California Department of Forestry and Fire Protection and California Air Resources Board

Greenhouse Gas Interim Quantification Methodology for the California Department of Forestry & Fire Protection Forest Management Program Greenhouse Gas Reduction Fund Fiscal Year 2014-15

A. Introduction

The California Air Resources Board (ARB) is required to develop quantification methods for agencies receiving Greenhouse Gas Reduction Fund (GGRF) appropriations per SB 862 (Senate Budget and Fiscal Review Committee, Chapter 36, statues of 2014).

Some administering agencies receiving appropriations of Fiscal Year (FY) 2014-15 GGRF funds developed interim quantification methodologies in consultation with ARB. For FY 2015-16 and future years, ARB will continue to develop or update quantification methodologies for GGRF funded programs.

B. Quantification Methodology

The California Department of Forestry and Fire Protection (CAL FIRE) developed the GGRF Forest Management Program to increase carbon sequestration and reduce greenhouse gas (GHG) emissions through measures including reforestation of lands degraded by fire or other catastrophic event, conservation of forest land threatened by conversion, stabilization of carbon through fuels reduction treatments, and suppression and management of forest pests. CAL FIRE used a contractor to develop a guidance document containing suggested methods that applicants could use to estimate the net GHG benefit of proposed projects. Applicants were free to use their own quantification methods, the quality of which was considered as part of project selection.

For purposes of project tracking and reporting, ARB, in consultation with CAL FIRE, modified the CAL FIRE guidance document to produce the attached standardized interim quantification methodology for use in estimating the net GHG benefit from forest management projects funded with FY 2014-15 GGRF monies. As of the posting of this document, there is not an approved quantification methodology for fuels reduction projects. ARB, in collaboration with CAL FIRE, is working to develop a GHG quantification methodology for fuels reduction projects funded with GGRF monies. The interim quantification methodology is used to estimate the net GHG emission reduction associated with the following:

- Carbon stored in live and dead trees;
- Carbon sequestered by live trees;
- Carbon stored long-term in harvested wood products;
- Avoided emissions resulting from the generation of renewable biomass energy; and
- Emissions from equipment used for site preparation for reforestation projects.

The interim quantification methodology provides direction on how to quantify the net GHG benefit for each project type including the period of time over which the benefits are assessed; which GHG sources, sinks, and reservoirs to include in the assessment; and which quantification tools to use. For some project types, the standardized interim quantification methodology provides two options for estimation: a lookup approach requiring the use of lookup tables and a modeling approach requiring the use of forest growth simulators and carbon accounting based on tree lists. Estimates of net GHG

benefits can be derived using either method applicable to the project type.

The interim quantification methodology utilizes GHG accounting principles, species specific volume and biomass equations, and plot data from the following sources:

- ARB Compliance Offset Protocol for U.S. Forest Projects (2014);[1]
- U.S. Forest Service Carbon On Line Estimator (COLE) Version 3.0;[2]
- Forest growth models such as the U.S. Forest Service Forest Vegetation Simulator (FVS);[3]
- Climate Action Reserve Quantification Guidance for use with Forest Carbon Projects;[4]
- U.S. Forest Service Forest Insect and Pathogen Hazard Rating System Database;[5]
- ARB and CalRecycle Biomass Conversion Study (2013);[6] and
- ARB Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Forest Waste (2009)[7]

C. Next Steps

ARB will continue to evaluate and update the GHG emission reduction quantification methodologies as necessary for future FY GGRF appropriations. The intent of providing a more standardized approach to quantification in future years is to aid applicants in their evaluation of GHG benefits and to streamline the review of that information by CAL FIRE and ARB. Quantification methods are posted on ARB's auction proceeds webpage at:
http://www.arb.ca.gov/cc/capandtrade/auctionproceeds/quantification.htm

[1] http://www.arb.ca.gov/regact/2014/capandtrade14/ctusforestprojectsprotocol.pdf
[2] http://www.ncasi2.org/GCOLE3/gcole.shtml
[3] http://www.fs.fed.us/fmsc/fvs/
[4] http://www.climateactionreserve.org/wp-content/uploads/2012/08/FPP_Quantification_Guidance_1.21.14.pdf
[5] http://www.fs.fed.us/foresthealth/technology/haz_rating_database.shtml
[6] http://www.arb.ca.gov/cc/waste/biomassconversion.pdf
[7] http://www.arb.ca.gov/fuels/lcfs/022709lcfs_forestw.pdf

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

Contents

INTRODUCTION 4

REFORESTATION 4

Net GHG Benefit Estimation 4

DEMONSTRATION STATE FOREST RESEARCH 15

Net GHG Benefit Estimation 15

FOREST LEGACY 16

Net GHG Benefit Estimation 16

FOREST PEST CONTROL 22

Net GHG Benefit Estimation 22

REFERENCES 26

INTRODUCTION

Greenhouse gas (GHG) quantification methodologies for four project types are covered in this document:

1. Reforestation
2. Demonstration State Forests Research
3. Forest Legacy Program
4. Forest Pest Control

The Air Resources Board (ARB) Compliance Offset Protocol, U.S. Forest Projects (ARB, 2014a) (ARB Protocol) will be relied on where feasible to provide consistent state policy. For some project types, there are two methodologies provided with varying degrees of analytical complexity: 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 lookup method may not be appropriate for all projects.

As of the posting of this document, there is not an approved quantification methodology for fuels reduction projects. ARB, in collaboration with CAL FIRE, is working to develop a GHG quantification methodology for fuels reduction projects funded with GGRF monies.

REFORESTATION

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 (CAL FIRE, 2014). 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, 2014b). 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.

Net GHG Benefit 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 should 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-year planning interval. In order to estimate the GHG benefit resulting from implementing the project, subtract the baseline scenario estimate from the reforestation project estimate.

Lookup Approach

This approach uses the COLE version 3 (http://www.ncasi2.org/GCOLE3/gcole.shtml) forest carbon online estimator, which is based on USDA Forest Service Forest Inventory and Analysis (FIA) Program 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 carbon 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):

Table 1

FIA	Mixed Conifer	Douglas-fir	Redwood
1	I	I	I
2	II	I, II	II
3	III	III	III
4	IV	IV	IV, V
5	V	V	V
6, 7	V	V	V

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. Carbon yield 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 ARB 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. Report in metric tons of carbon dioxide equivalent (CO_2e) per acre of the live and dead trees. Multiply the values by 1.486 to convert C per hectare to CO_2e per acre (i.e., multiply by 3.67 to convert from C to CO_2e and divide by 2.47 to convert from hectares to acres).

Repeat the process in COLE for the baseline scenario.

1) Select the same location of the project on the map.
2) Select "nonstocked" for all live stocking code.
3) 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.

Add the values from the live and dead tree columns for the age class that corresponds to the site productivity. If soil was included in the project scenario, also include it in the baseline. Again multiply the sum by 1.486 to convert C per hectare to CO_2e per acre.

