

Guidance on Methods for Evaluating GHG Emission Reductions for Programs in the CAL FIRE Greenhouse Gas Reduction Fund

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INTRODUCTION

The goal of this document is to provide a concise, objective and defensible set of guidelines/methodology for demonstrating how the project will reduce GHG emissions as compared to not undertaking the project. The Air Resources Board (ARB) Compliance Offset Protocol, U.S. Forest Projects (2014) will be relied on where feasible to provide consistent state policy. The protocol defines additionality as GHG emission reductions or removal enhancements that exceed any GHG reductions or removals otherwise required by law or regulation, or any GHG reduction or removal that would

otherwise occur in a conservative Business-As-Usual Scenario (Protocol § 3.1), which corresponds to not undertaking the project in the context of this paper.

Six project types require guidelines:

1. Reforestation of poorly stocked or burned areas.
2. Demonstration State Forests Research
 - a. Restocking poorly stocked areas on a State Forest, and
 - b. Climate and carbon research into GHG reduction benefits.
3. California Forest Legacy Program for Carbon Sequestration.
4. Fuels reduction.
5. Forest pest control.
6. Programmatic Timberland Environmental Impact Report (PTEIR).

Methods for conducting carbon reduction estimates were developed and may be used to estimate the greenhouse gas emission reductions that a project will achieve. Two methodologies with varying degrees of analytical complexity are provided for some project types: lookup (requires use of lookup tables) and modeling (requires use of forest growth simulators and carbon accounting based on trees lists). The carbon pools included or excluded in the methods are a result of what is feasible for the less complex method. An example is provided for each unique lookup method type. The methods described in this document are suggested methods. You are free to use your own methods. Using the methods in this document does not guarantee project approval. The lookup method may not be appropriate for all projects. CAL FIRE will review each project application on its merits, and the quality of the GHG estimate will be an important project selection criterion.

REFORESTATION OF POORLY STOCKED OR BURNED AREAS

Adequate site occupancy (14 CCR 895.1, 913.11(a)(3)) and maximum sustained production (14 CCR 913) are goals of California forest practice policy. Reforestation as a means to provide adequate site occupancy is encouraged by forest practice policy (14 CCR 913(a)) and is a method identified for achieving the forestry climate goals of the state (ARB 2014). Reforestation, either natural or artificial, is required for regeneration silvicultural methods (14 CCR 913.1-2). Outside of a plan to harvest and reforest, such as may occur with a wildfire or other natural disturbance, there is no state legal requirement to restock private timberlands.

After a fire or other catastrophic event, the business as usual baseline is to leave a site untreated, which will result in stands either unstocked or partially stocked with trees. Factors that will affect the long-term GHG sequestration caused by the reforestation project include:

- Survival of regenerated trees to the point where trees have out-competed other vegetation.
- Site occupancy percentage.
- Species composition: species adapted for the site will withstand stressors better, multi-species stands will reduce risk related to species-targeted pests, shade tolerant species mixed with intolerant may produce more carbon per acre, species wood density will affect carbon storage, and growth rate will affect rate of sequestration.

- Disturbance associated with site preparation may cause loss of carbon from duff, litter, or the soil.

Carbon Reduction Estimation

The goal of reforestation is to sequester carbon by restoring tree cover on land that is not at optimal stocking levels. Onsite (in the forest) and wood product pools may be considered in carbon accounting. Standard rotation ages commonly used by landowners with less than 50,000 acres of timberland ownership statewide are given by CCR 913.11(c) as 50 years for site class I, 60 years for site class II/III, and 80 years for site class IV/V. These stand ages will therefore be used for the carbon reduction estimation.

Two simulations are necessary:

- 1) The reforestation project , and
- 2) The baseline scenario.

The baseline scenario is the “do nothing” alternative, i.e. no site preparation, planting or competing vegetation control. Simulation of the baseline scenario would include residual trees, if any, as well as natural regeneration that may emerge over the 50/60/80-years planning interval. In order to estimate the greenhouse gas reduction resulting from implementing the project, subtract the baseline scenario estimate from the reforestation project estimate.

For the reforestation project type, wood products will not be considered because thinning timing and intensity would be speculative parameters for these forward looking evaluations that may occur over a large variety of forest types and market conditions.

Lookup Approach

This approach uses the COLE version 3 (<http://www.ncasi2.org/GCOLE3/gcole.shtml>) forest carbon online estimator, which is based on FIA data. Use the following procedure to obtain a per acre estimated yield of carbon. Stratify the project by existing vegetation type and/or site class where appropriate. The per acre values of CO₂ will be multiplied by the acreage in each strata.

- 1) Select approximate location of the project on the map.
- 2) Select the most common forest type or forest type group for the project. This should be the expected future forest type. For example, if pine and fir are being planted and it is expected that other species may seed in naturally then mixed conifer may be the most appropriate forest type.
- 3) Select the productivity class that most closely matches the average for the project area; and select the next lowest and highest productivity classes if available. The productivity classes are based on seven classes as defined by FIA. The crosswalk from the forest practice site classes are as follows (USFS/UCCE 1991):

FIA	Mixed Conifer	Douglas-fir	Redwood
1	I		I
2	II	I, II	II

3	III	III	III
4	IV	IV	IV, V
5	V	V	
6, 7			

- 4) Select "planted" condition.
- 5) Generate the report. If there are an insufficient number of plots as per the COLE message then expand the radius from the project until enough plots are included.

The COLE report provides a carbon yield stream assuming a bare ground initial condition and is reported in metric tons of carbon (C) per hectare by a number of onsite components (live tree, dead tree, soil, etc.). Consistent with the protocol, soil carbon is an excluded carbon pool when: 1) site preparation activities do not include deep ripping, furrowing, or plowing where soil disturbance exceeds or is expected to exceed 25% of the project area over the project life and 2) mechanical site preparation activities are exclusively conducted on contours. Add the live and dead tree columns for the age class that corresponds to the site productivity. We wish to report in metric tons of carbon dioxide (CO₂) per acre of the live and dead trees. Multiply the values by 1.486, which is multiplying by 3.67 to convert from C to CO₂ and dividing by 2.47 to convert from hectares to acres.

We now subtract an estimate of the carbon removed in site preparation from the yield stream of carbon. These were estimated from Scott and Burgan (2005) total aboveground biomass using fuel types GR4 (moderate load dry climate grass), SH2 (moderate load dry climate shrub) and SH7 (very high load dry climate shrub). If grass then subtract 3.6 metric tons CO₂ per acre, if light to medium shrubs then subtract 13.9 metric tons CO₂ per acre, and if heavy shrubs then subtract 24.0 metric tons CO₂ per acre.

Multiply the per acre CO₂ estimates by the number of acres in the project or by strata if applicable.

Finally, subtract an estimate of the mobile combustion emissions associated with site preparation activities. To do this use equation 6.2 from the ARB protocol (see box below), which multiplies the project acres by the per acre emission estimate based on brush cover categories. You now have the estimated net onsite tree carbon to report.

