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

March 4, 2015

CONTENTS

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.

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 CO_2e 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

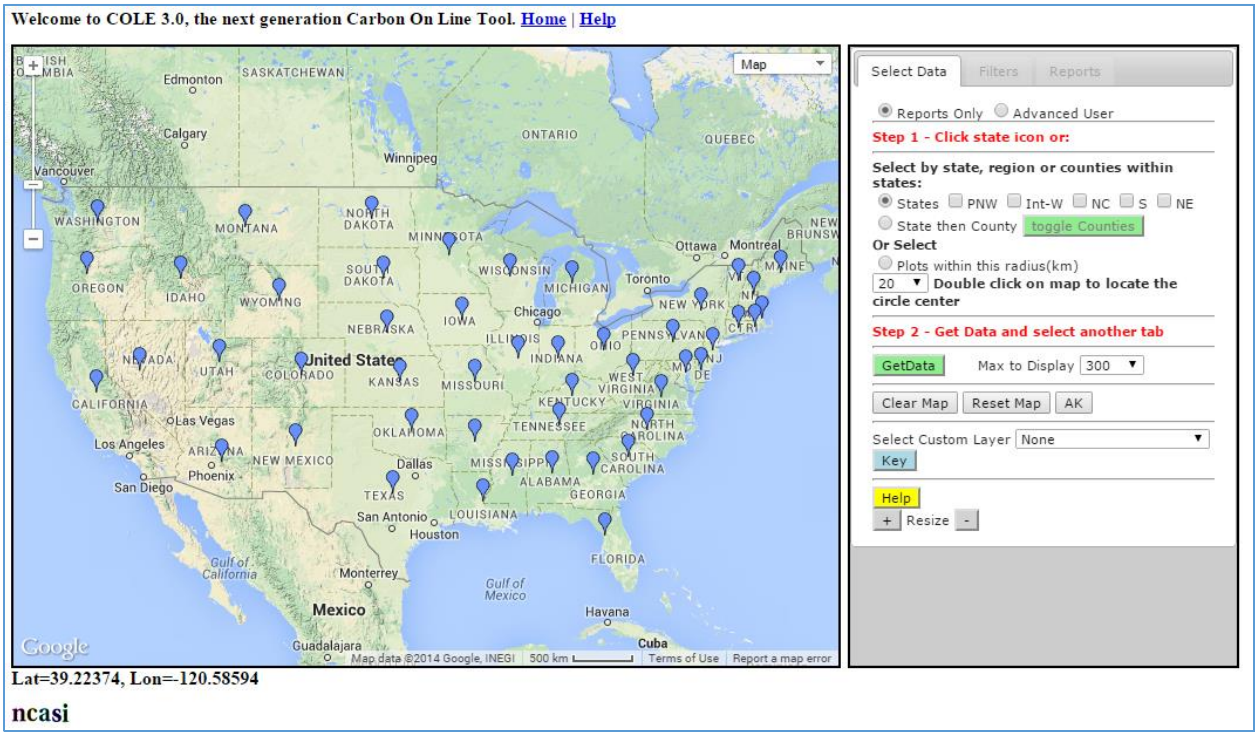
SITE PREP - REFORESTATION PROJECTS Emissions Associated with Mobile Combustion		
Average Metric Tons CO_2e per Acre		
Light	Medium	Heavy
0-25% Brush Cover	>25-50% Dense Brush Cover	>50% Brush Cover, Stump Removal
0.090	0.202	0.429

Figure 1. Equation 6.2 from ARB forest protocol.

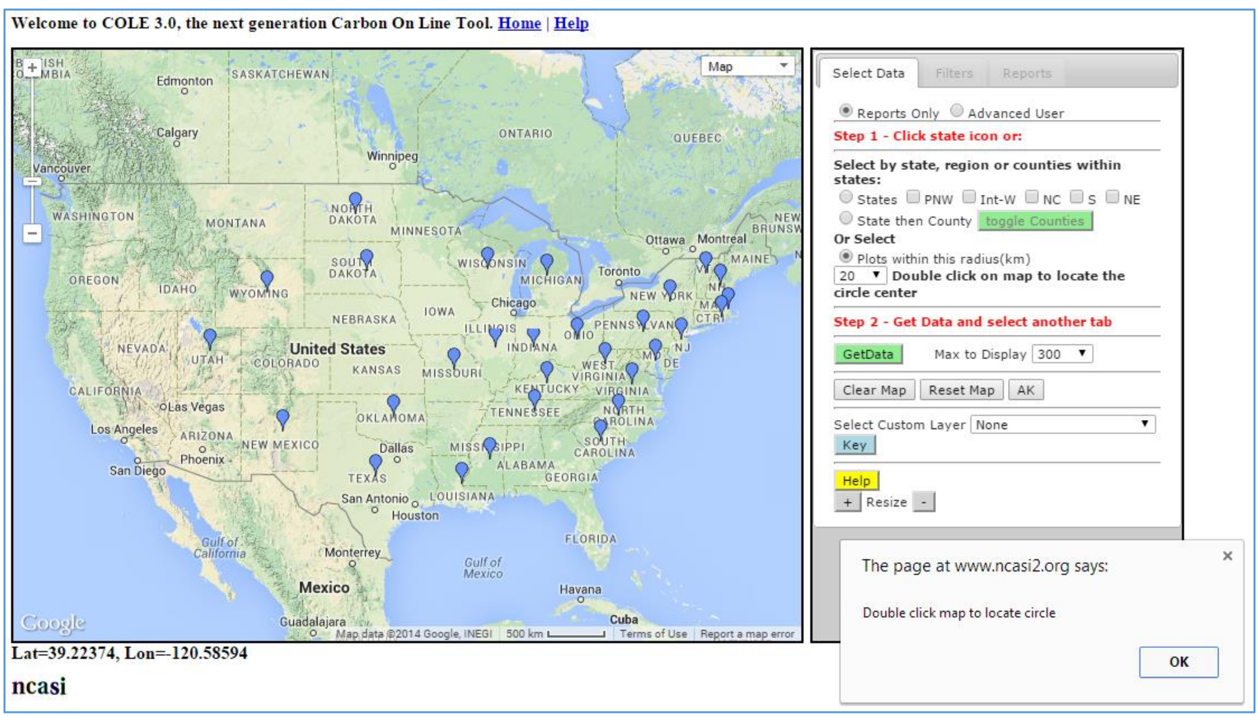
Example #1 – Reforestation, Lookup Approach

