEMMA-Gradient Nearest Neighbor (GNN) Structure Maps and uses simple conversion factors to estimate biomass, which does not account for variation in tree size which could have a significant impact on outcomes. The results are used to estimate economic feasibility to recover feedstock for energy production with the assumption that operations will be biomass-harvests exclusively.

5. ***Getting to Neutral: Options for Negative Carbon Emissions in California (2020)[8]:*** A first-of-its-kind report, Lawrence Livermore National Laboratory delivered this assessment of negative emission pathways for California to reach carbon neutrality by 2045 using existing and deployable technologies. UC Berkeley's Dr. Daniel Sanchez and Bodie Cabiyo performed an economically-driven model to identify forest management that could contribute to the Forest Carbon Plan goals and generate *positive net revenue*. The assessment includes forest-based feedstock sources from forest operations, mill residue, and shrubs and chaparral. They employed USFS's Forest Vegetation Simulator and FIA's BioSum as their core model inputs over a 20-year period. They present original data on their forest operation modeling in addition to using UC Davis' 2015 CBC Biomass Potential publication, described above, for mill residue, shrub and chaparral numbers[9].

Table 1: Summary of Scopes for all Reports

	Cal Biomass Collaborative (2015)	SIG Biomass Utilization Project (2016)	High Hazard Fuel Availability Study (2019)	Tubbesing et al. (2020)	Getting to Neutral (2020)
Acres Studied	22 million	statewide	13.2 million HHZ	12 of 58 counties	800,000 ac/yr
Units	Million BDT/year	Million BDT	(HHZ) Million BDT/yr	Million BDT	Million BDT/yr
Model	FIA, BioSUM, GBSM	FIA, BioSUM, FFE-FVS, GBSM	FIA, LEMMA, Aerial Survey, FVS	Aerial Surveys, LEMMA-GNN	FIA, FVS and BioSUM
Modeling Period	40	40	20	2012-2017	20
Forest Operations	x	x	x		x
Mill Residue					x
Shrubs and Chaparral					x
Mortality		x	x	X	
Environmental Considerations	BAU and policy driven wildfire incentive program	in-field surveys and multi-dimensional harvest scenarios	BAU technical and economic operating constraints	does not evaluate ecological trade-offs of tree removal	Forest Carbon Plan restoration goals

[8] Sarah E. Baker, et. al; *Getting to Neutral: Options for Negative Carbon Emissions in California.* Lawrence Livermore National Laboratory. 2020

[9] Dr. Sanchez. Personal Communication. April 16th, 2020.

Introduction

Led by the Governor's Office, the Forest Management Task Force (FMTF) Rural Economic Development Strategic Wood Utilization Group (REDS WUG) has asked to compile the best available information on the state of forest biomass supply while taking into consideration biomass that is already being consumed by existing electrical generation facilities. Five publications published in the last 5 years have been selected for review that attempt various scales of a state-wide biomass availability from the forestry sector[10]. Each report employs their own methodology of biomass availability which differ in scope, geography, modeling and results. These reports serve to complement one another in many respects, providing a baseline understanding of biomass utilization potential in California. Some of the work takes into consideration feedstock competition, distance of available feedstock to facilities, the costs or technical constraints of removal based on geography or road conditions and other issues related to new facility siting scenarios. The studies will be used to focus on whether forest biomass produced by an increase in the pace and scale of forest restoration could effectively supply a new wood products-based business economy[11].

The five studies covered in this review make up the bulk of current publicly available information on statewide forest biomass availability. There are several regional and site-specific studies available. Fine-grain data utilized for project specific assessment is ideal, but the detail needed for a definitive statewide feedstock assessment is not accessible. This makes comprehensive papers troublesome and expensive despite current efforts[12] [13]. The purpose of the studies reviewed in this report is to provide broad information that shows indications of total volumes, rather than the feedstock assessments for any specific region or project type.