Equation 6.2. Combustion Emissions Associated with Site Preparation

$$MC_y = (-1) \times (EF_{mc} \times PA)$$

Where,

MC_y = Secondary Effect CO₂e emissions due to mobile combustion from site preparation

EF_{mc} = Mobile combustion emission factor from Table 6.1

PA = The size of the Project Area, in acres

Table 6.1. Mobile Combustion Emissions for Reforestation Projects

SITE PREP - REFORESTATION PROJECTS		
Emissions Associated with Mobile Combustion		
Average Metric Tons CO₂e per Acre		
Light	Medium	Heavy
0-25% Brush Cover	>25-50% Dense Brush Cover	>50% Brush Cover, Stump Removal
0.090	0.202	0.429

Figure 1. Equation 6.2 from ARB forest protocol.

Example #1 – Reforestation, Lookup Approach

Go to the web site: <http://www.ncasi2.org/GCOLE3/gcole.shtml>

Screen initially looks like this:

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

Lat=39.22374, Lon=-120.58594
ncasi

Select the "Plots within this radius (km)" button, which gives you this screen:

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

The page at www.ncasi2.org says:
Double click map to locate circle

OK

Lat=39.22374, Lon=-120.58594
ncasi

Click OK on the small pop up box. Then screen will look like this:

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)



Select Data Filters Reports

Reports Only Advanced User

Step 1 - Click state icon or:

Select by state, region or counties within states:

States PNW Int-W NC S NE

State then County CA

Or Select

Plots within this radius(km)

20

Step 2 - Get Data and select another tab

Max to Display 300

Select Custom Layer: None

Begin by selecting a state or defining a circle, then push `getData`.

ncasi

Double click on location of your project area. Zoom in to map as needed.

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)



Select Data Filters Reports

Reports Only Advanced User

Step 1 - Click state icon or:

Select by state, region or counties within states:

States PNW Int-W NC S NE

State then County CA

Or Select

Plots within this radius(km)

20

Step 2 - Get Data and select another tab

Max to Display 300

Select Custom Layer: None

Lat=38.70159, Lon=-120.48706

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Next, select the green button that says "GetData", which looks like this:

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

N of recently measured plots meeting query criterion: 50. N displayed: 48

ncasi

Next, click on the “Filters” tab. Scroll down and select the forest or forest type group; in this case it is mixed conifer forest type. It was necessary to scroll down to the Forest Type window using the scroll bar on the far right and then click on a selection in the Forest Type box and arrow key down to the desired selection.

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

N of recently measured plots meeting query criterion: 50. N displayed: 48

ncasi

Next, scroll down until you see the “Site Productivity Class” window. In this example we have site class III primarily, which translates to a FIA site class 3. Therefore we shall select FIA site class 2, 3 and 4. This may be done by clicking on site class 2 and then holding down the shift key and clicking on site class 4. Note that the classes area labeled by the CMAI productivity in cubic feet per acre per year, but the order is 1 to 7 (high site to low site).

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

N of recently measured plots meeting query criterion: 50. N displayed: 48

ncasi

Scroll down and selected “Planted” stand origin as shown below.

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

Select Data Filters Reports

[Help](#) [Filter Map](#)

Reset
140
150
160
170
180
190
200

Stand Origin
Unknown
Natural
Planted

Stand-size class code
Large diameter
Medium diameter
Small diameter
Chapparral
Nonstocked

Survey Unit
Southwest-South-AL
Southwest-North-AL
Southeast-AL
West Central-AL

N of recently measured plots meeting query criterion: 50. N displayed: 48

ncasi

Go to the "Reports" tab next, as shown below. Turn off your browsers popup blocker or at least allow it for the NCASI site, otherwise the report window will not show up.

Welcome to COLE 3.0, the next generation Carbon On Line Tool. [Home](#) | [Help](#)

Select Data Filters Reports

[Help](#) [Submit](#) [email](#)

email:

Select Report Option
1605b Carbon Report

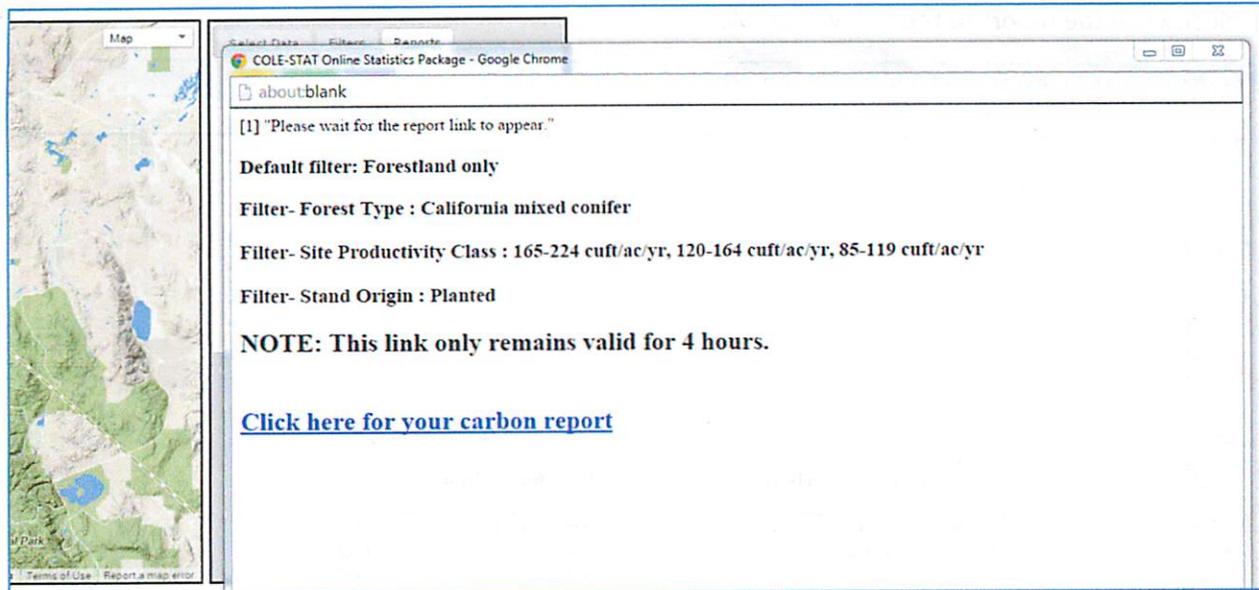
Help: The email option will cause the report link to be returned to you via email. The submit option returns the report link to a new browser window as soon as it is available.

See job progress indicator in lower left. You won't get results if popups are blocked.