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

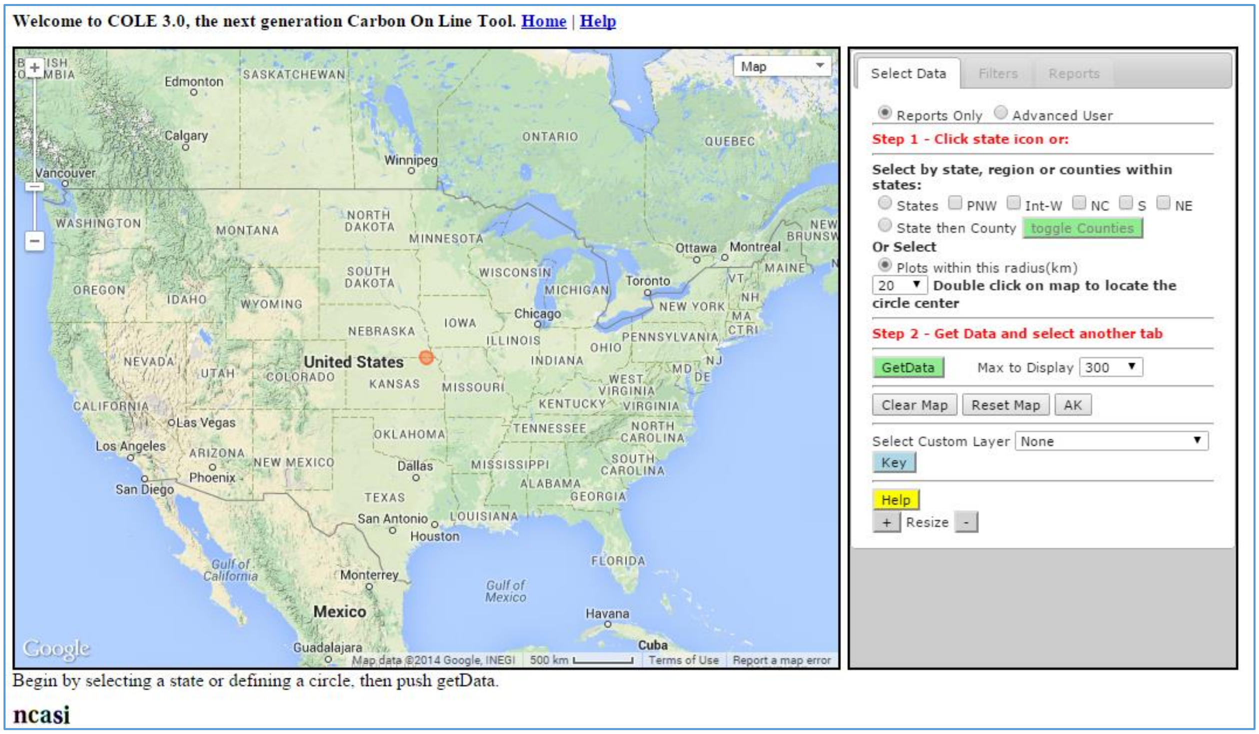
Screen initially looks like this:



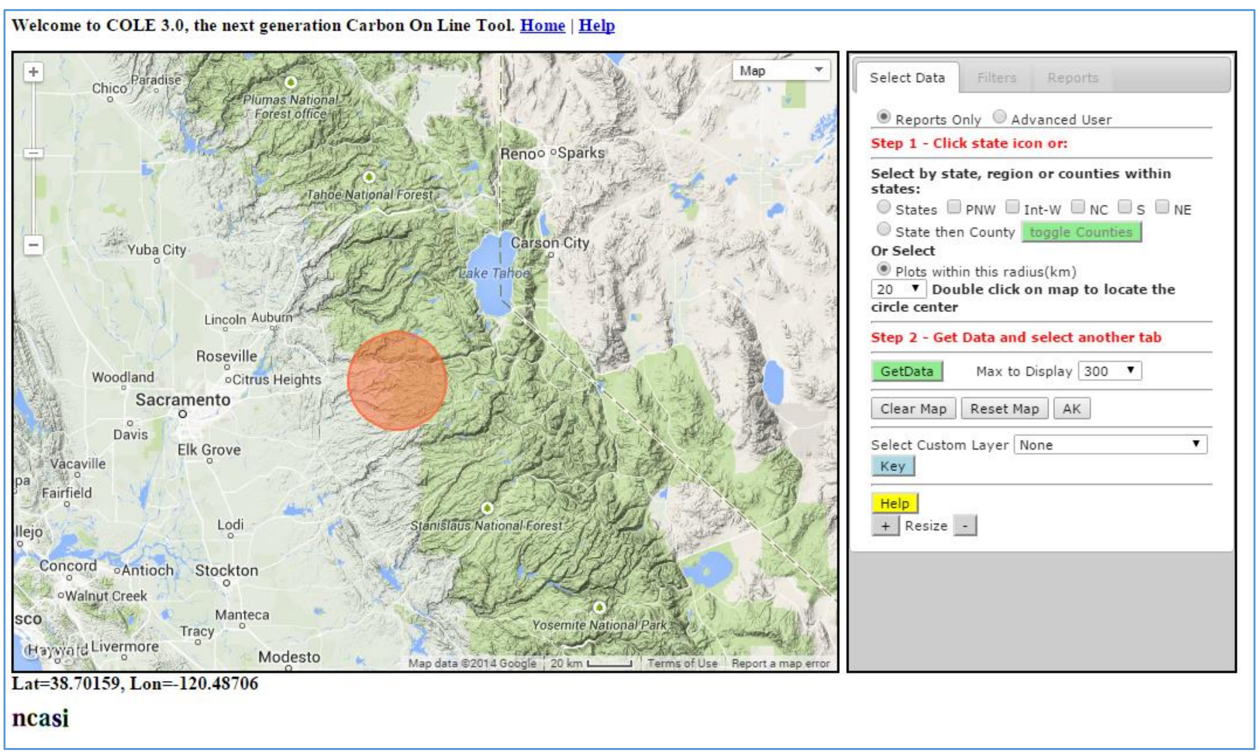
Select the “Plots within this radius (km) button, which gives you this screen:



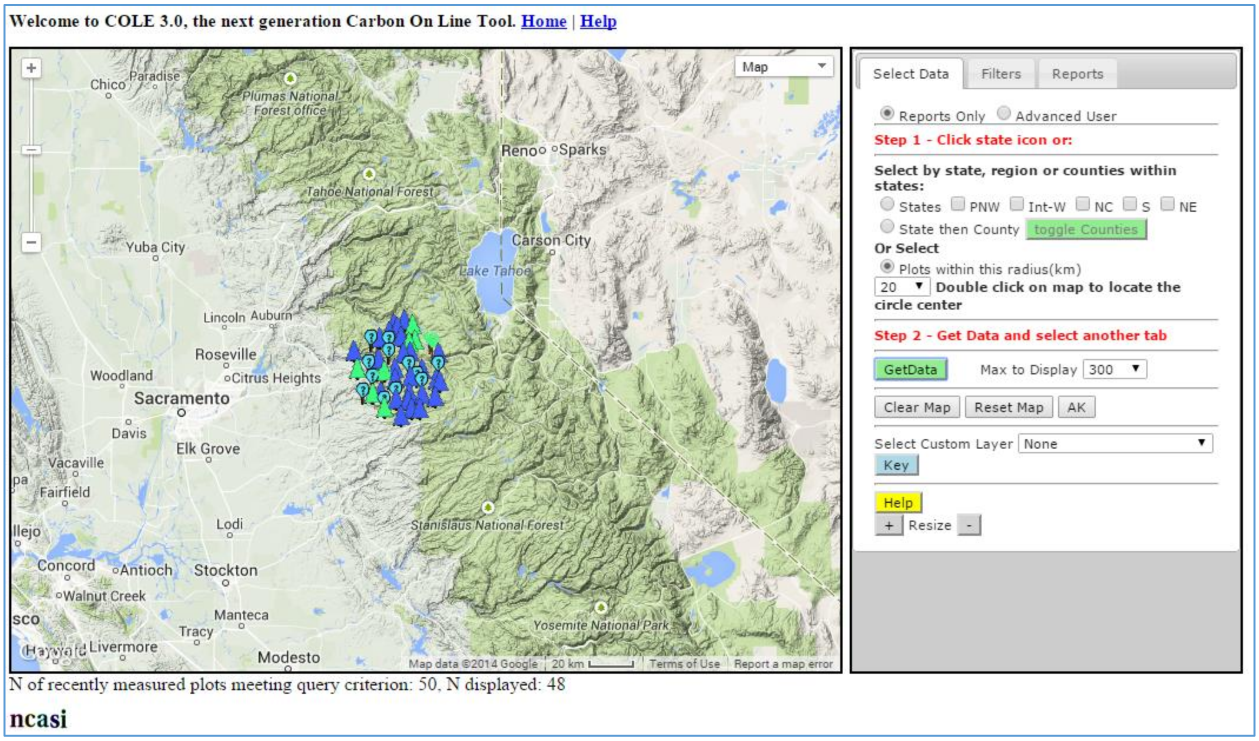
Click OK on the small popup box. Then screen will look like this:



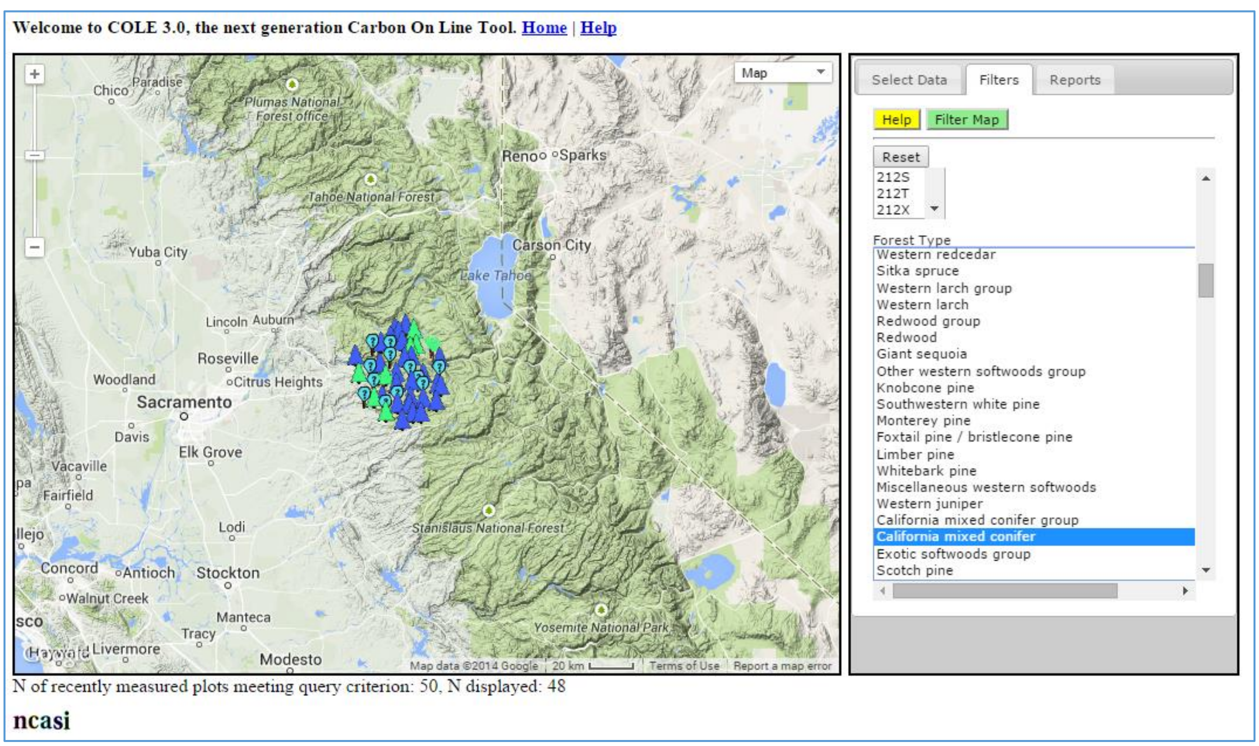
Double click on location of your project area. Zoom in to map as needed.



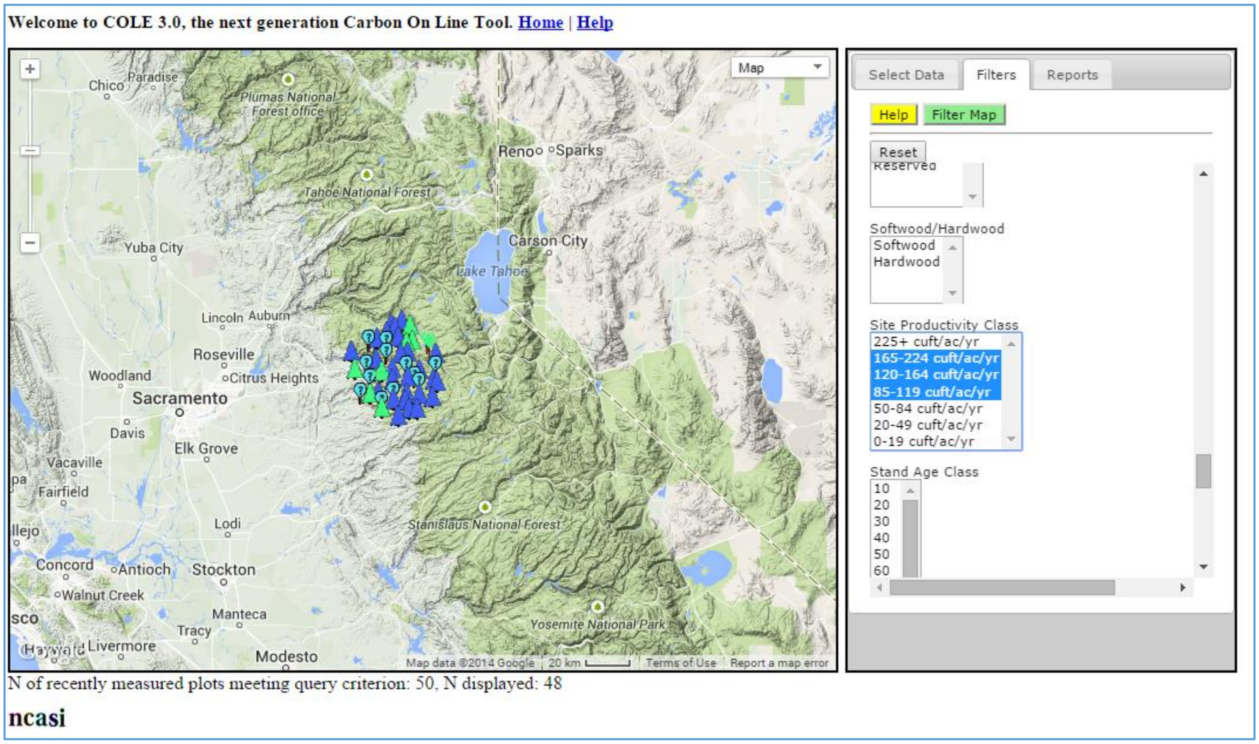
Next, select the green button that says "GetData", which looks like this:



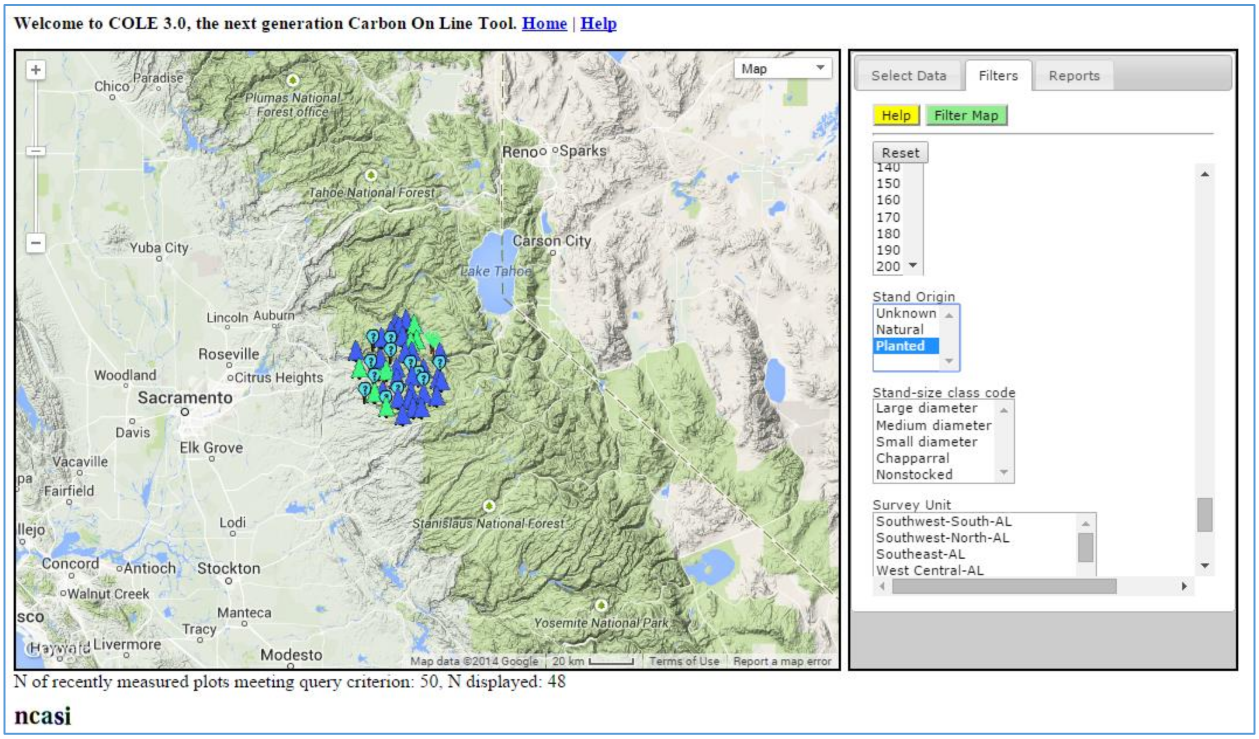
Next, click on the “Filters” tab. Scroll down and select the forest or forest type group; in this case it is mixed conifer forest type. It was necessary to scroll down to the Forest Type window using the scroll bar on the far right and then click on a selection in the Forest Type box and arrow key down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



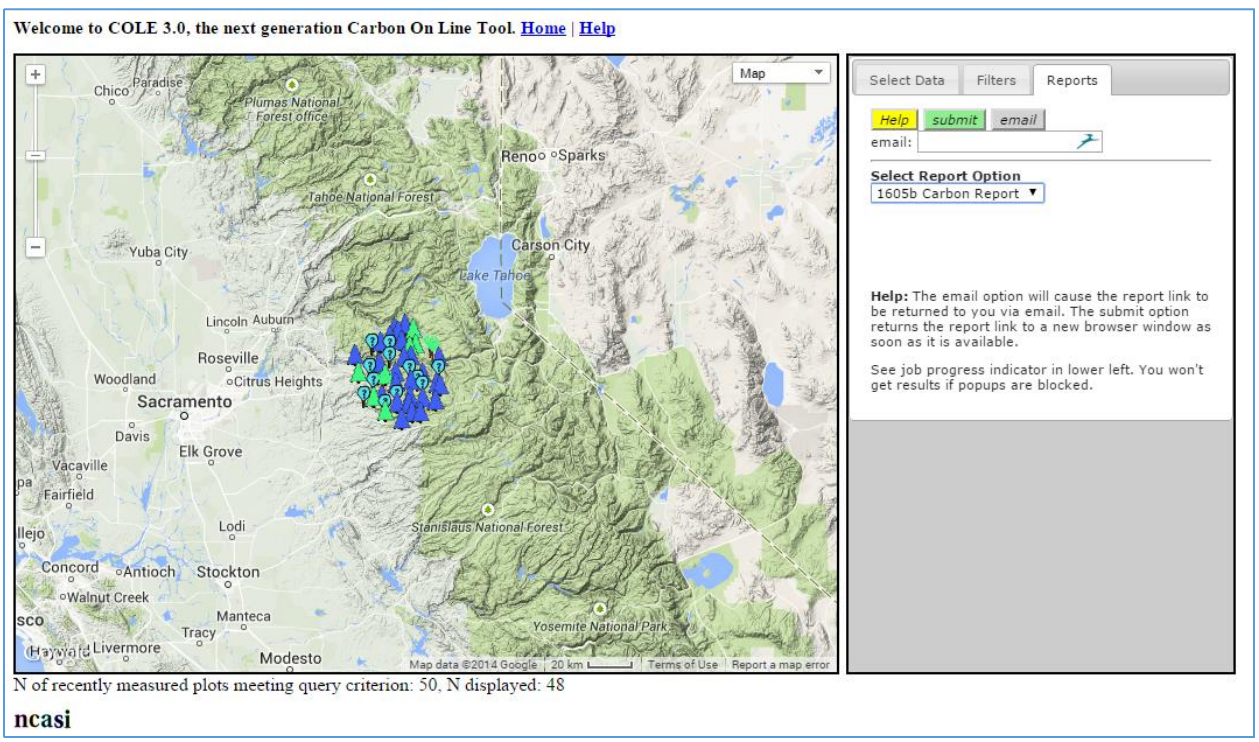
Next, scroll down until you see the “Site Productivity Class” window. In this example we have site class III primarily, which translates to a FIA site class 3. Therefore we shall select FIA site class 2, 3 and 4. This may be done by clicking on site class 2 and then holding down the shift key and clicking 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).