Subtract the baseline scenario from the project scenario to determine the change in CO_2e per acre as a result of the project.

Next, subtract an estimate of the carbon removed in site preparation according to Table 1 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 CO_2e per acre, if light to medium shrubs then subtract 13.9 metric tons CO_2e per acre, and if heavy shrubs then subtract 24.0 metric tons CO_2e per acre.

Table 2

Carbon Removed in Site Preparation	
Land Cover Type	MT CO_2e per acre
Grass	3.6
Light to medium shrubs	13.9
Heavy shrubs	24.0

Multiply the per acre CO_2e estimates by the number of acres in the project or by strata if applicable.

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 Figure 1 below), which multiplies the project acres by the per acre emission estimate based on brush cover categories.

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

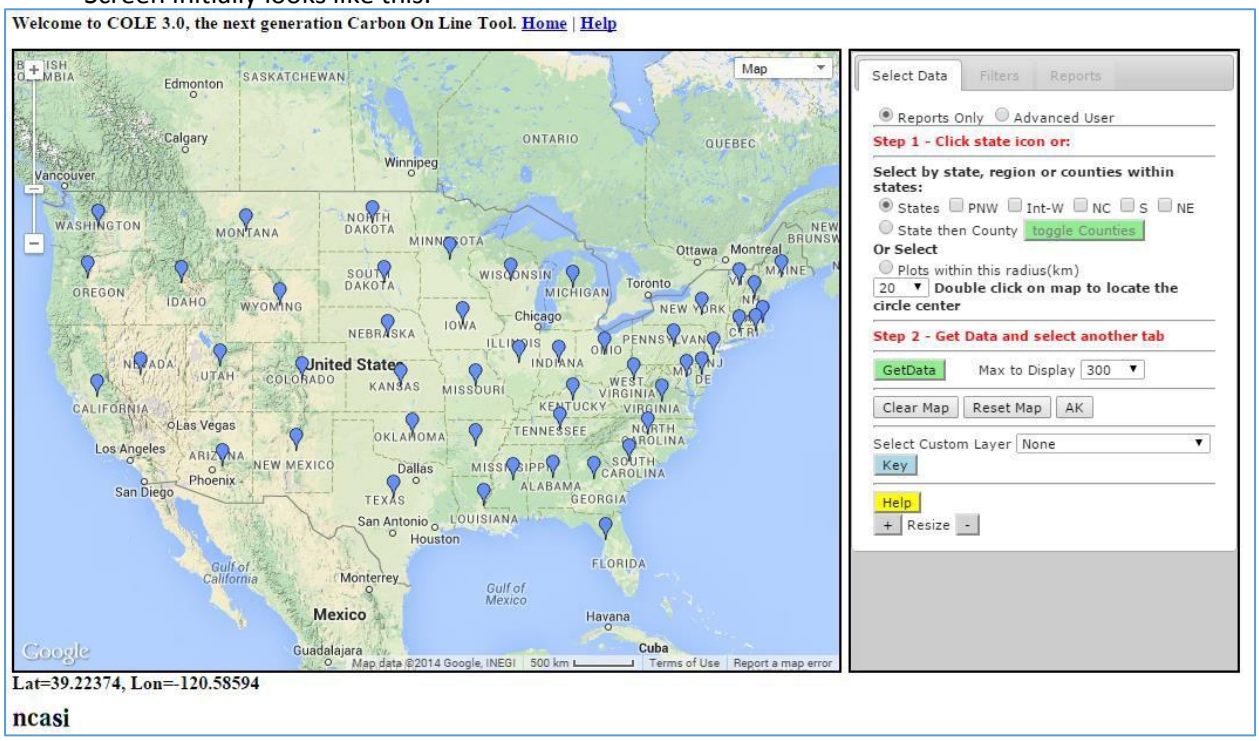
Figure 1. Equation 6.2 from ARB Protocol.

If harvesting is planned, estimate the amount of carbon that would remain stored in wood products using Appendix C of the ARB Protocol. An example of how to calculate carbon stored long-term in wood products can be found under the forest pest control project type of this document (pp. 22-25).

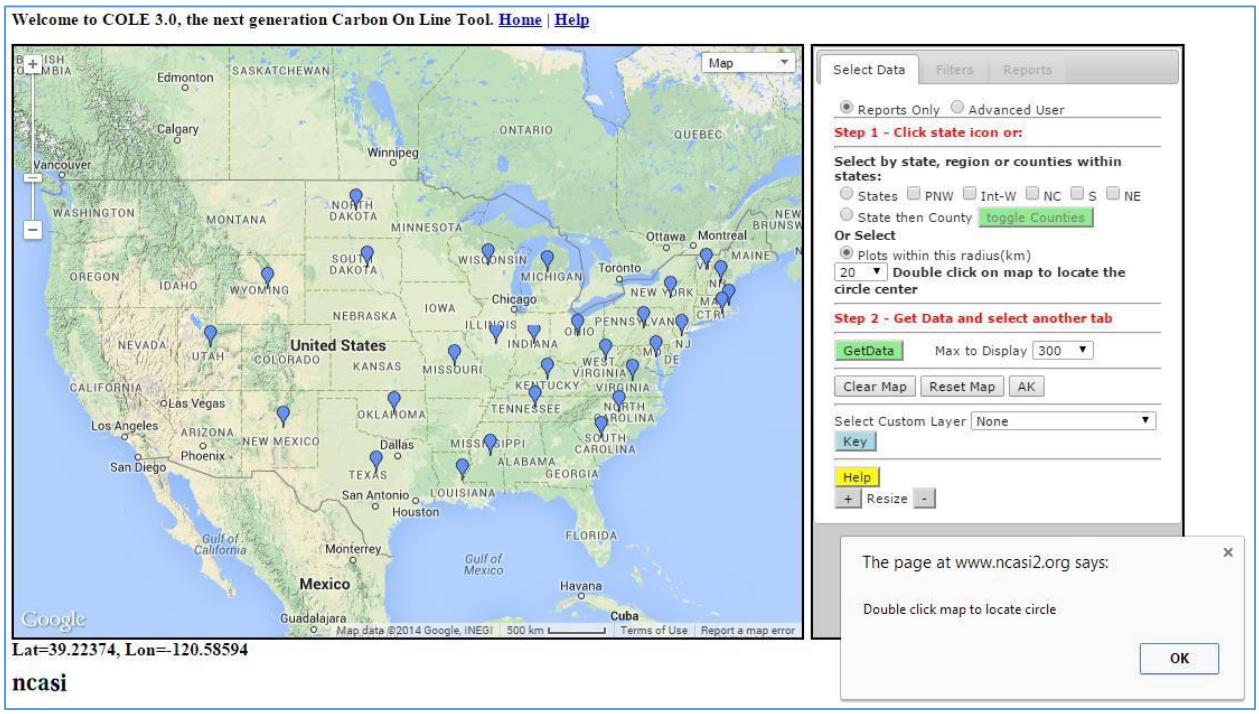
Example #1 – Reforestation, Lookup Approach