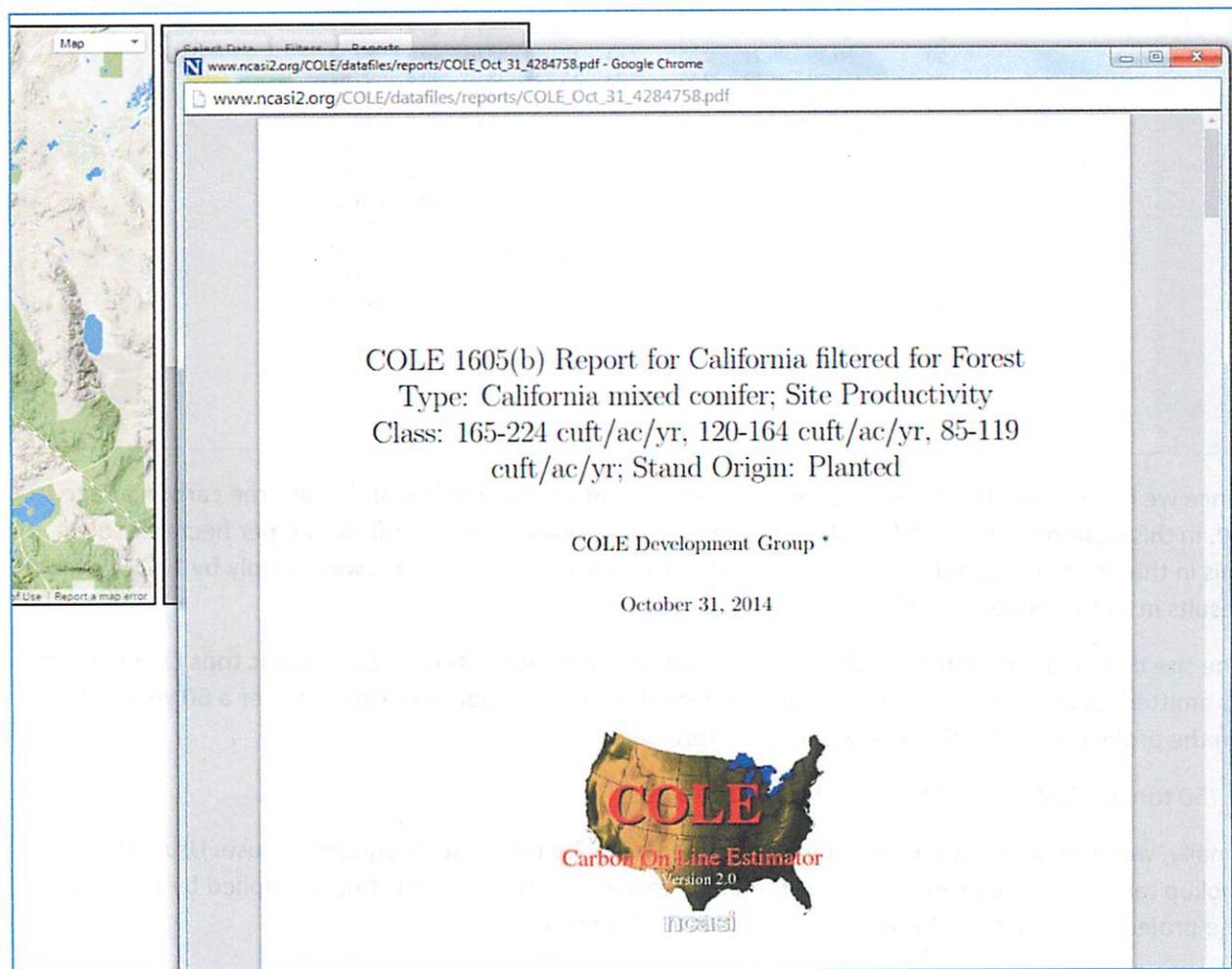
N of recently measured plots meeting query criterion: 50. N displayed: 48

ncasi

Press the green "Submit" button and wait while processing occurs. The following screen will appear:



Click on the blue hyperlink to get your report. The report shows up in the window as shown below.



Scroll down in the report to the following table.

COLE Carbon Report 5

Table 1: Carbon Stocks by Age Class for California

Age Class	Mean volume	Live tree	Dead tree	Under story	Down dead wood	Forest floor	Soil	Total non soil
years	m ³ /hectare	tonnes carbon/hectare						
0	0	0	2.55	0	15.2	33.04	49.8	50.79
5	3.97	2.44	2.55	6.77	14.24	33.04	49.8	59.04
10	21.21	11.57	2.55	4.43	14.18	33.04	49.8	65.77
15	48.83	24	2.55	3.22	14.6	33.04	49.8	77.41
20	80.58	36.21	2.55	2.64	15.08	33.04	49.8	89.52
25	111.72	46.52	2.55	2.34	15.42	33.04	49.8	99.87
30	139.67	54.56	2.55	2.16	15.56	33.04	49.8	107.86
35	163.39	60.52	2.55	2.05	15.52	33.04	49.8	113.67
40	182.81	64.81	2.55	1.98	15.34	33.04	49.8	117.72
50	210.47	69.96	2.55	1.91	14.74	33.04	49.8	122.2
60	227.12	72.44	2.55	1.87	14.02	33.04	49.8	123.92
70	236.83	73.6	2.55	1.86	13.3	33.04	49.8	124.35
80	242.39	74.14	2.55	1.85	12.65	33.04	49.8	124.23
90	245.54	74.39	2.55	1.85	12.07	33.04	49.8	123.9
100	247.32	74.51	2.55	1.85	11.57	33.04	49.8	123.52
a	249.6	74.61						
b	0.06	0.08						
se	223.57	81.4						
n	4							

Since we have a site class III project, we are interested in the yield of live and dead tree carbon at age 60. In this example it is 72.44 live plus 2.55 dead, which totals to 74.99 tonnes of C per hectare. To get this in the desired reportable units of tonnes (metric tons) of CO₂ per acre, we multiply by 1.486, which results in 111.4 tonnes of CO₂ per acre.

The site before site preparation was in light brush, therefore we subtract 13.9 metric tons CO₂ per acre as emitted carbon from existing vegetation removal. The net carbon sequestered over a 60 year period, on the project area of 100 acres, would therefore be:

$$9,750 \text{ tonnes CO}_2 = (111.4 \text{ t/a} - 13.9 \text{ t/a}) \times 100 \text{ acres}$$

Finally, we must subtract the emissions associated with site preparation equipment use. Using the lookup table from the protocol we see the 0.202 tonnes per acre CO₂ must be multiplied by the acres in the project, which was 100 acres. This results in 20.2 tonnes.

The final project scenario estimate is:

9,729.8 tonnes CO₂ = 9,750 tonnes CO₂ – 20.2 tonnes CO₂.

In order to arrive at the estimate of greenhouse gas emission reduction resulting from implementing the project, subtract the baseline estimate from this project estimate.

Modeling Approach

This approach uses an individual tree forest growth model such as FVS, FPS, or FORSEE. These are all approved simulators as per the ARB project protocol (ARB 2014). Use a small tree growth model if one is not built in to the simulator, so that you begin with the trees at an acceptable size for the models. Project the planted trees, and any existing residual trees (residual trees are included for proper competition, but do not count toward additional carbon), forward to the age specified by the respective site class. Use the ARB forest protocol (ARB 2014) specified volume and biomass equations for California, which may be found on the ARB websites (<http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtlldoc2.pdf> and <http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtlldoc1.pdf>). These should be applied to the tree lists output from the simulator for standing live trees with minimum dbh of 5 inches. Dead trees are not modeled due to the lack of verified standing dead tree decay models that cover the entire forested areas in the state.