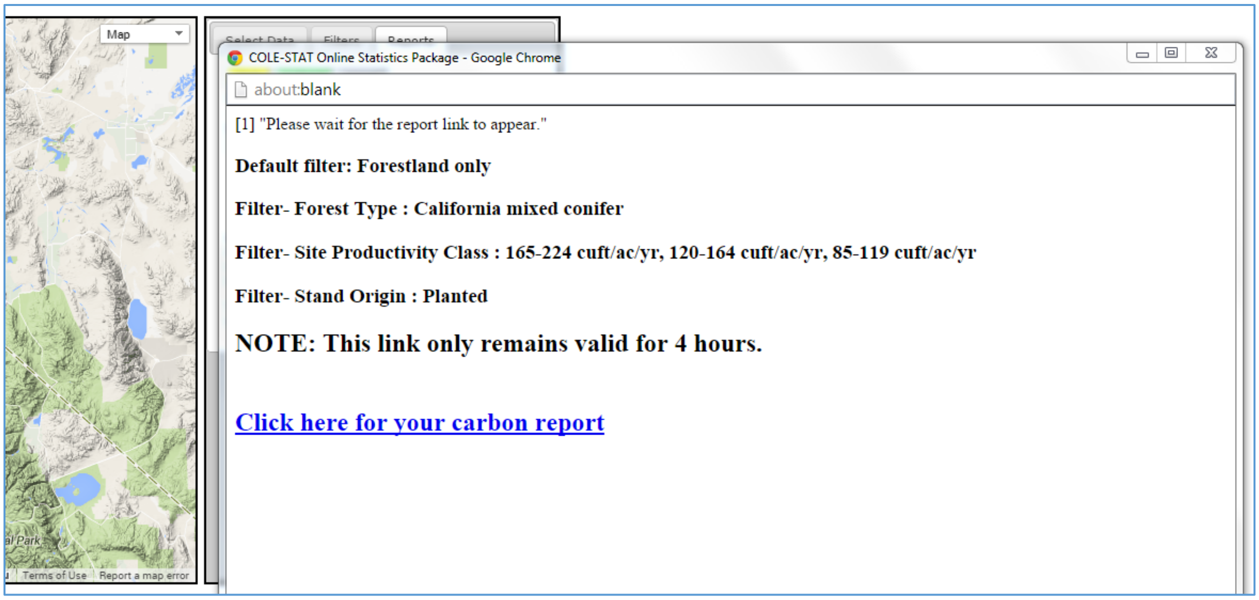
Scroll down and selected “Planted” stand origin as shown below.



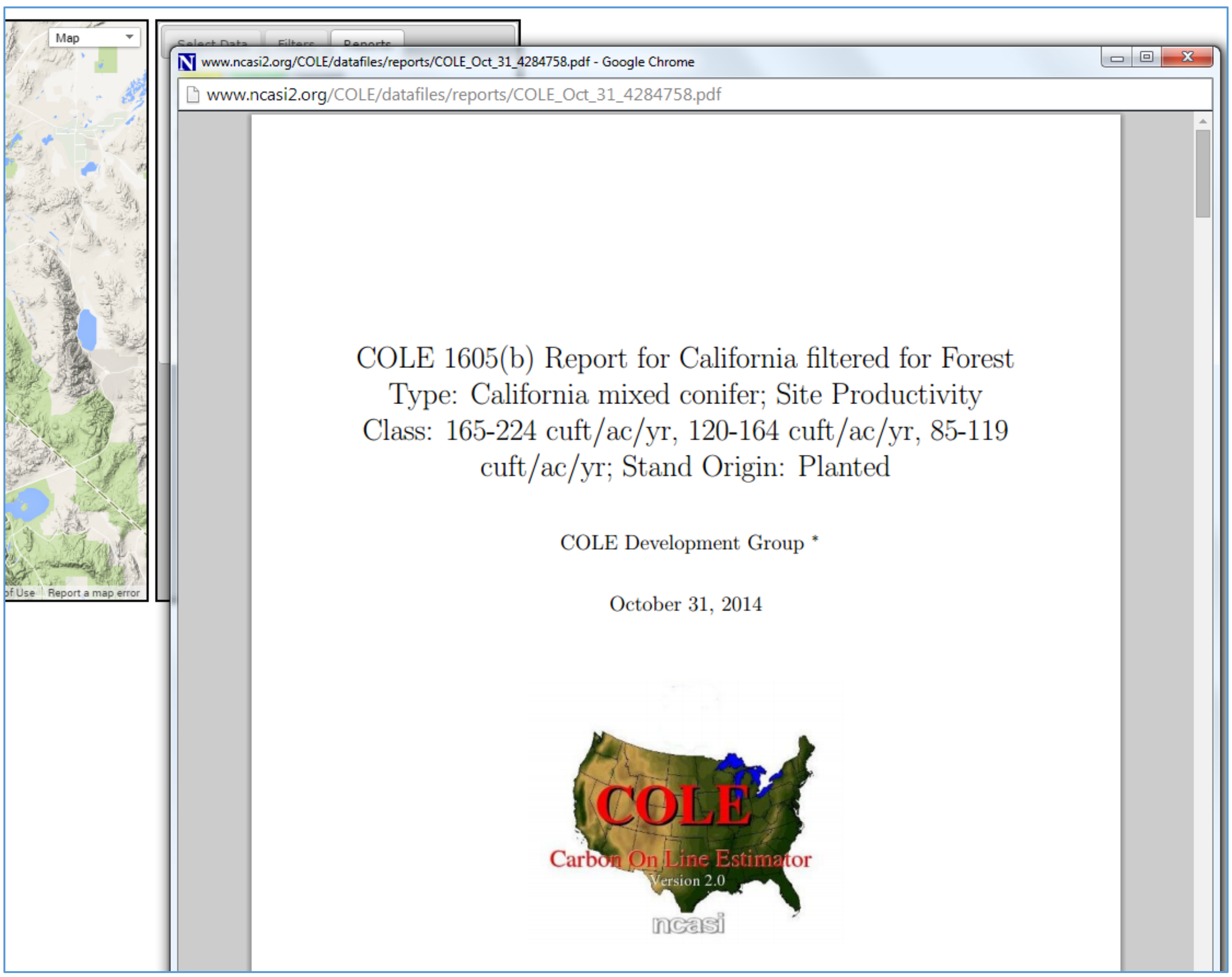
Go to the “Reports” tab next, as shown below. Turn off your browsers popup blocker or at least allow it for the NCASI site, otherwise the report window will not show up.