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

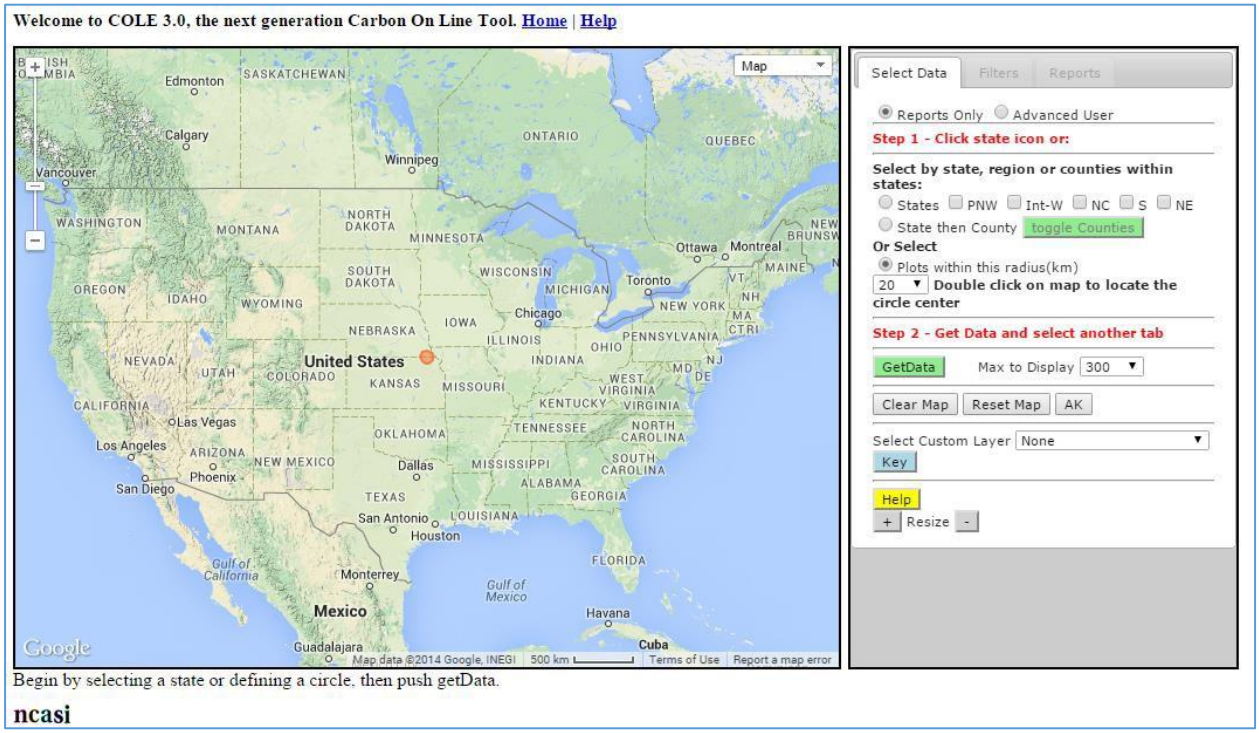
Screen initially looks like this:



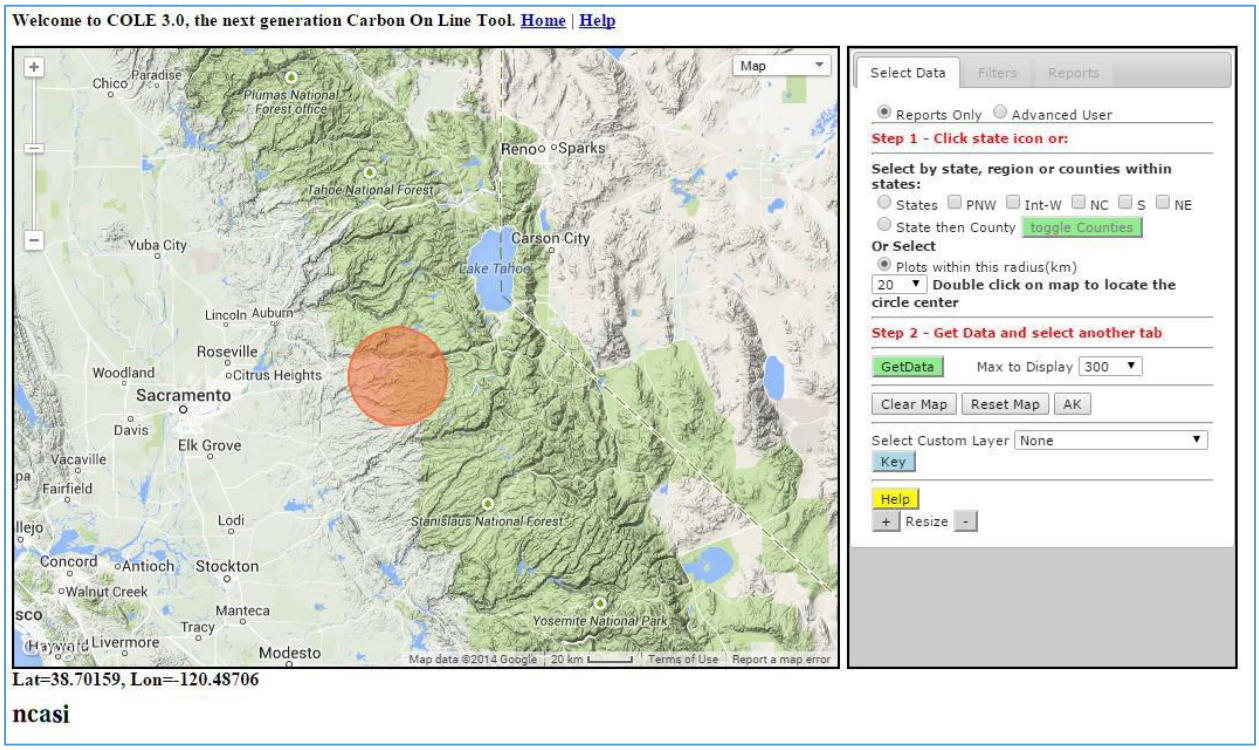
Select "Plots within this radius (km)" button, which gives you this screen:



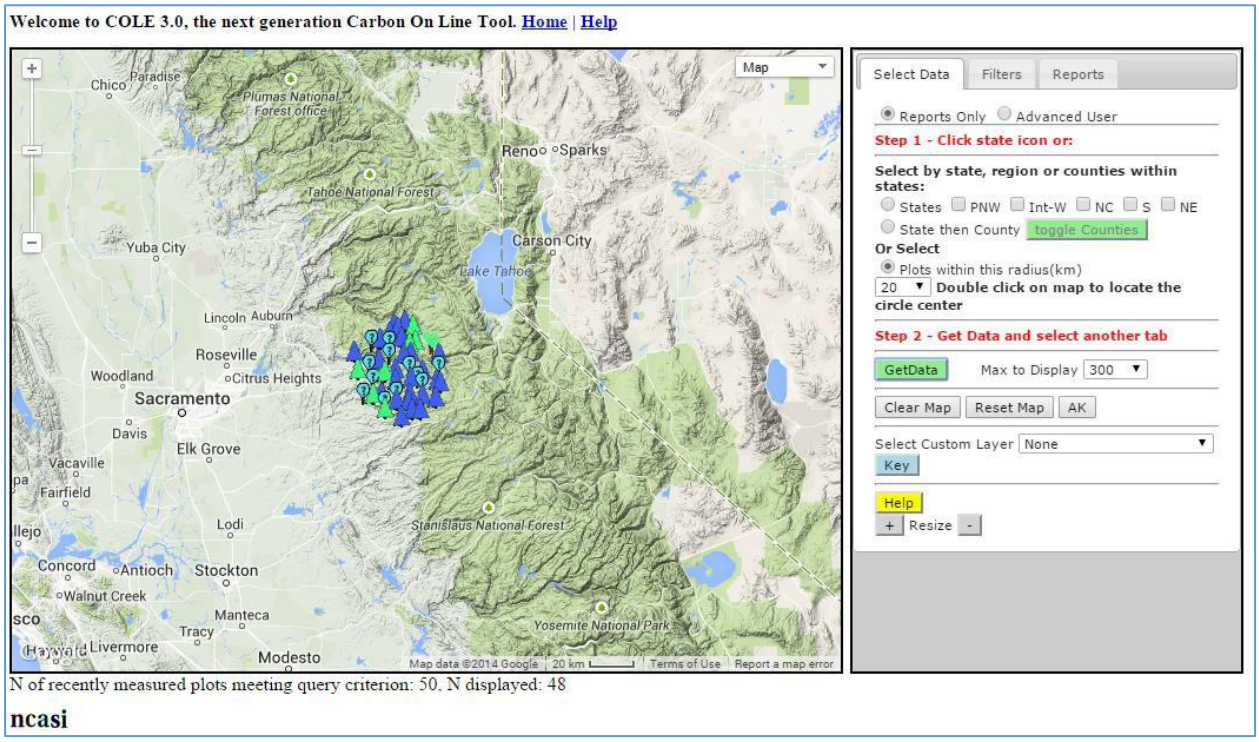
Click OK on the small popup box. Then screen will look like this:



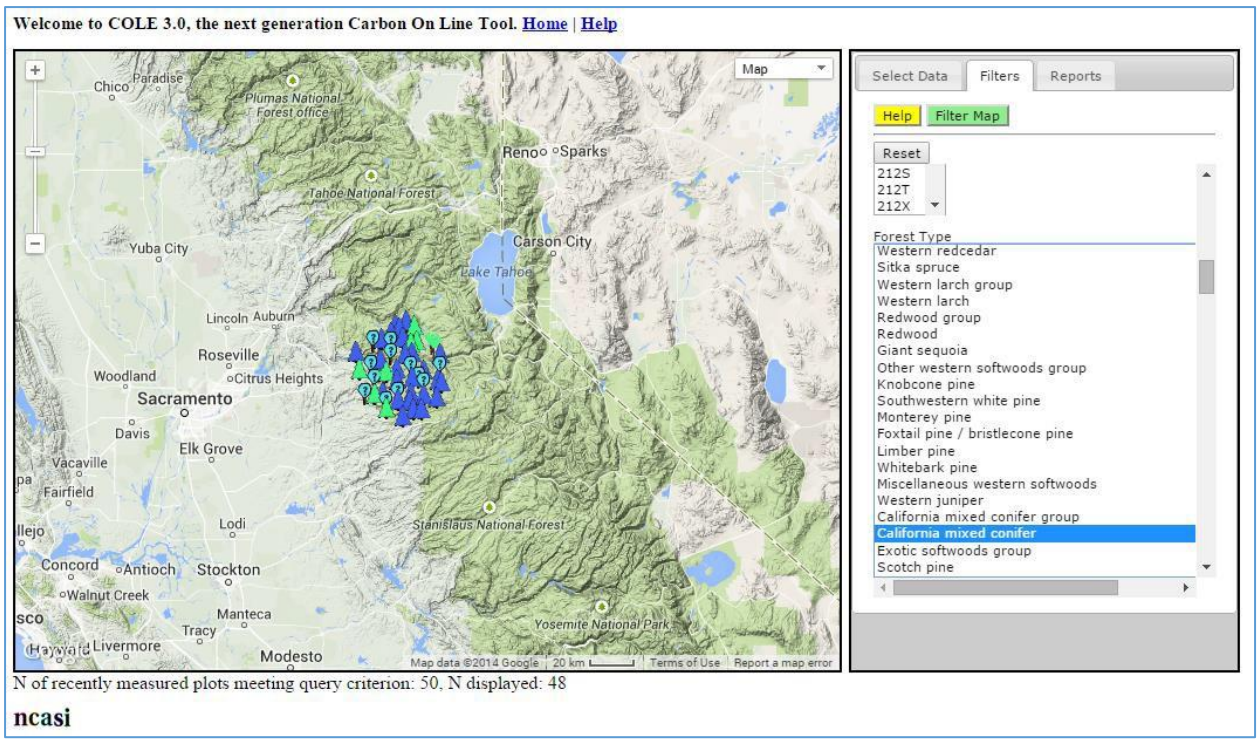
Double click on location of your project area. Zoom in to map as needed.