Use the methodology of the Lookup Approach to estimate standing dead wood, carbon removed in existing vegetation, and mobile combustion emissions.

RESEARCH

Climate and Carbon Research into GHG Reduction Benefits

In order to be funded with GGRF grants, research projects must include an on-the-ground component that produces a direct GHG emission reduction.

Because research projects can take almost any form, carbon reduction estimation methods are not described for research as a category. The GHG reduction achieved as a result of a research project however, can be estimated as a forest management project. For example, if the study investigated fuel reduction treatments, the fuel reduction methodology described below could be used.

CALIFORNIA FOREST LEGACY

A conservation easement prevents conversion and associated carbon loss relative to a business-as-usual baseline. Conservation easements that consider carbon sequestration a priority may or may not include a market component. In general, conservation easements that prioritize carbon sequestration and storage could consider the following factors:

- protecting forests/carbon stocks for the near-term benefit of carbon storage,
- the risk to carbon stocks from natural disturbance,

- risk mitigation from natural disturbance,
- long-term storage potential from onsite and long-term wood product carbon,
- leverage created by combining public and private financing so as to conserve maximum acreage,
- encourage practices that maintain or increase forest resilience to climate change,
- consider off-site effects of carbon sequestration through maintaining biodiversity, genetic diversity or seed source for nearby understocked forests,
- consider potential leakage associated with foregone near-term harvest and potential reverse-leakage associated with long-term increases in wood product storage.

The ARB protocol has an avoided conversion (AC) project type that requires a qualified conservation easement. Having an easement can also reduce the required buffer pool contribution from all projects (up to 7 percent) due to the reduction in risk to the project afforded by the easement. In order to qualify for an AC project under the protocol, the appraised value of the conversion must be at least 40 percent higher than the current land use appraisal; and must be 80 percent or greater to avoid a reduction in credits. This assessment is used to demonstrate that the land is under threat of conversion. Forest legacy projects should demonstrate that the land faces a real threat of conversion using this or another valid metric.

Carbon Reduction Estimation

For the forest legacy project type, the period of time considered for carbon accounting will be 10 years, which is consistent with the Avoided Conversion project type in the ARB protocol (ARB, 2014). Projects may be longer than 10 years, where credits from growth are accruing, but most benefit accrues in the first ten years. Carbon stored long-term in wood products and landfills will be considered because the conversion has the potential to produce significant long-term wood products storage, although this will count against the net reduction estimate. Two methodologies are provided, a relatively simple protocol approach that uses the assumptions provided in the ARB protocol, and a more project specific modeling approach.

Lookup Approach

First, make an estimate of the current project carbon stocks from live and standing dead trees. If the project area has a carbon project then use that information, otherwise derive an estimate from a random sample of plots. The plot data should meet a level of statistical rigor of +/- 20 percent at the 90 percent confidence level, which is the minimum allowed under the protocol. Use the ARB forest protocol (ARB 2014) specified volume and biomass equations for California, which may be found on the ARB websites (<http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtldoc2.pdf> and <http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtldoc1.pdf>). These should be applied to the tree data with a minimum dbh of 5 inches. Dead trees ≥ 15 feet tall are estimated using methodologies that incorporate portions lost (limbs, bark, tops) and loss of wood from decay. One methodology may be found on the Climate Action Reserve (CAR) website at (CAR, 2014, sec. 2.7 of the Quantification Guidance): <http://www.climateactionreserve.org/how/protocols/forest/dev/version-3-3/>.

Estimate a 10-year baseline that models a reduction of onsite carbon stocks using the schedule found in Table 6.3 of the ARB protocol (below), which is based on the type of conversion to be avoided.

Table 6.3. Default Avoided Conversion

Type of Conversion Identified in Appraisal	Total Conversion Impact	Annual Conversion
Residential	<p>This is the assumed total effect over time of the conversion activity. (The total conversion impact is amortized over a 10-year period to determine the annual conversion in the next column.)</p> <p>Estimate using the following formula:</p> $TC = \min(100, (P \cdot 3 / PA) \cdot 100)$ <p>Where: TC = % total conversion (TC cannot exceed 100%) PA = the Project Area (acres) identified in the appraisal P = the number of unique parcels that would be formed on the project area as identified in the appraisal</p> <p>*Each parcel is assumed to deforest 3 acres of forest vegetation.</p>	<p>This is the assumed annual conversion activity. The percentages below are multiplied by the initial onsite carbon stocks for the project on an annual basis for the first 10 years of the project.</p> <p>Estimate using the following formula:</p> $AC = TC / 10$ <p>Where: AC = % annualized conversion TC = % total conversion</p>
Mining and agricultural conversion, including pasture or crops	90%	9.0%
Golf course	80%	8.0%
Commercial buildings	95%	9.5%

Figure 2. Default avoided conversion impacts from the ARB forestry protocol.

The difference between the project and the baseline includes the carbon that was not lost and growth and harvests of the initial carbon stocks. Project growth over the ten years may be estimated as the net percent growth after planned harvests. If all of growth is to be harvested then annual growth is 0 percent. Increment cores may be used to estimate growth using the stand table projection method. Increment data collection should follow the guidelines provided in the ARB forest protocol (Appendix B1).

Harvests in the baseline and project should use Appendix C of the protocol to estimate long-term wood products storage in the in-use and landfill pools.

To estimate the carbon reduction benefit over a ten year period, add the onsite carbon after 10-years and the carbon stored long-term in wood products for the project scenario. Then deduct the onsite carbon after 10 years and the carbon stored long-term in wood products for the baseline scenario.

Example #2 – Conservation Easements, Lookup Approach

In this example the easement protects a 1,000 acre forest at risk of conversion to vineyards. An inventory was installed using a simple random sample. The tree records were loaded into an excel spreadsheet where the ARB volume and biomass equations were applied. The live tree components are the bole, bark and crown (no foliage or fine limbs). Equations are provided for the volumes. Separate equations are provided for the bark and crown. Note that many of the hardwood volume equations (Pillsbury and Kirkley 1984) include bark and crown and so there are not separate equations for those.

Two example trees are given, a Douglas-fir and a tanoak. Douglas-fir in California uses equation 3. A 16-inch tree with a total height of 77 feet would have its total cubic volume calculated using the equation 3 formula for CVTS.