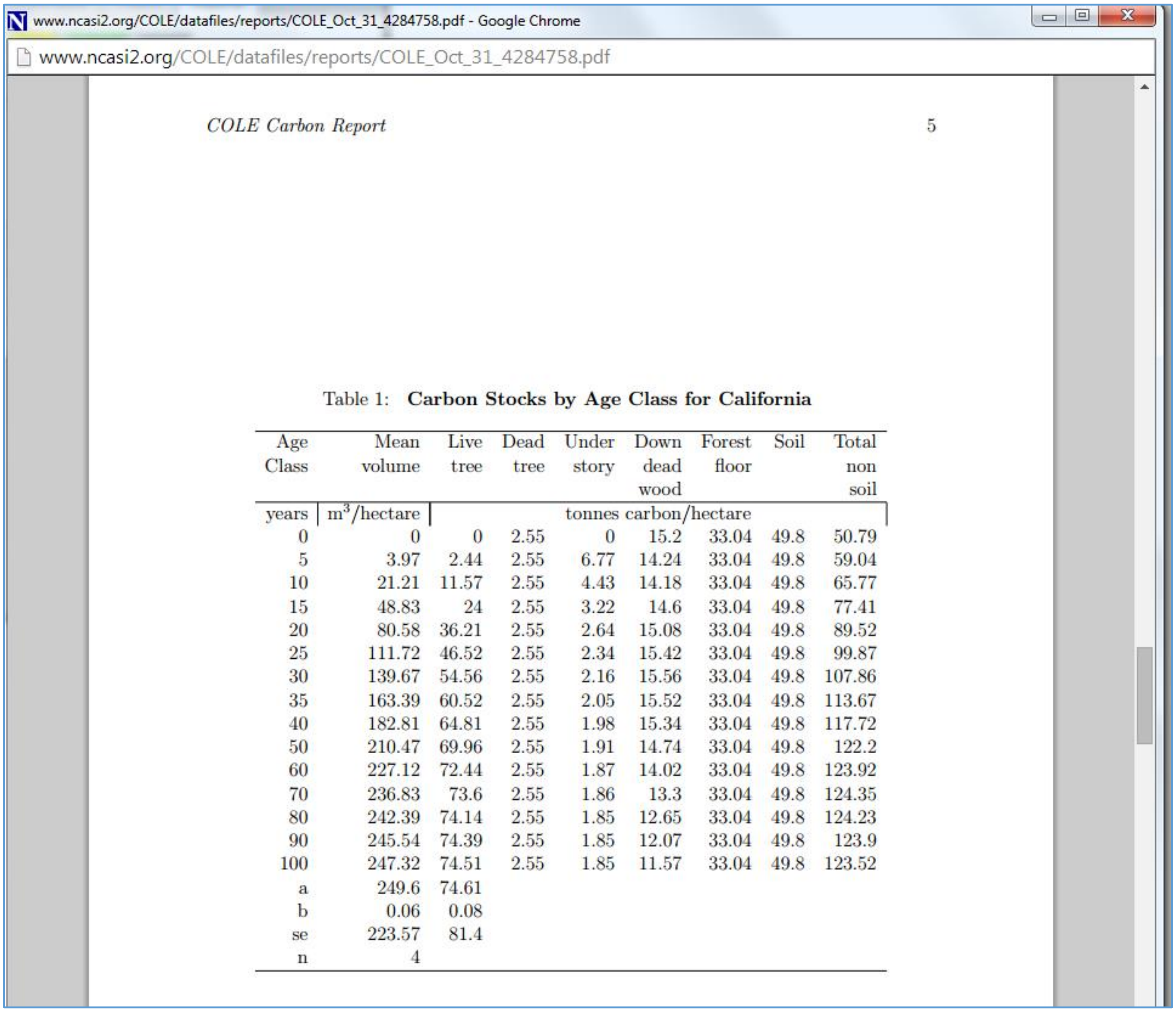
Press the green “Submit” button and wait while processing occurs. The following screen will appear:



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.


www.ncasi2.org/COLE/datafiles/reports/COLE_Oct_31_4284758.pdf - Google Chrome

www.ncasi2.org/COLE/datafiles/reports/COLE_Oct_31_4284758.pdf

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 tonnes CO2 = (111.4 t/a – 13.9 t/a) x 100 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 CO_2 = 9,750 tonnes CO_2 – 20.2 tonnes CO_2

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/capandtrade14addtldoc2.pdf and http://www.arb.ca.gov/regact/2014/capandtrade14/capandtrade14addtldoc1.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

The GHG reduction achieved as a result of a project 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.

Research priorities included in the BCP were as follows:

Evaluating vegetation types and associated management strategies that are more resilient to climate change.

This could be a literature review, data-driven empirical analysis examining climatic and edaphic ranges of species, and/or modeling of vegetation responses to projected climate change including alterations to disturbance regimes. There is a body of work already developed on this, and it becomes somewhat theoretical without an ability to verify or falsify, which can make it not strictly scientific inquiry. Perhaps it would be useful to force researchers to focus on one or two important vegetation types and do an exhaustive study endeavoring to base models on best data available. This would include vegetation management and natural disturbance. Ideally the predictions would be subjected to independent data sets for evaluation.

Estimating tradeoffs between carbon efficient healthy wildland areas as compared to more decadent areas of vegetation with higher wildlife values.

There has been a long running debate on the best way to manage forested landscapes for carbon sequestration and storage, simply put as the old forest versus young forest debate. A valid comparison will have to consider all the pools in the forest (live trees, snags, down wood, litter, duff, soil carbon), storage and emissions associated with wood products, substitution of wood products for other building materials and substitution of biomass energy for other energy sources.

This type of analysis is ideally addressed by a life cycle analysis (LCA) that has well defined boundaries on the landscape (spatially), in the economy (by economic sector), and temporally (period of time needed to take full account of effects). A LCA such as this would have to be model driven. The models used have the potential to bias results and must be carefully selected. Substitution effects may appear well researched from an engineering perspective but not an economic tradeoff perspective, which would arguably be critical for a LCA.

This research spans a number of disciplines and would require a team effort to properly implement. There may be an opportunity to coordinate with the work being done at FRAP on analyzing the GHG impacts of the Forest Practice Regulations.

Developing general descriptions of fire resilient forest and wildland landscapes.

This would provide desired future condition targets that would optimize long-term carbon sequestration and storage by considering both the carbon stored and its probability of volatilization due to disturbance risk. This could be done through an empirical data analysis or a modeling approach. Or a modeling approach could be calibrated or tested using the empirical approach. An empirical approach might use FIA data plots to develop a probability of disturbance (logistic regression for example) or carbon loss based on variables such as stand density index, fuels model(s), fuels characterization in horizontal and vertical context, etc.