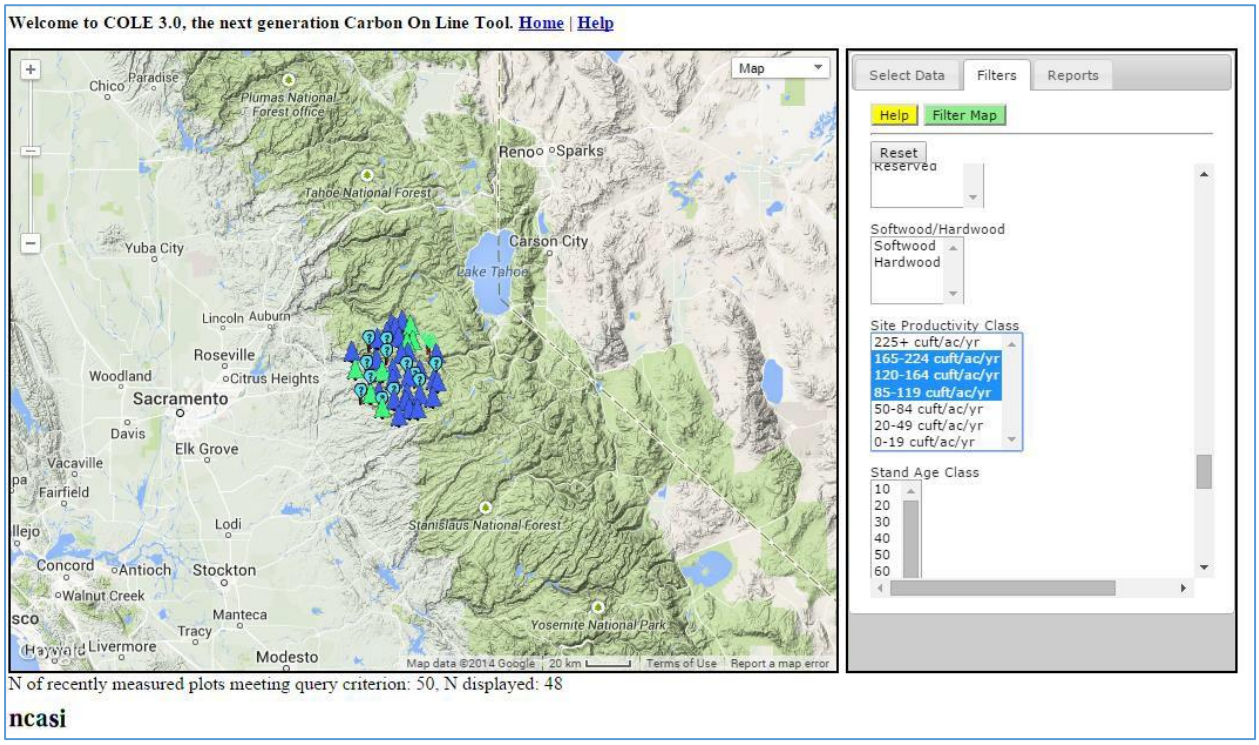
Next, select the green button that says “GetData.” Data icons will appear in the selected area.



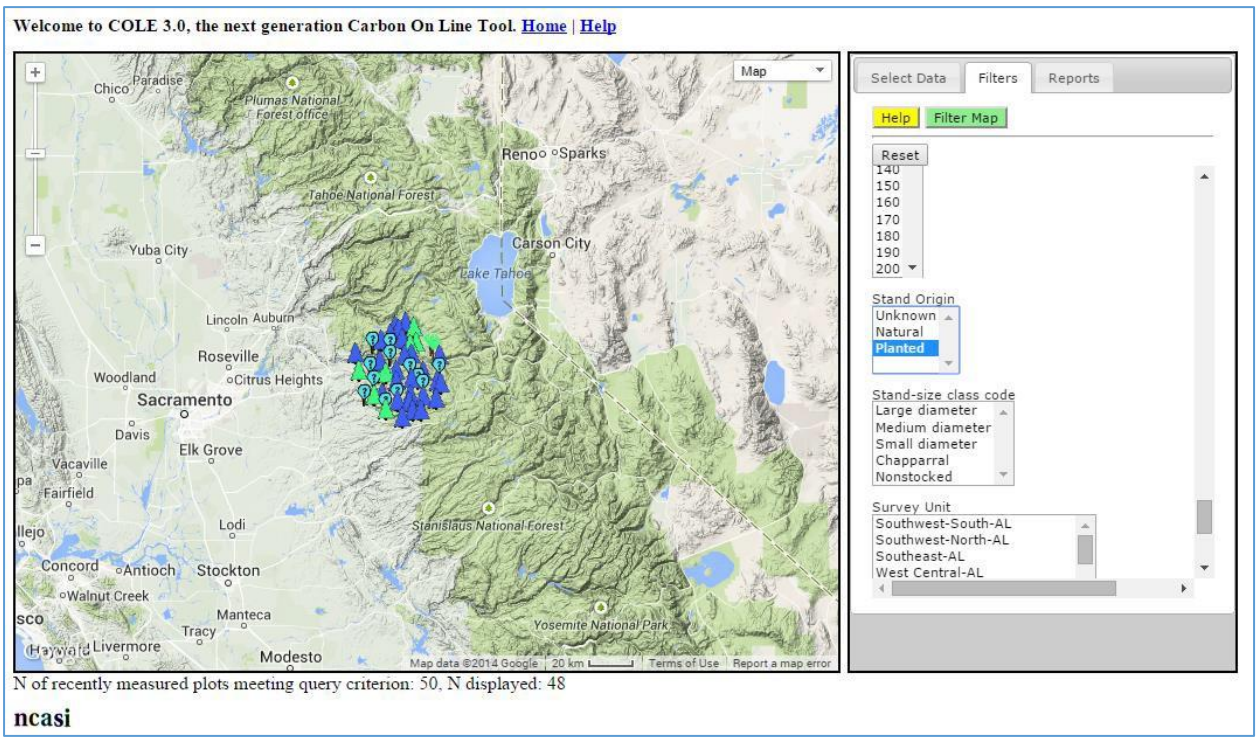
Next, click on the “Filters” tab. Scroll down to the “Forest Type” window and select the forest or forest type group for your project. In this case it is mixed conifer forest type. It may be necessary to scroll down to the “Forest Type” window using the scroll bar on the far right and then click on a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



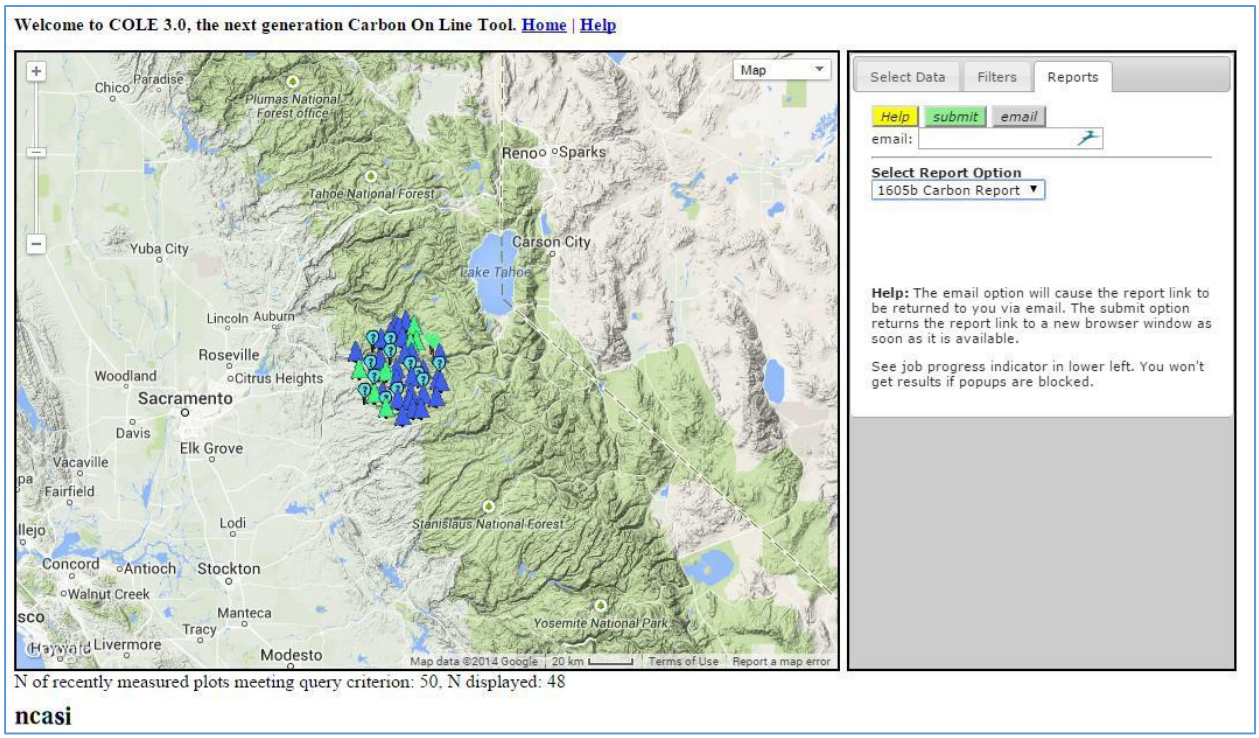
Next, scroll down until you see the “Site Productivity Class” window. In this example we have site class III primarily, which translates to a FIA site class 3. Therefore we select FIA site class 2, 3 and 4. This may be done by clicking on site class 2 and then holding down the shift key and clicking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