Review of Literature Findings- Opportunities and Challenges

Forest Biomass: Volume and Availability

Across all five publications, biomass availability exceeds current electrical facility consumption, and could sustain those facilities several times over. Currently, the existing biomass to energy feedstock consumption estimates about 4.48 million BDT per year producing between 550-560 MW throughout the state[14]. This includes waste from all forest-based waste streams (including forest operations) as well as agriculture and municipal solid waste. Comparing this to the estimates described within the studies illustrates that there is more than enough waste wood coming from the forest sector alone to add an

[10] To note, there is a persisted interest in biomass studies coming from research groups on advanced transportation and biofuels technology

[11] These reports do not analyze municipal solid waste or agricultural waste; it should be noted that the numbers found in this review are only a fraction of the total state-wide biomass availability.

[12] Personal Communication with Larry Swan, USFS Woody Utilization Program Manager.

[13] Lara, Jose Daniel. Personal Communication April 9, 2020. UC Davis school of engineering is currently attempting a new comprehensive model that applies predictive growth patterns to estimate state-wide biomass potential.

[14] Tad Mason, TSS Consultants Presentation to NorCal SAF/UC Extension Webinar. April 2015; and California Society of American Foresters. 2019. As of 2018, total biomass capacity is 560 MW.

additional 315-2,440 MW of energy to the California grid by 2045[15]. We now explore the specifics within the reports on this subject.

In 2015, the California Biomass Collaborative (CBC Report) found 277 million BDT available over a 40-year modeling period using 2012 data. This equated to about 7 million BDT per year. The CBC report excluded mill residue in order to highlight the amount of unutilized biomass availability (mill residues typically are already allocated, leaving behind at most 1.5% unutilized)[16]. The report integrated the Biomass Summarization Model (BioSUM) [17] with the Geospatial Biorefinery Siting Model (GBSM). Unifying these two models extrapolated financially feasible zones where new facilities could procure unutilized feedstock from existing facilities. Based on their annual BDT estimates, they suggested ten locations that could potentially achieve break-even costs from producing biofuels. Most of the economically viable facilities were sited in the North Coast under their first business as usual (BAU) scenario, with one location sited along the western slope of the Sierra Nevada. The second scenario applied the model to a "Fire Hazard Score" which dispersed BDT potential throughout the state based on an area's potential for crown fire, fire intensity, torching index and potential tree morbidity. When prioritizing this policy-driven scenario, five facilities were sited in the Sierra Nevada, yielding 1.6 times greater BDT potential than the economic-driven BAU scenario. This amounts to about 10.9 million BDT of forest woody biomass per year, an increase in almost 4 million BDT than the BAU scenario. The numbers found through the second scenario modeled several forest stand locations that could supply wood chips at $50/BDT or less in the Western Sierra.

Under CEC's Alternative and Renewable Fuel and Vehicle Technology (ARFVT) Program, a team of researchers at Spatial Informatics Group (SIG) conducted two different methods using BioSUM v5.0 to arrive at statewide feedstock potential under various regimes of improving forest health, carbon stock and reducing crown fire risk. The first method evaluated two feedstock supply scenarios which first considered harvest activity on private lands alone, and then private land harvest with added National Forests wherever restoration was effective. This method produced roughly 550 million gallons per year of drop-in fuels with 250 million gallons being economically viable with biofuel prices over $4/gallon of gasoline equivalent (GGE). The second method simulated 25 different silvicultural scenarios on private and federal lands and applied an optimization approach to define best prescriptions for each acre. This method found an output of about 10 million BDT per year under these forest operations. When both methods are compared, they conclude that there is a range of 8 million to 11 million BDT economically available per year. When these numbers are applied to biorefinery siting model GBSM, SIG found that an optimal scenario to provide homogenous pricing for forest residues would require thirty facilities producing 18 million gallons per year. Facility siting estimates include expanding existing facilities to accommodate biofuel conversion.

The High Hazard Availability Study (the HHZ Report) written in 2019 was tasked with determining the amount of BioRAM-eligible HHZ biomass that could be removed from California's forest. This reduced

[15] 1MW facility = 8,000 BDT/yr; using LLNL estimates of 24 million BDT/year available across forest operations, mill residues and shrubs and chaparral represent the upper bounds while CBC's 7 million BDT/year represent the lowest bound.

[16] CBC 2015 Report.