Equation 3

TMP_DBH = DBH

IF DBH < 6.0 inches then TMP_DBH = 6.0 inches and BA = $6^2 \times 0.005454154$

$$CF4 = 0.248569 + 0.0253524 \times \frac{HT}{TMP_DBH} - 0.0000560175 \times \left(\frac{HT^2}{TMP_DBH} \right) \quad (1)$$

IF CF4 < 0.3 THEN CF4 = 0.3

IF CF4 > 0.4 THEN CF4 = 0.4

$$CV4 = 0.005454154 \times TMP_DBH^2 \times HT \times CF4 \quad (2)$$

$$TARIF = \frac{CV4 \times 0.912733}{BA - 0.087266} \quad (3)$$

IF TMP_DBH > 6.0 THEN

$$CVTS = CV4 \times \frac{\left(\left(1.033 \times \left(1.0 + 1.382937 \times \exp\left(-4.015292 \times \left(\frac{DBH}{10.0} \right) \right) \right) \right) \right) \times (BA + 0.087266) - 0.174533}{(BA - 0.087266)} \quad (4)$$

$$CVT = \frac{TARIF \times (0.9879 - 0.1051 \times 0.5523^{DBH - 1.5}) \times \left(\left(1.033 \times \left(1.0 + 1.382937 \times \exp\left(-4.015292 \times \left(\frac{DBH}{10.0} \right) \right) \right) \right) \times (BA + 0.087266) - 0.174533}{0.912733}}{0.912733} \quad (5)$$

IF TMP_DBH = 6.0 THEN

$$SMALL_TARIF = 0.5 \times (6.0 - DBH)^2 + (1.0 + 0.063 \times (6.0 - DBH)^2) \times TARIF \quad (3)$$

IF SMALL_TARIF <= 0.0 THEN SMALL_TARIF = 0.01

$$CVTS = SMALL_TARIF \times \left(\left(1.033 \times \left(1.0 + 1.382937 \times \exp\left(-4.015292 \times \left(\frac{DBH}{10.0} \right) \right) \right) \right) \right) \times (BA + 0.087266) - 0.174533 \quad (4)$$

$$CVT = \frac{TARIF \times (0.9879 - 0.1051 \times 0.5523^{DBH - 1.5}) \times \left(\left(1.033 \times \left(1.0 + 1.382937 \times \exp\left(-4.015292 \times \left(\frac{DBH}{10.0} \right) \right) \right) \right) \times (BA + 0.087266) - 0.174533}{0.912733}}{0.912733} \quad (5)$$

WHERE:

DBH (inches) = DBH (CM) CONVERTED TO INCHES (DBH/2.54)

HT (feet) = HT (M) CONVERTED TO FEET (HT/0.3048)

BA = BASAL AREA/ACRE (DBH IN INCHES) $BA = 0.005454154 \times DBH^2$

CVTS = CUBIC FOOT VOLUME, INCLUDING TOP AND STUMP

TARIF = TARIF NUMBER EQUATION (REF. DNR NOTE NO.27, P.2)

CVT = CUBIC FOOT VOLUME ABOVE STUMP

CV4 = CUBIC FOOT VOLUME ABOVE STUMP, 4-INCH TOP

The above box is from the ARB volume equation document found on their web site. Our other example tree is a tanoak that is 14 inches dbh and 52 feet tall. The document says to use equation 34 for tanoak volume, which is shown in the box below. This is a relatively simple equation (equation 1) as we are only interested in CVTS. Note that the dbh and total height are in inches and feet respectively for both equations.

EQUATION 34

$$CVTS = 0.0058870024 \times DBH^{1.94165} \times HT^{0.86562} \quad (1)$$

$$CV4 = 0.0005774970 \times DBH^{2.19576} \times HT^{1.14078} \quad (2)$$

$$CV8 = 0.0002526443 \times DBH^{2.30949} \times HT^{1.21069} \quad (3)$$

$$CVT = CVTS * RTS \quad (4)$$

$$RTS = 0.9679 - 0.1051 \times 0.5523^{(DBH-1.5)}$$

$$CV4X = CVT \times \left(0.99875 - \frac{43.336}{DBH^3} - \frac{124.717}{DBH^4} + \frac{(0.193437 \times HT)}{DBH^3} + \frac{479.83}{(DBH^3 \times HT)} \right) \quad (5)$$

$$TARIF = \frac{(CV8 \times 0.912733)}{\left((0.983 - 0.983 \times 0.65^{(DBH-8.6)}) \times (BA - 0.087266) \right)} \quad (6)$$

WHERE

DBH = DBH(CM) CONVERTED TO INCHES (DBH/2.54)

HT = HT (M) CONVERTED TO FEET (HT/0.3048)

BA = BASAL AREA

CVTS = CUBIC FOOT VOLUME, TOTAL STEM, WITH TOP AND STUMP

TARIF = TARIF NUMBER EQUATION

CVT = CUBIC FOOT VOLUME ABOVE STUMP

CV4 = CUBIC FOOT VOLUME, 4-IN TOP

CV8 = CUBIC FOOT VOLUME, SAWLOG (8-IN TOP)

The bark biomass equation for Douglas-fir is equation number 8; and equation number 6 for live branches. The tanoak equation numbers are blank in the table because these components are already included in the bole volume equations. The boxes below show the bark and live branch equations for Douglas-fir. Note that the DBH is in cm and "log" means natural log. To convert from inches to centimeters multiply by 2.54. To convert from feet to meters multiply by 0.3048.

EQUATION 8

$$BB = \exp(-4.3103 + 2.4300 \times \log(DBH))$$

EQUATION 6

$$BLB = \exp(-3.6941 + 2.1382 \times \log(DBH))$$

Our example trees have the following intermediate and final results. These are from a spreadsheet set up to do the equations. Note that defect and missing tops may be accounted for by reducing the gross cubic volume (CVTS) by the appropriate percentage. Board foot deductions (ex. sweep, crook, knots, form) do not necessarily apply, only deductions where actual biomass is missing.

Inputs			Cubic Volume (ft ³)						Biomass Calculations									
Species	DBH	HT	TMP_DBH	BA	CF4	CF4_Corrected	CV4	CVTS	Defect (%)	Net Volume	Wood Density	Bole Biomass (kg)	Bark Biomass (kg)	Live Branches (kg)	Live Tree Above Ground Biomass (kg)	Live Tree Above Ground Biomass (tonne)	Trees Per Acre	Live Tree Above Ground Biomass (tonne per acre)
DF	16.0	77	16.0	1.396	0.350	0.350	37.610	39.12	15%	33.25	28.7	432.82	109.10	68.54	610.46	0.610	5	3.05
TO	14.0	52						30.25	0%	30.25	36.19	496.52			496.52	0.497	5	2.48

The aboveground biomass for each plot is calculated and then the belowground biomass is calculated on a plot by plot basis using the Cairns et al. (1997) equation from the ARB protocol, shown below.

$$BGB = \exp(-0.7747 + 0.8836 * \ln(AGB))$$

Where, BGB = below-ground biomass

AGB = above-ground biomass.

For a given plot we had 48.7 tonnes per acre of above-ground biomass. First, convert this to tonnes per hectare by multiplying by 2.47, which results in 120.289 tonnes per hectare. Then plug into the equation above, which results in 31.74 tonnes per hectare. Divide by 2.47 to convert back to acres. This results in 12.85 tonnes per acre in belowground biomass. Note that standing dead tree above-ground biomass could be estimated and added to the live tree above-ground biomass, then the total above-ground biomass is plugged into the Cairns et al. (1997) equation to estimate below-ground biomass.