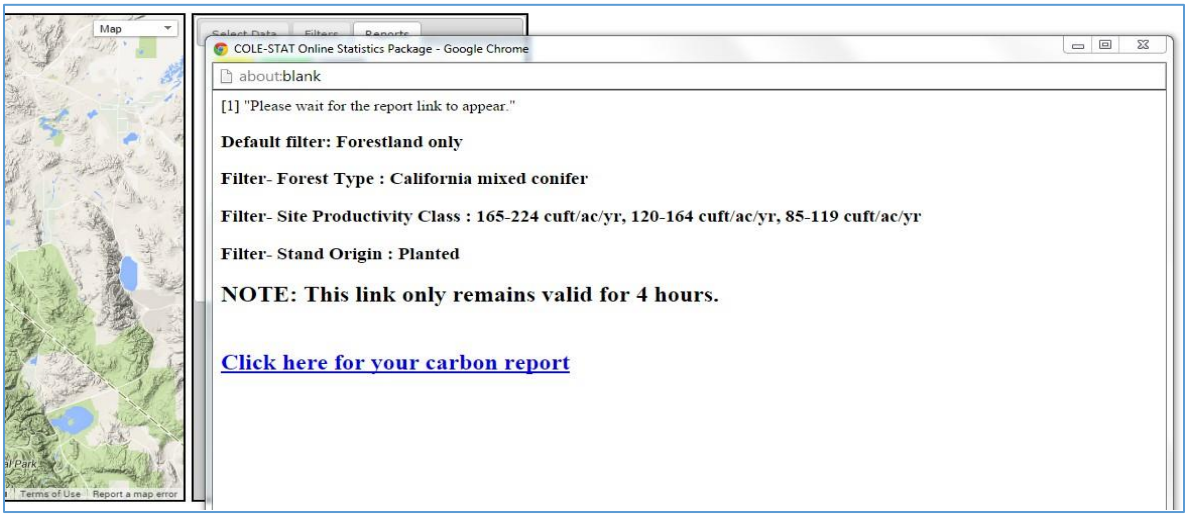
Scroll down to the “Stand Origin” window and selected “Planted” as shown below.



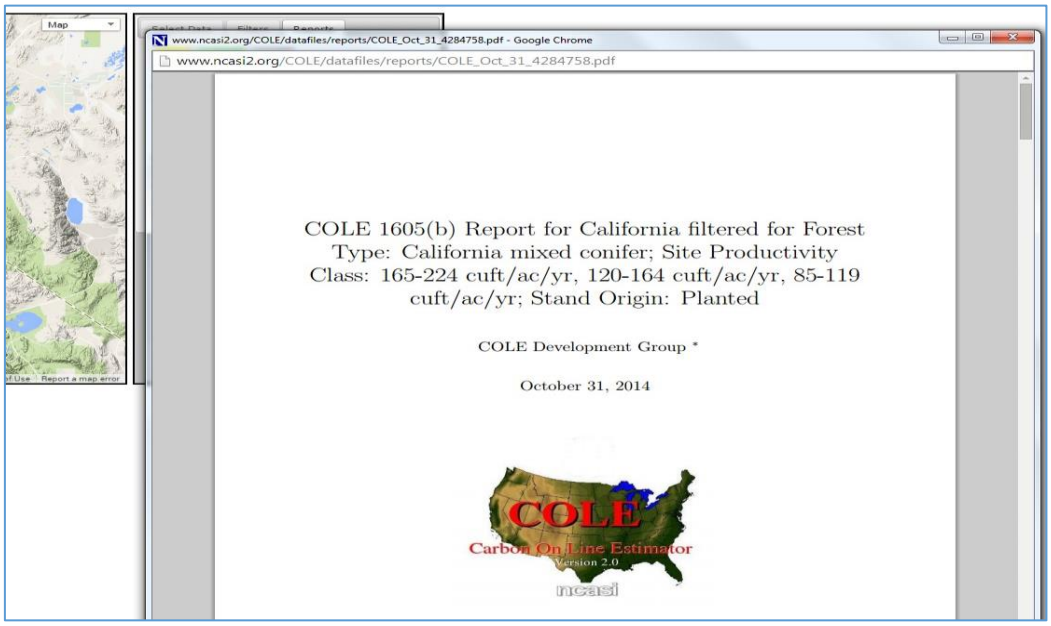
Go to the “Reports” tab next, as shown below. Turn off your browsers popup blocker or at least allow it for the NCASI site, otherwise the report window will not show up.



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.