[17] Dr Dan Sanchez. Personal Communication. April 16, 2020.

the available amount to about half of what is technically available forest acreage.[18] The Study found that 248 million gross BDT of biomass would be available over a 20-year period from qualifying fuel sources in the BioRAM HHZ. The HHZ Report concluded that there is about 12.4 million BDT per year gross potential forest biomass feedstock, with 3.85 million BDT per year of that total currently unused by existing facilities. The Report applied a "financially feasible radius of operation" when performing their calculations which is discussed further later in the this literature review. As required by the BioRAM program, the Report considered feedstock that was sourced from forest operations, and not from mill residue. This provides an important distinction that may be relevant to state policy makers.

Lawrence Livermore National Lab's *Getting to Neutral* report (LLNL Report) includes an assessment of biomass from forest operations, mill residue and shrubs and chaparral feedstock across the entire State. Their results are consistent with the previous reports and conclude with total forest-based biomass amounting to 24 million BDT available per year by 2045. While mill residue and shrub and chaparral numbers were based on the CBC Report's findings, Dr. Sanchez and Bodie Cabyio presented original data within the LLNL Report by modeling the FCP's ambitious 1 million acre forest restoration goal. For forest management alone, they estimate 15 million BDT available per year. It is important to note that their findings are based off a 20-year and 40-year modeling period. Through personal communication with Sanchez and Cabyio, a 40-year modeling period would estimate biomass potential to be equivalent to the other reports reviewed in this document[19]. The reason for LLNL's higher number is because they incorporated sawmill residue and shrub and chaparral biomass, which are two sources that are not often accounted for in the other reports featured in this document. In their model, they prioritized optimal stand dynamics, wildfire regimes and increase in carbon stock as recommended by the FCP in addition to the BioSUM model. They also incorporated economic assumptions into their BioSUM model such as operating costs, labor, and wood processing fees from the biomass removal value chain to define financially feasible operations. Dr. Sanchez and Cabiyo assumed a delivered biomass value of $100/BDT.

Finally, Carmen Tubbesing and Jose Daniel Lara's *Woody Characterization of Woody Biomass* (Tubbesing et al. Report) underscores these numbers by finding 26.2-95.1 million BDT resulting from the 2012-2017 drought. Under various technical constraints, 18.4-68.9 million BDT of biomass *from only tree mortality* is available, which the study goes on to conclude could yield an energy potential of 194-730 MW[20]. The yearly estimate for biomass extraction was not rigorously studied in the paper's scope, but rather emphasizes energy potential if extracted. The Paper found that cost-effective supply of biomass was available for 16-60 years at 80% operational capacity. Tubbesing et al. explored the economic viability of biomass extraction, paying attention to distance from existing facilities and usable road conditions. The economic parameters resulted in an available 7.5-27.8 million BDT. The authors made explicit note of the wide margin that reflects the disparity between what is technically available versus economically available[21]. The authors assert that future initiatives will need to reconcile the disparity between the

[18] Implementing a series of parameters to their modeling, they conclude that 13.2 million acres is available for biomass removal in the HHZ.
[19] Dr. Sanchz and Bodie Cabyio. Personal Communication. April 24,2020.
[20] Tubbesing et al. Report
[21] Jose Daniel Lara. Personal Communication. April 9,2020.

two constraints, and provide the study as evidence of the ample amount of biomass available after the 2012-2017 California drought induced tree mortality event, mostly in the southern sierra region.

As a side note, some state policy makers may be specifically interested in tree mortality biomass, specifically. A comparison of the HHZ Report's 20-year modeling outcomes to Tubbesing et al.'s mortality numbers reveals that the papers substantiate the other[22] -- there is about 3.45 million BDT available over a 20-year period.

Report	Acres treated	Modeling period	Millions of available BDT/yr
The CBC Report (2015)	22 million	40 years	7-10.9
The SIG Report (2016)	Statewide	40 years	10
The HHZ Report (2019)	13.2 million	20 years	12.4
LLNL Report (2020)	800,000 ac/year	20 years	24
			Million BDT
Tubbesing et al. (2020)	12 out of 58 counties	n/a	18.4-68.9

Forest Biomass Feedstock Value

Current Consumption and Economics

The valuation of forest biomass continues to be an incredibly challenging aspect of forest health restoration projects and fuel reduction work statewide. It is a key factor when understanding how much forest biomass feedstock is truly "available" for use. Several of the studies considered this issue and produced similar conclusions.