Calculate the carbon (CO₂ per acre) for each plot by multiplying the biomass by 0.5 to convert to carbon (C) and then multiply by 3.67 to convert C to CO₂. Sum the above and below-ground carbon to get live tree carbon per acre.

A total of 150 plots were inventoried with an average of 112.7 tonnes per acre of live tree CO₂. The standard deviation was 24.3 tonnes per acre. We would like to construct a 90% confidence interval to ensure that our error is within +/- 20 percent. The standard error is the standard deviation divided by the square root of the sample size, which is 1.984 tonnes per acre. The t-value to multiply the standard error by is 1.645. This results in a confidence interval of 3.638 tonnes per acre, which is 2.9 percent of the average estimate. Since the error is less than 20 percent, it is acceptable.

Increment cores were used to construct a stand table projection that resulted in an average growth rate of 3.4 percent. There is a planned harvest of 10 percent of the volume in about 3 years. We use compound growth to grow the carbon stocks and deplete them assume the volume and carbon stocks are proportional.

Since this is a conversion to agriculture we will assume that 90 percent of the carbon stocks are lost during the 10-year period leaving 11.27 tonnes per acre in the baseline.

We used Appendix C of the protocol to estimate the long-term wood storage from the baseline and project harvests, which were 28.43 and 6.27 tonnes per acre of CO₂ respectively over the ten-year period. An example of how to calculate carbon stored long-term in wood products can be found under the forest pest control project type.

The figure below shows a spreadsheet model of the carbon stock growth and depletion for the project, as well as the baseline and carbon reduction estimate over the 10-year period. The reductions are the difference between the estimated project stocks at the end of 10 years and the baseline at the end of 10 years, with the long-term wood products from the project added and from the baseline subtracted.

A	B	C	D	E
	Annual Growth Rate:			3.4%
	Project			
	Year	CO2/Acre	Harvest	
	0	112.7		
	1	116.5		
	2	120.5		
	3	124.6	12.46	
	4	116.4		
	5	120.3		
	6	124.4		
	7	128.6		
	8	133.0		
	9	137.5		
	10	142.2		
	Baseline:			11.27
	Wood Products, Baseline:			28.43
	Wood Products, Project:			6.27
	Reduction:			108.79

The reduction estimate for onsite carbon and carbon in wood products for the 10-year period is 108.79 tonnes per acre, which is 108,790 tonnes total for the 1,000 acre project.

Modeling Approach

The modeling approach uses the same general accounting framework as the protocol approach except that the baseline may be modeled based on the following protocol language:

Referencing planning documentation for the Project Area (e.g. construction documents or plans) that specifies the timeframe of the conversion and intended removal of forest cover on the Project Area;

The project activity may also be modeled. The ARB protocol volume and biomass equations are applied to the tree lists output by the growth simulator.

FUELS REDUCTION

The State Fire Plan (BOF, 2010) defines fuels treatment as the manipulation or removal of fuels to reduce the likelihood of igniting and to reduce fire intensity (e.g., lopping, chipping, crushing, piling and burning). Fuels reduction projects are defined as the modification of vegetation in order to reduce potential fire threat. Business-as-usual would be to not implement a fuel reduction project and leave the project area and surrounding area at risk from a wildfire.

There is not an approved forest carbon protocol for fuel reduction projects. Fuel for wildfires is biomass, which is about 50 percent carbon. Removing fuel is removing carbon (Stephens et al. 2012). Some fuel may be merchantable and go into long-term wood products, but most fuel that carries a surface fire is dead woody material (Perry 1990) or unmerchantable live trees or other woody plants and grasses. While treating surface fuels is the most common and effective measure, treating ladder fuels, or crown fuels may also be beneficial in a high severity fire (Agee and Skinner 2005).

If the fuel is burned in a controlled manner to produce electricity then it is likely offsetting the burning of fossil fuels, mostly natural gas in California (CEC 2010). In this case it might be considered carbon neutral, but the policy on this is not fully established (Jacobs and Chemnick 2013). Most likely the fuel removed is not used for energy and may be disposed of by the following means (Saah et al. 2012):

- Left to decompose on site.
- Pile burned on site.
- Landfilled.

Woody material left on site to decompose causes carbon and methane emissions to occur over time (Placer County 2013). When woody material is piled and burned on site then the carbon is mostly emitted immediately with GHG emissions from methane production, which has a much higher global warming potential than carbon dioxide. If woody material is landfilled, which is unlikely, then its carbon may be stored for a long time with a relatively slow rate of emission. However, methane may be produced from decay.

Soil disturbance can release carbon in long-term storage in the soil colloid, as well as reduce the productivity of a site and therefore the ability of a site to sequester terrestrial carbon. Careful implementation of mechanical and other treatments will not cause soil disturbance and carbon loss (Stephens 2012). Projects with methodologies that exclude soil as a carbon pool should sufficiently articulate how the proposed treatments will avoid soil disturbance.

On an acre treated for fuels the carbon balance is the carbon emitted from the treatment subtracted from the carbon retained multiplied by its reduced probability of loss over the time the treatment is effective. The reduced probability of loss will shrink with time as fuels rebuild. Residual tree and regeneration growth also factor in to the equation.

In addition to the treated acres, there are nearby areas in the vicinity of the treatment that may receive a measure of decreased risk and/or a reduction in burn severity. This too, will decrease as time elapses after the treatment. The total GHG benefit is a sum of the average treated acres emission loss reduction from wildfire, the nearby areas emission loss reduction from wildfire, the emissions associated with fuel disposition, and any storage in wood products or landfill storage (Saah et al. 2012).

Carbon Reduction Estimation

The period of time considered for carbon accounting will be 20 years, as this was near the optimal result from the Saah et al (2012) study. Wood products is included where merchantable timber is produced. If material is provided to a biomass facility then that is also included.

Modeling Approach

The modeling approach allows a detailed site specific spatial analysis that incorporates carbon accounting and stochastic events. See **Robards and Wickizer (2009)** and Saah et al. (2012) for a basic framework for a methodology. The silvicultural prescriptions and fire modeling should be derived from the project specific parameters. For example, the fire frequency could be derived from fire history data available from the CALFIRE Fire and Resources Assessment Program (FRAP). The baseline is a "let grow" or no treatment scenario.

The conceptual framework is shown in the figure below (from Saah et al. 2012). The analysis requires "... characterizing fireheds and their elements, estimating forest stock and growth, quantifying the life cycle of forest carbon wood products, assessing the risk of fire to the fireshed, determining direct wildfire emissions, quantifying the effect of treatments on wildfire emissions outside their boundaries, and calculating net GHG benefits or liabilities resulting from treatments".