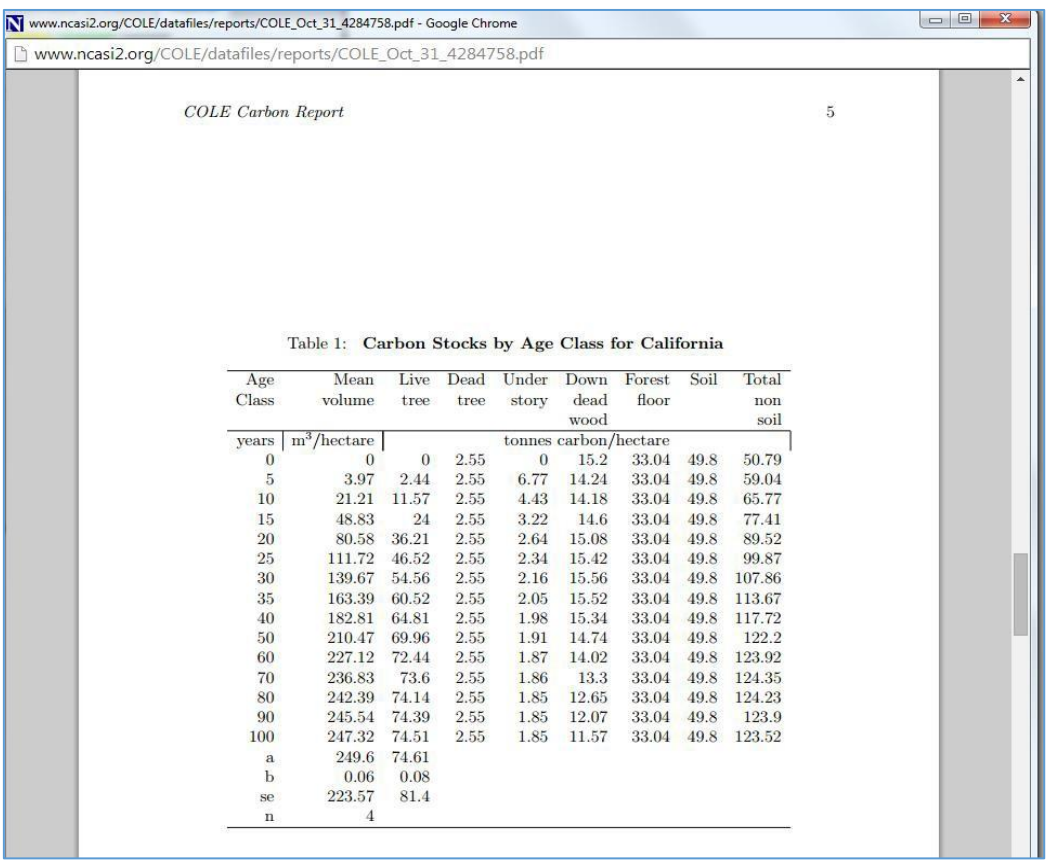
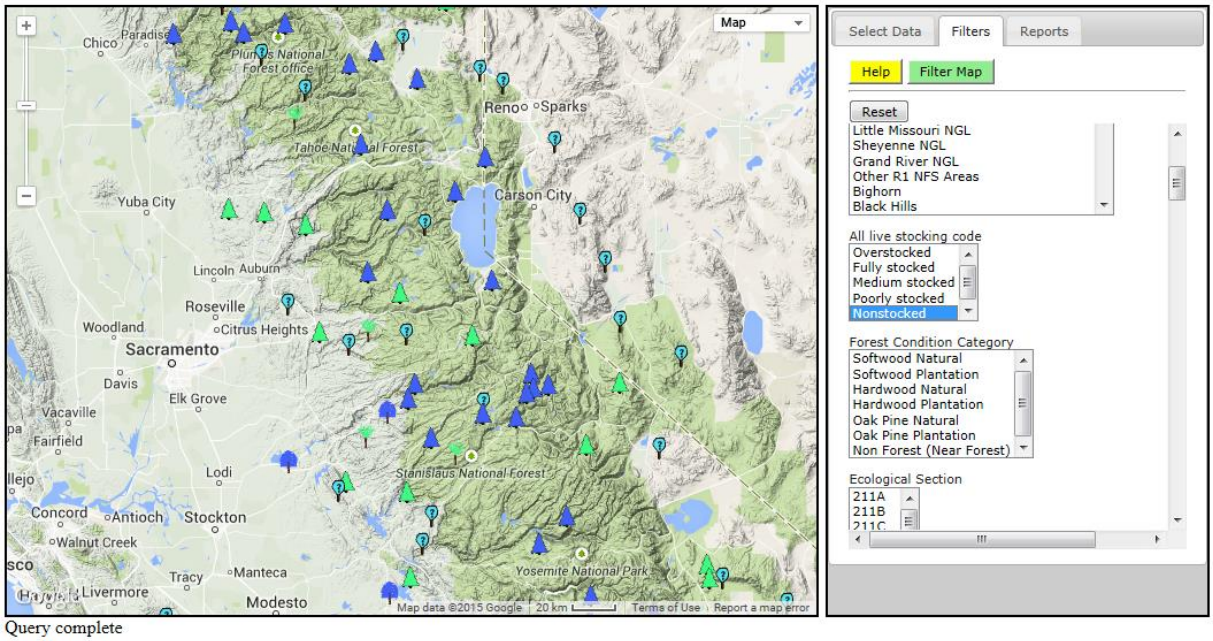


Table 1: **Carbon Stocks by Age Class for California**

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 CO_2e per acre, we multiply by 1.486, which results in 111.4 tonnes of CO_2e per acre.

For the baseline, keep the information in the “Select Data” tab of COLE constant. Click on the “Filters” tab and click “Reset.” Scroll down and select “Nonstocked” under “All Live Stocking Code.”



Query complete

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Return to the “Reports” tab and generate a new report as previously shown. If the report does not generate and you are instructed to “choose a larger area of interest or deactivate some filters,” return to the “Select Data” tab and expand the radius. Click “Get Data” and then return to the “Reports” tab and generate the report. Scroll down in the report to the following table.

Table 1: **Carbon Stocks by Age Class for California, and Nevada**

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	14.46	0	1.52	20.3	34.09	36.29
5	5.9	2.41	14.46	7.92	1.52	20.22	34.09	46.54
10	6.07	2.92	14.46	8.02	1.52	20.25	34.09	47.18
15	6.08	2.96	14.46	8.02	1.52	20.7	34.09	47.66
20	6.08	2.96	14.46	8.02	1.52	21.4	34.09	48.36
25	6.08	2.96	14.46	8.02	1.52	22.19	34.09	49.16
30	6.08	2.96	14.46	8.02	1.52	22.99	34.09	49.95
35	6.08	2.96	14.46	8.02	1.52	23.73	34.09	50.69
40	6.08	2.96	14.46	8.02	1.52	24.4	34.09	51.37
50	6.08	2.96	14.46	8.02	1.52	25.53	34.09	52.49
60	6.08	2.96	14.46	8.02	1.52	26.4	34.09	53.37
70	6.08	2.96	14.46	8.02	1.52	27.09	34.09	54.05
80	6.08	2.96	14.46	8.02	1.52	27.63	34.09	54.6
90	6.08	2.96	14.46	8.02	1.52	28.07	34.09	55.04
100	6.08	2.96	14.46	8.02	1.52	28.43	34.09	55.4
a	6.08	2.96						
b	0.93	0.54						
se	12.07	4.7						
n	93							

Again we are interested in the yield of live and dead tree carbon at age 60. In this example it is 2.96 live plus 14.46 dead, which sums to 17.42 tonnes of C per hectare. To get this in the desired reportable units of tonnes (metric tons) of CO_2e per acre, we multiply by 1.486, which results in 25.9 tonnes of CO_2e per acre.