Background: BioRAM versus BioMAT

When reviewing literature on feedstock competition, it is important to clarify the differences between BioMAT and BioRAM, two market mechanisms implemented by the CPUC to financially incentivize the use of forest biomass at electrical generation facilities. *Biofuel Market Adjusted Tariff* (BioMAT) was created in 2012 through SB 1122 (Rubio), directing the CPUC to procure 250 MW electricity from small bioenergy plants less than 5 MW. It uses standard long-term contracts and a market-based mechanism to arrive at offered contract prices for eligible projects. *Biofuel Renewable Auction Mechanism* (BioRAM) was developed in 2015 in response to Gov. Brown's Proclamation on Tree Mortality, directing the CPUC to expand their pre-existing RAM program to existing forest biomass to electricity facilities if they procure feedstock from the High Hazard Zone areas(HHZ) as defined by CAL FIRE. It directs state investor owned utilities (IOU) to procure at least 50 MW statewide, with 20 MW from Southern California Edison from organic waste streams[23]. Note that in 2016, SB 859 added another 125 MW of

[22] The HHZ Report was used to check Tubbesing et al.'s report due to its similarity in geography and associated biomass composition. The HHZ Report estimates 3.85 million BDT per year of unutilized biomass and applied calculations to Tubbesing et al.'s Report would equate to 3.45 million BDT per year.

[23] Swezy, et al., and California Public Utilities Commission website

forest-based biomass feedstock to the BioRAM requirements[24]. The most important distinction is that BioRAM was put in place to support existing large scale biomass to energy facilities, while BioMAT requires 250 MW statewide procurement across all organic waste streams to incentivize the development of *new* small scale (under 5 MW) electrical generation facilities.

One of the Studies, the HHZ Report, specifically considered the BioRAM program related to biomass conversion and economics[25]. Currently, 24 biomass plants exist producing over 550-560 MW of generating capacity. Seven are contracted under BioRAM and procure feedstock from lands designated at HHZ by CAL FIRE, which accounts for just under half of the forest land base accessible for harvest operations (13.2 million acres). However, these BioRAM facilities also allow for feedstock procurement from non-designated areas and sources for 20% of their needs. As required by BioRAM contracts, facilities increased HHZ-qualified feedstock consumption from 340,000 BDT in 2017 to 691,000 BDT in 2018[26]. Based on those contract requirements, BioRAM facilities will need a combined total of 940,000 BDT per year to operate going forward[27]. Outside of the HHZ, total consumption of biomass between all waste streams averaged 3.4 million BDT per year over CalRecycle's 2015-18 reporting period[28]. Forest-based biomass accounted for about 1.55 million BDT on average with mill residuals contributing over 70 percent of the total[29]. Using a generally accepted magnifier for simple calculations[30], 560 MW would calculate to about 4.48 million BDT of biomass consumption per year.

Two of the Studies Considered Options for New Facility Siting

Model Scenarios for New Facilities: CBC Report

The 2015 CBC Report developed a model to assess potential biorefinery siting based on maximizing industry profit through RNG production. The CBC Report located ten biorefineries where the lowest cost resource was financially feasible: the North Coast. There were a few located in the central Sierra, but no sites located in the Southern Sierra, where the highest percentage of tree mortality occurred. When a second scenario adjusted modeling for wildfire abatement prescriptions, biorefineries were heavily shifted to site five facilities in Northern and Central Sierra. When siting new facilities in the Sierra Nevada, the report found an increase in BDT potential to be 1.6 times greater than the original profit maximizing scenario. Total estimates rise to about 10.9 million BDT per year available when taking into consideration wildfire abatement treatments. The biorefineries production rate would range from 45 – 154 million GGE per year.

Model Scenarios for New Facilities: SIG Report

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[24] Camille Swezy, Kyle Rodgers and Johnathan Kusel, PhD. *Paying for Forest Health: Improving the Economics of Forest Restoration and Biomass Power in California*. Funded by CEC contract EPC-16-047 for the Schatz Energy Research Center, California Biopower Impacts Project. P. 13. 2020

[25] Note that the HHZ Report was published in 2019 and included Loyalton Biomass Facility into its calculations. Without Loyalton, more biomass feedstock will have no place to go in the central Sierra/Tahoe region.