Increasing the Use of Wood/Biomass Residue

The California Biomass Collaborative could be used to aid in identifying research gaps related to the use of biomass residue. To increase the use of biomass energy requires the investment of private equity. It may be that technical issues and demonstration are less important at this time than identifying barriers to investment and developing public policy solutions to address them. There has been an explosion of investment in wood pellet production in the Gulf and Atlantic seaboards, primarily for export to northern Europe. Near and long-term wood pellet demand from the Pacific Rim could be studied, with emphasis on South Korea, China and Japan.

Carbon Inventory and Yield of Forest Products

Carbon yields of onsite and harvested wood products are useful data for CEQA analysis of forest management, conversion impacts analysis, and carbon project preliminary assessments. Carbon yields are already available for most forest growth simulators. Yield tables would be useful in that they are simple to use and of sufficient accuracy for many applications. Carbon yield tables for shrublands (coastal, climax, forestland, etc.), woodlands (savannah, riparian, etc.), and forestlands would provide complete geographic coverage for California. Yield tables could be produced for even and uneven-aged scenarios, levels of density, site productivity and species composition.

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 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.)	Annual Conversion 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.
Residential	Estimate using the following formula: TC = min(100, (P*3 / PA)*100) *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 *Each parcel is assumed to deforest 3 acres of forest vegetation.	Estimate using the following formula: AC = TC / 10 *Where:* AC = % annualized conversion TC = % total conversion
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

$$\textbf{TMP\_DBH} = DBH$$

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

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

IF CF4 < 0.3 THEN CF4 = 0.3
IF CF4 > 0.4 THEN CF4 = 0.4

$$\textbf{CV4} = 0.005454154 \times TMP\_DBH^2 \times HT \times CF4 \quad (2)$$

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

IF TMP_DBH > 6.0 THEN

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

$$\textbf{CVT} = \frac{TARIF \times \left(0.9679 - 0.1051 \times 0.5523^{DBH-1.5}\right) \times \left(\left(1.033 \times \left(1.0 + 1.382937 \times exp\left(-4.015292 \times \left(\frac{DBH}{10.0}\right)\right)\right)\right) \times \left(BA + 0.087266\right) - 0.174533\right)}{0.912733} \quad (5)$$

IF TMP_DBH = 6.0 THEN

$$\textbf{SMALL\_TARIF} = 0.5 \times \left(6.0 - DBH\right)^2 + \left(1.0 + 0.063 \times \left(6.0 - DBH\right)^2 \times TARIF\right) \quad (3)$$

IF SMALL_TARIF <= 0.0 THEN SMALL_TARIF = 0.01

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

$$\textbf{CVT} = \frac{TARIF \times \left(0.9679 - 0.1051 \times 0.5523^{DBH-1.5}\right) \times \left(\left(1.033 \times \left(1.0 + 1.382937 \times exp\left(-4.015292 \times \left(\frac{DBH}{10.0}\right)\right)\right)\right) \times \left(BA + 0.087266\right) - 0.174533\right)}{0.912733} \quad (5)$$

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

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

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

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

$$\text{CVT} = CVTS * RTS \quad (4)$$
$$RTS = 0.9679 - 0.1051 \times 0.5523^{(DBH-1.5)}$$

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

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

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

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

EQUATION 6

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

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.

$$BGB = \exp(-0.7747 + 0.8836*\mathrm{LN}(AGB))$$

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 (CO_2 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 CO_2. 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 CO_2. 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 CO_2 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 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 firesheds 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".

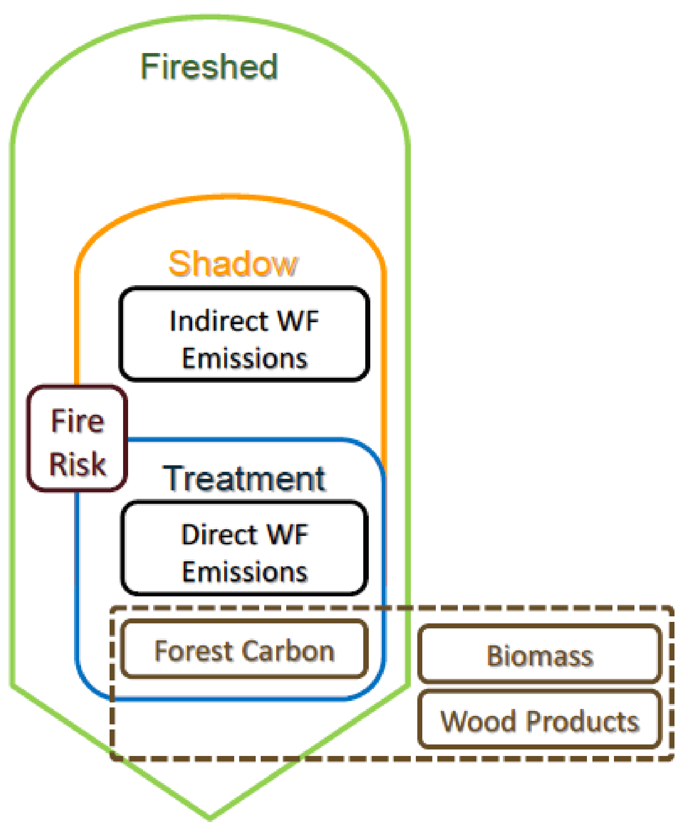


Figure 4: Conceptual Framework

An 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, 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. Consistent with the protocol, landfill carbon storage is excluded if the harvesting in the project scenario exceeds what is estimated in the baseline.

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 an estimated yield of carbon.

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 a species is targeted by a pest for likely extirpation or reduction then the resulting type should be estimated.
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 all but the overstocked density classes.
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.). Use only the live tree column at ½ of the age class that corresponds to the site productivity. For example, if site class III (3) then this corresponds to stand age 60; use age 30 in the table. 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. This provides the estimate of carbon stocks at average stand maturity if in a fully regulated condition, which means if there were an equal distribution of age classes.