~~A recommended **alternative** approach is to use a stand-level analysis for the fuel treatment areas and the shadow area and analyze the effects using FVS-FFE (Forest Vegetation Simulator – Fire and Fuels Extension). Simulate high severity fires after 10 years of growth (**weighed by the risk that the project area will see fire**), which is the mid-period of the analysis period. Simulate the fuel reduction treatment on the project stands. Account for removed carbon, growth of carbon, wood products using the ARB protocol Appendix C, and risk of fire for the project area. **The shadow acres may be weighted to have a reduced likelihood of fire if the project is in a strategic location. A suggested default value of 50 percent assumes there is a 50/50 chance the fire is approaching from the opposite side of the treatment area and suppression efforts are successful.**~~

Regardless of the approach taken, the ARB protocol volume and biomass equations are applied to the tree lists output by the growth simulator. If treatments produce significant wood products then the ARB protocol wood products calculations found in Appendix C should be applied. Use the replacement value of natural gas emissions, net of transportation and processing emissions, if material is shipped to a biomass energy facility.

PEST CONTROL

There are no protocols available to provide guidance for forest health and pest control, except that carbon sequestration is predicated on maintaining or increasing carbon stocks. The identification, monitoring, education, amelioration and restoration issues associated with forest pests can have a direct effect on the forest carbon stocks of California, but may also affect the rest of the country since pests originating here can spread. The business-as-usual baseline is not to address forest health and pest management issues. Day-to-day management of a forest property typically does not capture pest-affected trees due to the sporadic nature of forest pests.

Carbon Reduction Estimation

The estimate of carbon reduction is based on the concept of avoided loss, similar to the avoided conversion project type in the ARB protocol. Standard rotation ages commonly used by landowners with less than 50,000 acres of timberland ownership statewide are given by CCR 913.11(c) as 50 years for site class I, 60 years for site class II/III, and 80 years for site class IV/V. These stand ages will therefore be used for the carbon reduction estimation.

For the forest pest control project type, forest carbon in in-use wood products and biomass energy will be considered because tree removal is a common strategy. **Carbon in dead trees needs to be accounted for. Consistent with the protocol, landfill carbon storage is excluded if the harvesting in the project scenario exceeds what is estimated in the baseline.**

Modeling Approach

This approach allows a site specific analysis based on a risk assessment made by a forest pest specialist. Depending on the project scale, project plot data or FIA data may be used to estimate the stocks at risk. Where appropriate, an individual tree forest growth model such as FVS, FPS, or FORSEE may be used. These are all approved simulators as per the ARB project protocol (ARB 2014). FVS has pest extensions that may be of utility for the analysis. Use the ARB forest protocol (ARB 2014) specified volume and biomass equations for California, which may be found on the ARB website (<http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtldoc2.pdf> and <http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtldoc1.pdf>). These should be applied to the tree lists for standing live trees with minimum dbh of 5 inches. Dead trees are not modeled as the objective is to avoid dead trees. Hazard rating methods may be found at http://www.fs.fed.us/foresthealth/technology/haz_rating_database.shtml.

Example #4 – Carbon Stored in Wood Products

We will treat the affected stands by harvesting trees that are dead and dying, and as part of a thin from below to reduce stand densities to healthier levels. It is anticipated that 1.4 MCF/acre will be harvested. We will use Appendix C of the ARB protocol to estimate the long-term wood products storage in-use ~~and landfill storage~~ over 100 years. ~~While calculated to provide an example, carbon stored in landfills is unlikely to be an included carbon pool for forest pest control projects as it is expected that harvesting in the project scenario will exceed harvesting in the baseline.~~

Use the table below to multiply the volume of wood by the wood density. In this example we have mixed conifer softwoods:

$$\begin{aligned} \text{Biomass of delivered wood (zero moisture)} &= 1.4 \text{ thousand cubic feet per acre (MCF/ac)} \times 24.59 \text{ lbs/ft}^3 \\ &= 34,426 \text{ lbs per acre.} \end{aligned}$$

This project is 100 acres so the total biomass delivered to the mill is 3,442,600 lbs.

Multiply this value by 0.5 to get carbon weight, multiply by 3.67 to convert to CO₂, and divide by 2,204.6 to convert to tonnes.

$$\text{CO}_2 \text{ tonnes delivered to the mill} = 3,442,600 \text{ lbs.} \times 0.5 \times 3.67 / 2,204.6 = 2,865.4 \text{ tonnes CO}_2.$$

Table C.1. Specific gravity and Wood Density of green softwoods and hardwoods by forest type for the Pacific Southwest from Table 1.4.

Forest Type	Specific Gravity of Softwoods	Specific Gravity of Hardwoods	Wood Density of Softwoods (lbs/ft ³)	Wood Density of Hardwoods (lbs/ft ³)
Mixed conifer	0.394	0.521	24.59	32.51
Douglas-fir	0.429	0.483	26.77	30.14
Fir-spruce-hemlock	0.372	0.510	23.21	31.82
Ponderosa pine	0.380	0.510	23.71	31.82
Redwood	0.376	0.449	23.46	28.02

The mill efficiencies are shown below. For this example we will use 0.675, which is for softwood sawlogs.

Multiply the CO₂ delivered to the mill by the mill efficiency, which results in 527.0 tonnes CO₂.

Mill Efficiencies by Region		Hardwood		Softwood	
Region	States	Saw Log	Pulpwood	Saw Log	Pulpwood
	Nebraska				
	Kansas				
	Missouri				
	Iowa				
	Illinois				
	Indiana				
Pacific Coast:	Washington	0.568	0.568	0.637	0.637
Pacific Northwest, East (PWE)	Oregon				
Pacific Coast:	Washington	0.531	0.531	0.740	0.500
Pacific Northwest, West (PWW)	Oregon				
Pacific Coast:	California	0.568	0.568	0.675	0.675
Pacific Southwest (PSW)					
Rocky Mountain:	Montana	0.568	0.568	0.704	0.704
Rocky Mountain, North (RMN)	Idaho				
Rocky Mountain:	Nevada	0.568	0.568	0.704	0.704
Rocky Mountain, South (RMS)	Arizona				
	New Mexico				
	Colorado				
	Utah				
	Wyoming				
South:	Virginia	0.609	0.591	0.636	0.553
Southeast (SE)	North Carolina				
	South Carolina				
	Georgia				
	Florida				
South:	Texas	0.587	0.581	0.629	0.570
South Central (SC)	Oklahoma				
	Arkansas				
	Louisiana				
	Mississippi				
	Alabama				
	Tennessee				
	Kentucky				
West: Includes RMN, RMS, PWE, PSW except where stated otherwise		0.568	0.568		

Use the following table to calculate the wood stored in in-use wood products. The default percentages in each class may be found in the Assessment Area Data File on the ARB website, in the "Supersections_HWPs" tab (screenshot shown below). The Sierra Nevada is 97% softwood lumber and 3% hardwood.