[26] The HHZ Report: Mason, Bruce and Girard; The Beck Group

[27] Ibid.

[28] The HHZ Report covering CalRecycle reporting period

[29] Ibid.

[30] The Beck Group; Mason, Bruce and Girard. 1 MW facility = 8,000 BDT/yr

In a separate study, conducted by Spatial Informatics Group (SIG) for the 4th California Climate Assessment, supplements the UC Davis model and was featured in the 2018 Forest Carbon Plan. It evaluated "the sustainability of increased forest biomass utilization for transportation fuels under differing management practices across public and private lands and under expected fire regimes". In subtasks 3 and 8 of this project, they developed a BioSum model to assess 40-year impacts of optimally selected treatments to reduce severe fire probabilities, increase carbon uptake, incorporated costs of implementation, and examined how a sustainable biomass industry could be developed from these treatments. Using Forest Inventory and Analysis (FIA) data, their concluding scenarios found overall improvement in forest health in multiple performance metrics and has the potential to reduce the fire hazard across California by 50 percent.

Under modeled scenarios that cover all areas generating substantial forest residuals, several dozen facilities could be sited within the State, producing a combined total of 250 million gallons per year of economically available drop-in fuels priced above $4 per gallon of gasoline equivalent (GGE)[31]. When adding public lands to reduce fire hazard, the amount of potential biofuels doubles, adding another 275 million gallons per year for a total of 525 million gallons of economically viable biofuels. Subtask 8 concluded that forest residual biomass could provide as much as 4.5 million credits to California's Low Carbon Fuel Standard (LCFS) credit market.

The SIG team then used the Geospatial Biorefinery Siting Model (GBSM) to evaluate the feasibility of using existing and new biomass facilities where the end-product would reduce the capital cost of the facility. Like in CBC's model, they found a number of facilities located in the North Coast due to low cost of transportation where greater supply sources are available on private lands[32]. In an optimal scenario, the SIG report finds that a biofuel industry consisting of a combined 30 existing new facilities producing 18 million gallons per year would facilitate the best pricing for forest residues. They comment that if new facilities were to be built to cover public land restoration projects, production costs would drop 15% and better serve important regions of California's forests[33].

Specific Economic Challenges Limiting Biomass Removal

The difficult economics of non-merchantable biomass removal is well known. Non-merchantable biomass includes slash, limbs, dead tops and trees with a BDH smaller than 10 in and understory shrubs cleared during fuel thinning[34]. The literature reviewed in this report discuss issues related to feedstock extraction, including technical, transportation and the associated in-forest labor costs. Combined they represent a significant hurdle to accomplishing more biomass removal in forest operations.

Transportation

All the publications name transportation as the central barrier to biomass extraction. Across all publications, prices for biomass removal fluctuated around $50/BDT. This number is found through an equation that essentially combines harvest and hauling costs and compares it to the value-added end product. The CBC Report uses $50/BDT as break even cost and assess the amount of biomass availability

[31] SIG Report. Subtask 8
[32] Ibid.
[33] Ibid.
[34] Forest Carbon Plan p.94

accordingly[35]. Similarly, the SIG Report uses the metric of $4 per gallon of biofuel to calculate financial feasibility[36]. The HHZ Report states a broad estimate of break-even fuel costs could be around $65-75/BDT making a 40-60 mile radius financially feasible[37]. The LLNL Report uses a different methodology and combines both sawlog value with chipping value, when other reports have only considered chipping value. LLNL Report then compared these values to harvest and transportation costs related to distance to a conversion facility. This is reflected in their higher estimate of $100/BDT as an input to their BioSUM model[38]. It is worth noting that even with LLNL's higher price of removal, they still have a significant BDT potential statewide that would necessitate a robust build out of new biomass facilities. The SIG Report points out that these high costs of removal are near unattainable for private landowners who currently contribute to a significant portion of available feedstock statewide[39].