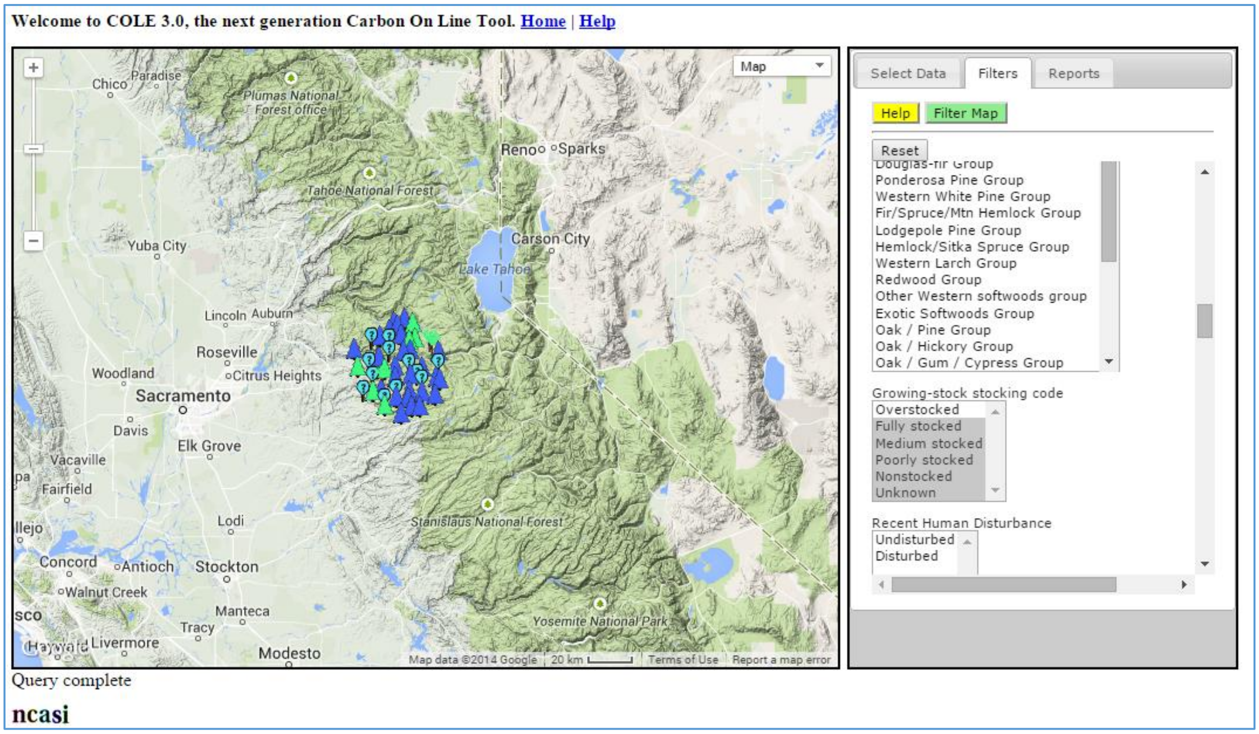
We assume that the baseline is that no action is taken and some long-term vegetation complex will occupy the site. We also assume that this will be a less resilient and less carbon stocked condition. Subtract the following baselines from the estimate of long-term stocks to arrive at an estimate of carbon reductions.

1) If a moderate threat then the baseline is 75% of current stocks.
2) If a high threat then the baseline is 50% of long-term stocks.
3) If an extreme threat then the baseline is 25% of long-term stocks.

Add in long-term wood products storage using the ARB protocol appendix C methodology.

Example #3 – Forest Health and Pest Management Control, Lookup Approach

Look to example #1 for how to query the COLE website. Do not select the planted condition, however. But do select all but the overstocked density classes as shown below.



The resulting table is shown below.

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	0	0	18.95	35.53	49.8	54.48
5	0.75	0.23	0.01	3.1	18.95	35.53	49.8	57.82
10	5.14	1.61	0.05	7.05	18.95	35.53	49.8	63.19
15	14.88	4.7	0.14	6.48	18.95	35.53	49.8	65.8
20	30.34	9.66	0.31	5.27	18.95	35.53	49.8	69.72
25	51.11	16.39	0.56	4.33	18.95	35.53	49.8	75.76
30	76.38	24.67	0.89	3.66	18.95	35.53	49.8	83.71
35	105.2	34.22	1.31	3.18	18.95	35.53	49.8	93.19
40	136.58	44.72	1.81	2.82	18.95	35.53	49.8	103.84
50	203.47	67.47	3.02	2.34	18.95	35.53	49.8	127.32
60	271.11	90.94	4.49	2.04	18.95	35.53	49.8	151.95
70	335.52	113.71	6.15	1.84	18.95	35.53	49.8	176.17
80	394.35	134.9	7.93	1.7	18.95	35.53	49.8	199.01
90	446.56	154.05	9.79	1.6	18.95	35.53	49.8	219.91
100	491.89	170.96	11.68	1.52	18.95	35.53	49.8	238.64
a	714.59	261.41	37.77					
b	0.02	0.02	0.01					
se	369.01	135.75	16.27					
n	25							

We want the 30-year value (1/2 of the 60-year rotation associated with site class III) for live trees, which is 24.67 tonnes C/hectare. Multiply this value by 1.486 to convert to tonnes of CO2 per acre. This results in 36.66 tonnes of CO2 per acre.

In this example there is an extreme threat so that the baseline is 25 percent of the stocks. The baseline is therefore:

Baseline Carbon = 0.25 X 36.66 tonnes/acre = 9.16 tonnes/acre.

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. On average 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 in-use and landfill storage over 100 years.

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

Biomass of delivered wood (zero moisture) = 1.4 thousand cubic feet per acre (MCF/ac) X 24.59 lbs/ft3

= 34,426 lbs per acre.

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 and divide by 2,204.6 to convert to tonnes.

CO2 tonnes delivered to the mill = 3,442.6 lbs. X 0.5 / 2,204.6 = 780.8 tonnes CO2.

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

Region	States	Hardwood		Softwood	
		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: Pacific Southwest (PSW)	California	0.568	0.568	0.675	0.675
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 appendix F excel file on the ARB website, in the "Supersections_HWPs" tab (screenshot shown below). The Sierra Nevada is 97% softwood lumber and 3% plywood.

CO_2 produced in softwood lumber = 0.97 X 527.0 tonnes = 511.2 tonnes.

CO_2 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.

CO_2 stored in softwood lumber = 511.2 tonnes X 0.463 = 236.7 tonnes.

CO_2 stored in plywood = 0.03 X 527.0 tonnes = 15.8 tonnes X 0.484 = 7.7 tonnes.

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)

	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%

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.

Table C.3. Worksheet to Estimate Long-Term Carbon Storage in Wood Products in Landfills

	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 (landfills)	0.298	0.414	0.287	0.233	0.344	0.454	0.178
Average C stored in landfills (metric tons)	(4A)	(4B)	(4C)	(4D)	(4E)	(4F)	(4G)

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.

The total benefit of this project is:

Total CO2 reduction estimate (tonnes) = 36.66 t/a stocks - 9.16 t/a baseline + 4.01 t/a wood products

= 31.5 tonnes per acre CO2

Since the project is 100 acres this means that 3,150 tonnes CO2 is the reduction benefit.

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 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:

Biomass of delivered wood (zero moisture) = 1.4 thousand cubic feet per acre (MCF/ac) X 24.59 lbs/ft3

= 34,426 lbs per acre.

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 and divide by 2,204.6 to convert to tonnes.

CO2 tonnes delivered to the mill = 3,442.6 lbs. X 0.5 / 2,204.6 = 780.8 tonnes CO2.

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

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

CO_2 produced in softwood lumber = 0.97 X 527.0 tonnes = 511.2 tonnes.

CO_2 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.

Table C.3. Worksheet to Estimate Long-Term Carbon Storage in Wood Products in Landfills

	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 (landfills)	0.298	0.414	0.287	0.233	0.344	0.454	0.178
Average C stored in landfills (metric tons)	(4A)	(4B)	(4C)	(4D)	(4E)	(4F)	(4G)

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.

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.

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