	A	B	C	D	E	F	G	H
1	Wood Products Generated							
2	Supersections	Softwood Lumber	Hardwood Lumber	Plywood	Oriented Strand Board	Non-structural Panels	Miscellaneous	Paper
73	Sierra Nevada	97%	0%	3%	0%	0%	0%	0%
74	Sierra Nevada Foothills	99%	0%	0%	0%	0%	0%	0%
75	Snake River Basin	96%	0%	0%	0%	0%	4%	0%
76	Southern Allegheny Plateau	1%	78%	0%	6%	4%	2%	8%
77	Southern California Coast	0%	0%	0%	0%	0%	0%	0%
78	Southern California Mountains	0%	0%	0%	0%	0%	0%	0%
79	Southern Cascades	70%	1%	28%	0%	0%	1%	2%
80	Southern Rockies Front Range	87%	2%	0%	0%	1%	10%	0%
81	Southern Rocky Mountains	86%	1%	0%	0%	1%	12%	0%
82	Southwest High Plains	85%	0%	0%	0%	1%	13%	0%
83	Southwest Plateau	0%	0%	0%	0%	0%	0%	0%
84	Southwestern Desert	0%	0%	0%	0%	0%	0%	0%
85	Southwestern Rocky Mountains	63%	7%	0%	19%	2%	9%	0%
86	St Lawrence & Mohawk Valley	19%	22%	0%	0%	1%	1%	56%
87	Subtropical Prairie Parkland Gulf & Oak Prairie	45%	16%	38%	0%	0%	0%	0%
88	Utah Mountains	55%	4%	0%	24%	2%	15%	0%
89	Wasatch Range	48%	12%	0%	23%	2%	16%	0%
90	Western Allegheny Plateau	4%	88%	0%	0%	0%	0%	7%
91	Western Basin and Range	92%	0%	0%	0%	1%	7%	0%
92	Western Great Plains	90%	0%	0%	1%	1%	7%	1%
93	White Mountains	36%	14%	0%	0%	0%	0%	51%
94	Willamette Valley	74%	3%	14%	0%	0%	0%	9%
95	Yellowstone / Bighorn	89%	0%	2%	0%	0%	8%	1%

CO2 produced in softwood lumber = 0.97 X 527.0 tonnes = 511.2 tonnes.

CO2 produced in plywood = 0.03 X 527.0 tonnes = 15.8 tonnes.

Based on the table in C.2 from the protocol, 0.463 is the 100-year average storage factor for softwood lumber and 0.484 is the average for softwood plywood.

Table C.2. Worksheet to Estimate Long-Term Carbon Storage In In-Use Wood Products

	A	B	C	D	E	F	G
Wood Product Class	Softwood Lumber	Hardwood Lumber	Softwood Plywood	Oriented Strandboard	Non Structural Panels	Miscellaneous Products	Paper
% in each class	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)	(X%)
Metric tons C in each class	(3A)	(3B)	(3C)	(3D)	(3E)	(3F)	(3G)
100-year average storage factor (in-use)	0.463	0.250	0.484	0.582	0.380	0.176	0.058
Average C stored in in-use wood products (metric tons)	(4A)	(4B)	(4C)	(4D)	(4E)	(4F)	(4G)

CO2 stored in softwood lumber = 511.2 tonnes X 0.463 = 236.7 tonnes.

CO2 stored in plywood = 0.03 X 527.0 tonnes = 15.8 tonnes X 0.484 = 7.7 tonnes.

The total in-use wood products stored is 244.3 tonnes of CO2. ~~A similar process is followed for long-term landfill storage, using ARB protocol table C.3 below.~~

~~CO2 stored in softwood lumber = 511.2 tonnes X 0.298 = 152.3 tonnes.~~

~~CO2 stored in plywood = 0.03 X 527.0 tonnes = 15.8 tonnes X 0.287 = 4.5 tonnes.~~

~~The total landfill wood products stored is 156.9 tonnes of CO2.~~

~~The total long-term wood products storage including in-use and landfill is 401.2 tonnes CO2.~~

If waste is sent to a biomass energy facility then calculate the net reduction using the following tool. A more specific analysis may be used where available.

Web site for wood biomass study and related emissions tool:

<http://data.orcaa.org/reports/all-reports-entries/woody-biomass-emissions-study/>

Excel based woody biomass emissions tool:

http://data.orcaa.org/index.php/download_file/view/151/168/

The following cells in the "Main" tab should be modified where appropriate:

Cell B20: 1a: on-site decomposition is default current fate, adjust if needed.

Cell B22: Project acres.

Cell B23: Tons per acre.

Cell D25 (radio button): Project-specific emissions.

Cell I18 (radio button): Mg CO2e.

Cell K22 (radio button): GHGs only.

Cell N23 (radio button): Select if chip and transport or vice versa.

Cell Q22: (radio button): Fate of unrecovered biomass.

Cell D45 (row for displacement of NG, row 46 if used as hog fuel): Recovery rate.

Cell E45: miles to processing facility.

Cell F45: miles to market from processing facility, zero if processing facility co-located with biomass plant

Cell B80: Report CO2.

Cell B118: Chart GHGs.

Report Cell F64 (or other row like 65 is on-site combustion), net on-site decomposition emissions in CO2 tonnes.

Report Cell E186 (unless used as hog fuel then row 185): tonnes of CO2 displaced.

Report Cell F186: Net tonnes of CO2 displaced. This is a net benefit if negative, in parentheses.

PROGRAMMATIC TIMBERLAND ENVIRONMENTAL IMPACT REPORT (PTEIR)

This effort can, for small forestland owners, address forest health, wildland fire risk reduction through fuels treatments and increasing long-term carbon sequestration and storage. The GHG benefits of this section combines a number of elements from sections above, but in this section there is the additional benefit of integrated planning. The business-as-usual baseline is to not do a PTEIR and continue with ad-hoc activities.

There is no forest carbon protocol equivalent for this approach, but there are elements of the other sections that may apply. This could include the reforestation, fuel reduction and forest pest control sections.

Carbon Reduction Estimation

Use the applicable section(s) above based on the stated objectives of the PTEIR. For example, if reforestation is planned to occur on 25 percent of the area, fuel treatments planned to protect all of the area, and forest pest and health treatments on 50 percent of the area, then use the applicable carbon calculations with weights of 1:4:2 respectively. Either the simple or more complex methods apply to this approach.

The following example pertains to a PTEIR for a project consisting of 200 acres. Half of the project area will consist of reforestation and half of the project area will consist of pest control. In the pest control project, dead and dying trees will be harvested in a thin from below to reduce stand densities to healthier levels.

For the 100 acres reforestation area, Example #1 above yields a total of 9,729.8 tonnes CO2. For the 100 acres pest control project, Example #4 above yields a total of 2,865.4 tonnes CO2. It follows that the total carbon reduction for the project is 12,595.2 tonnes CO2.

Carbon reduction for projects that do not have reforestation, fuel treatment or pest control components may be estimated using a recognized growth and yield methodology in which inventory, growth, ingrowth, mortality, yield, species (e.g. where the project proposes reducing the site occupancy of hardwoods relative to conifers) and in-use wood products are captured to estimate the volume (translated in metric tonnes of CO2 equivalents through crosswalk equations) for a "no project" scenario and a "project" scenario.

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