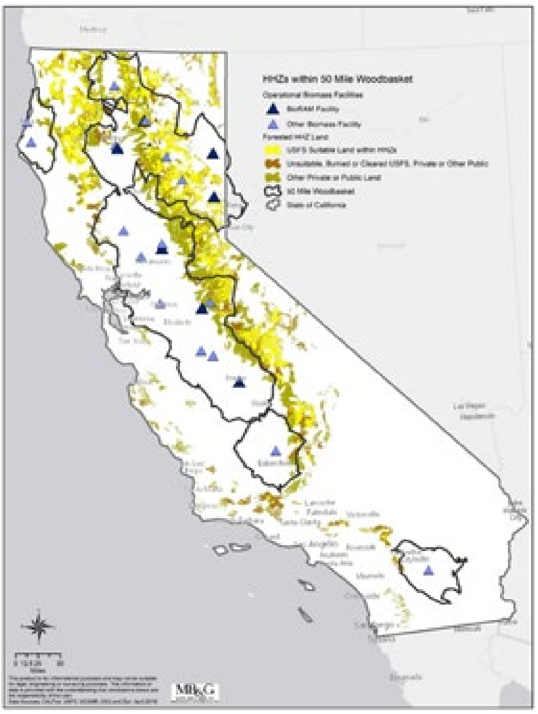

Figure 1: All existing facilities with WoodBasket of financially feasible radius - HHZ Report

Included in the financial burden to remove biomass, the HHZ Report points out that forest road conditions, the definition of "qualifying fuel" for BioRAM procurement and limited organizational capacity all contribute to the barriers of a robust non-merchantable biomass market[40].

The HHZ report goes in depth on the issue and illustrates a series of graphs that reflect their findings. As illustrated by Figure 1, operations would be economically feasible in only 23% of the HHZ for BioRAM facilities[41]. Therefore, we can infer the remaining 77% of the HHZ incurs higher hauling costs for existing facilities. Future biomass projects taking place in these areas could become viable if transportation issues are addressed. However, currently, future projects will be more expensive for biomass procurement because it is harder-to-reach[42]. Additionally, the SIG Report finds that there are multiple sources of potential woody residues like logging slash, powerline, road right of way clearance and masticated material that all represent different economic value and transportation costs complicating the economics of the issue further[43].

The Tubbesing et al. Report chose to analyze the accessibility of standing dead trees from the nearest road which gives perspective on the feasibility of access. They however did not calculate hauling costs

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35 CBC Report
36 SIG Report
37 HHZ Report
38 LLNL Report
39 SIG Report
40 HHZ Report
41 LLNL Report
42 HHZ Report
43 SIG Report

due in part because their findings were focused on the opportunity for the development of new facilities rather than hauling the available BDT to existing facilities. That being said, Tubbesing's research team did consider the Tuolumne County Pacific Ultrapower Chinese Camp biomass facility as a case study of potential standing dead BDT availability and found up to 2.5 million BDT of feedstock available within a cost-effective radius of 30 miles[44].

Consideration of Competition for Feedstock

The HHZ Report expands on their transportation research to develop a methodology on assessing feedstock competition between facilities that would compete over BioRAM eligible fuel. As shown in Figure 2, the potential biomass volume by distance to *any 23 biomass facilities* is particularly high. With the y-axis indicating biomass potential in the HHZ and the x-axis indicating miles from facilities, it shows that the next phase of biomass extraction will need to be further away from existing facilities. Notice after a certain mileage, other biomass facilities will have easier access to feedstock thereby decreasing availability. However, if more facilities develop under BioMAT or another BioRAM solicitation occurs, the HHZ feedstock supply could significantly contract and facilities could end up hauling biomass over extreme distances in order to meet BioRAM-designated material for operation. We have already seen this competition resulting in inflating prices for qualifying forest biomass feedstock an additional $8/BDT to a total of $57.97/BDT between 2017 and 2018[45].

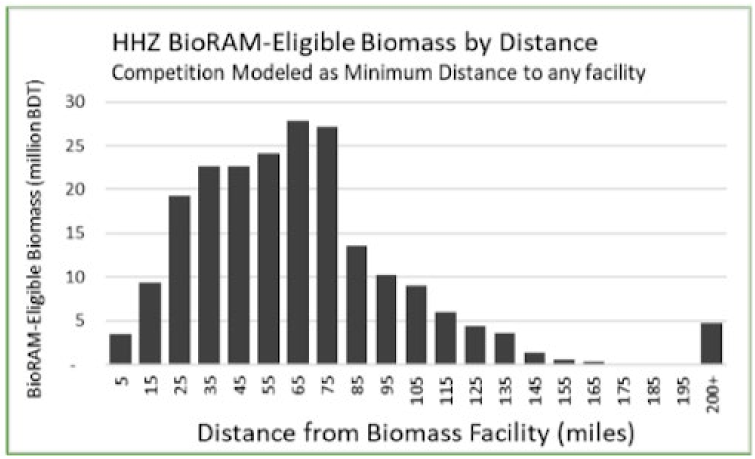

Figure 2: Feedstock Competition Availability by Distance – HHZ Report

Environmental permitting and Contracting and Technical Constraints – Operational constraints that limit biomass extraction are codified in law as best-practice silvicultural prescriptions and include but not limited to: logging systems for slope, harvest cycles, wildlife protection, tree diameter limits and cultivating a new cohort of tree saplings[46] [47] [48]. Each study culls their numbers based off these constraints.

The HHZ Report dedicates a chapter to barriers to operation. Notably, they discuss regulatory and short-term contracts that limit investment and planning. Because BioRAM contracts only offer five-year agreements, private forest operators are reluctant to invest in expensive equipment and long-term personnel[49]. The Forest Carbon Plan calls out the need to streamline environmental permitting as a solution to increase forest restoration and discusses the need to innovate through collaborative

[44] Tubbesing et al.
[45] HHZ Report
[46] Tubbesing et al.
[47] SIG Report
[48] CBC Report
[49] HHZ Report

authorities that allow for more private and state management on federal land[50]. NEPA and CEQA are required by state and federal law and are a fundamental component to ensuring environmental and ecosystem integrity during forest operations. The complexity and costs to complete these reviews, however, presents challenges. For example, due to high staff turn over rate and conditional annual federal budget allocations, permitting biomass removal projects through NEPA can be difficult to accomplish for Forest Service personnel. While it might be possible to lighten this burden through the private sector, it is difficult for third party contractors to provide NEPA analysis and project management through the same contract, leading to a slower pace and scale of forest restoration.

The Future of Forest Biomass: Author's Notes

As reflected in this literature review, there is enough biomass available to support existing facilities and support the development of new businesses. To emphasize this point, one of the Governor's 35 priority communities for fuel reduction averaged 1.5 loads of chips per acre which equates to 18 BDT per acre. This was along HWY 44 in the Shasta-Trinity Unit and can be expected to be equal to or higher in some other regions of the state with severe wildfire risk[51]. The HWY 44 project expects to treat 1,112 acres, which means this one project alone is likely to produce roughly 90,000 BDT of biomass.

The challenge is getting the biomass out of the forest, transported to businesses, and processed for use. One significant hurdle is that public landowners are not able to commit to a guaranteed feedstock supply due to the inability to predict their discretionary budget, multi-year regulatory planning processes and high staff turnover rates. Additionally, the federal agreement mechanism to allow third party operators to manage forestry projects on public land and develop feedstock contracts is highly complex, further straining the potential for streamlined action. Without a feedstock guarantee, business models are constrained, and securing a loan guarantee can be jeopardized.

In addition to feedstock contracting, building a new facility is complex. Land zoning, ownership lease and purchasing rights, and political support are the biggest hurdles to new site development[52].

Locating a site can be a highly controversial aspect of developing a facility. For example, locating biomass to energy facilities must be sited within one of the three IOU's in order to participate in BioRAM or BioMAT, while also being within feasible distance to the feedstock supply-chain. The decision to own or lease land for a long-term industrial facility also complicates matters, requiring careful legal agreements between owners and operators[53]. Air permits, water permits, grading permits and building permits are all required for facility development. In particular, air districts apply different air restrictions to their jurisdiction in addition to federal Title V air quality requirements. All of this requires a supportive local community and government staff to ensure the success of forest biomass to wood products or energy projects.

Now that it is well understood that there is a significant amount of forest biomass in California, further work should be done to determine what is needed to dispose of it in the best way possible.

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[50] Forest Carbon Plan. 2018. Section 10.3.2 Statutory Requirements for Forest Biomass.

[51] Benjamin C Rowe, CAL FIRE Shasta-Trinity Unit. Personal Communication 9/27/19

[52] Darlington, Christiana. "Stepping Stones…"

[53] Ibid.

Conclusion

According to all studies, there is enough biomass technically and economically available to support existing facilities and enough to support new business models and markets. To achieve public land restoration goals of the Forest Carbon Plan, the HHZ Report points out that current levels of operation will need to increase 200,000 acres of treatment per year, supplying a range of 150,000-300,000 more BDT per year on top of their current estimates[54]. The LLNL Report is the only study that applies a methodology to anticipate state-wide biomass availability under the Forest Carbon Plan 1 million acre forest restoration goal and concludes 24 million BDT will be available per year by 2045[55]. Several of the studies place a high value on forest health and wildfire reduction projects, in addition to employing economic modeling software, BioSUM[56] [57].

The other reports featured in this Literature Review mostly focus on procurement from forest management sources, thereby lessening the cumulative feedstock number as estimated by LLNL. Over a 40-year modeling period, report findings and personal communication with primary authors have indicated that biomass availability levels fluctuate around 10 million BDT/year. The LLNL model estimates reflect an increase for a total of 15 million BDT available per year for both their 20-year and 40-year modeling research. Combined with the HHZ Study and Tubbesing et al. reports, focusing on biomass availability in priority zones with heavy mortality numbers, we can infer that initiatives that would further expedite removal of these trees in the next 10-20 years would result in a higher BDT availability than what models suggest.

The efforts of quantifying available forest biomass have been active over the past decade and will undoubtedly continue into the future. With the biggest challenge being the ability to develop accurate granular data that can produce a higher resolution to validate a 20-year or 40-year wood supply. This literature review by no means incorporates all work done on this sector, but attempts to summarize the primary sources of information, and will now briefly mention other work and upcoming work.

Related and Forthcoming Studies on Forest Biomass Waste Availability

Joint Institute for Wood Products Innovation Literature Review Published in 2020, this report was submitted to the California Board of Forestry and Fire Protection to review forest product innovation literature, identify gaps in forest product innovation research, evaluate strategic partnerships and recommend near-term priorities to expand in-state production of various end-use timber products. The report features many useful figures and trends about forest availability for non-merchantable and merchantable timber production and suggests a new strategic partnership to develop a viable supply chain for timber markets. It was not featured in this report but serves as a companion study to help bolster woody utilization in California. While this literature review supplies some baseline numbers of feedstock availability, the Institute's literature review primarily assesses the viability of various wood utilization technologies and high value-added products.

The California Biopower Impacts (CBI) Project is managed by the Schatz Energy Research Center at Humboldt State University and supported by grant funding from the California Energy Commission. This

[54] The HHZ Report

[55] LLNL Report

[56] SIG Report

[57] CBC Report

three-year project – which is expected to conclude in August of 2020 – investigates many of the greenhouse gas (GHG) and other environmental considerations associated with utilization of forest-derived woody biomass and agricultural residues for electricity and process heat generation, as well as investigating project economics and developing policy recommendations. This work will consider available feedstock within its analysis and could provide further insight on this topic. A methodology was developed for this report in 2018 and includes an exhaustive description on how the CBI study was conducted[58].

The Next Generation of Wildfire Models for Grid Resiliency The proposed research will advance wildfire science by incorporating the interaction of tree mortality and extreme fire weather in next-generation fire models. The project will develop zero-to-seven-day risk forecasts for the grid with predictive capabilities, computational efficiency and scalability. To support planning, the team will develop long-term fire projections using a coupled fire-climate-vegetation statistical and dynamical model to integrate the latest climate projections, tree mortality, development in the wildland-urban interface, and adaptation strategies. This work will undoubtedly contribute to relevant work and development further refined analytics related to forest biomass.

Forest Operations BioSUM and FVS Modeling In-Forest Carbon Expected to be released in the late spring of 2020, this paper is a continuation of LLNL *Getting to Neutral* report and written by the main researchers who modeled statewide forest-based biomass availability by 2045. It goes into depth on the methodology of how Dr. Dan Sanchez and Bodie Cabiyo applied forest growth models, full-cycle carbon accounting of various forest products centered around the Forest Carbon Plan 1 million acre forest restoration goal which produced their findings of 24 million BDT per year available. They discuss the effectiveness, net costs and revenues generated from five management sequences with BioSUM in addition to how they arrived at their economic calculations.

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