The expected change in onsite carbon as a result of the project would be:

85.5 tonnes CO_2e/acre = 111.4 t/a – 25.9 t/a

In this example, the site before site preparation was in light brush, therefore, per Table 2 on page 6 of this document, we subtract 13.9 metric tons CO_2e 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:

7,160 tonnes CO_2e = (85.5 t/a – 13.9 t/a) x 100 acres

Finally, subtract the emissions associated with site preparation equipment use. Using the lookup table from the ARB Protocol, included in this document as Figure 1 on page 7, we see the 0.202 tonnes per acre CO_2e must be multiplied by the acres in the project, which was 100 acres. This results in 20.2 tonnes.

The final project estimate is:

7,139.8 tonnes CO_2e = 7,160 tonnes CO_2e – 20.2 tonnes CO_2e

Modeling Approach

This approach uses an individual tree forest growth model such as Forest Vegetation Simulator (FVS), Forest Projection System (FPS), or FORest and Stand Evaluation Environment (FORSEE). These are all approved simulators as per the ARB Protocol. 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 model chosen. 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 Protocol specified volume and biomass equations for California, which may be found on the ARB website at http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/volume_equations.pdf and http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/biomass_equations.pdf. These should be applied to the tree lists output from the simulator for standing live trees with minimum diameter at breast height (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 Lookup Approach to estimate standing dead wood, carbon removed in existing vegetation, and mobile combustion emissions.

DEMONSTRATION STATE FOREST RESEARCH

Net GHG Benefit Estimation

In order to be funded with GGRF grants, research projects must include an on-the-ground component that produces a direct GHG benefit. The net GHG benefit will be calculated using the quantification methodologies presented in this document consistent with the project type undertaken as part of the research.

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 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. Forest legacy projects need to demonstrate that the land faces a real threat of conversion according to the "Threatened" criteria listed in the USFS Forest Legacy Program Project Scoring Guidance available at: http://www.fs.fed.us/spf/coop/library/flp_score_guide.pdf.

Net GHG Benefit 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. 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 lookup approach that uses the assumptions provided in the ARB Protocol, and a more project specific modeling approach.

Lookup Approach

First, estimate 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 ARB Protocol. Use the ARB Protocol specified volume and biomass equations for California, which may be found on the ARB website at http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/volume_equations.pdf and http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/biomass_equations.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. To quantify the carbon in dead trees, use section 2.7 of the Climate Action Reserve's Quantification Guidance (Climate Action Reserve, 2014) available at: http://www.climateactionreserve.org/wp-content/uploads/2012/08/FPP_Quantification_Guidance_1.21.14.pdf.

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 will 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 must follow the guidelines provided in the ARB Protocol (Appendix B1).

Harvests in the baseline and project will use Appendix C of the ARB Protocol to estimate long-term wood products storage in the in-use and landfill pools. An example of how to calculate carbon stored long-term in wood products can be found under the forest pest control project type of this document (pp. 22-25).

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.

For the Douglas-fir in California, equation 3 from the ARB volume equation document is used. A 16-inch tree with a total height of 77 feet would have its total cubic volume calculated using the equation 3 formula for gross cubic volume (CVTS).

Equation 3

TMP_DBH = DBH

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

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

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

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

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

IF TMP_DBH > 6.0 THEN

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

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

IF TMP_DBH = 6.0 THEN

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

IF SMALL_TARIF <= 0.0 THEN SMALL_TARIF = 0.01

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

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

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

For the tanoak example, for a tree that is 14 inches dbh and 52 feet tall, the document says to use equation 34 for tanoak volume, 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

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

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

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

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

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

$$\mathbf{TARIF} = \frac{(CV8 \times 0.912733)}{\left(\left(0.983 - o.983 \times 0.65^{(DBH-8.6)}\right) \times (BA - 0.087266)\right)} \quad (6)$$

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

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

EQUATION 6

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

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 must be accounted for by reducing the CVTS by a percentage appropriate to the estimated volume of the cavity, broken top, or other deformity. Board foot deductions (ex. sweep, crook, knots, form) do not necessarily apply, only deductions where actual biomass is missing.

I puts			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 should 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_2e 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_2e. 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_2e. The standard deviation was 24.3 tonnes per acre. We 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.

For this example, 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 and deplete the carbon stocks assuming 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 ARB 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_2e 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 in this document (pp. 22-25).

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 onsite carbon stocks and carbon stored long term in wood products at the end of 10 years and the baseline onsite carbon stocks and carbon stored long term in wood products at the end of 10 years.

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 CO_2e per acre, which is 108,790 tonnes CO_2e total for the 1,000 acre project.

Modeling Approach

The project activity may also be modeled. The modeling approach uses the same general accounting framework as the lookup approach except that the baseline rate of conversion is estimated by 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.

Once the conversion rate is established, use an individual tree forest growth model such as Forest Vegetation Simulator (FVS), Forest Projection System (FPS), or FORest and Stand Evaluation Environment (FORSEE) to model the associated change in carbon stocks in the baseline and project scenarios over the 10-year project life.

Apply the ARB Protocol volume and biomass equations, found on the ARB website at: http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/volume_equations.pdf and http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/biomass_equations.pdf to the tree lists output from the growth simulator.

FOREST 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 business-as-usual baseline is that forest health and pest management issues are not addressed or controlled. Day-to-day management of a forest property typically does not capture pest- affected trees due to the sporadic nature of forest pests.

Net GHG Benefit Estimation

The estimate of the net GHG benefit 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 be used for the carbon reduction estimation in this method.

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 ARB 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. Hazard ratings can be found at:
http://www.fs.fed.us/foresthealth/technology/haz_rating_database.shtml. Where appropriate, an individual tree forest growth model such as Forest Vegetation Simulator (FVS), Forest Projection System (FPS), or FORest and Stand Evaluation Environment (FORSEE) may be used. These are all approved simulators as per the ARB Protocol. FVS has pest extensions that may be of utility for the analysis. Use the ARB Protocol (ARB 2014) specified volume and biomass equations for California, which may be found on the ARB website at:
http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/volume_equations.pdf and
http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/2014/biomass_equations.pdf. These should be applied to trees with 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. To quantify the carbon in dead trees, use section 2.7 of the Climate Action Reserve's (CAR) Quantification Guidance (CAR, 2014) available at:
http://www.climateactionreserve.org/how/protocols/forest/dev/version-3-3/.

Example #3 – 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 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, multiply by 3.67 to convert to CO_2e, and divide by 2,204.6 to convert to tonnes.

Tonnes CO_2e delivered to the mill = 3,442,600 lbs. X 0.5 X 3.67 / 2,204.6 = 2,865.4 tonnes CO_2e.

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 CO_2e delivered to the mill by the mill efficiency, which results in 1,934.2 tonnes CO_2e.

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	0.568	0.568	0.637	0.637
	Oregon				
Pacific Coast: Pacific Northwest, West (PWW)	Washington	0.531	0.531	0.740	0.500
	Oregon				
Pacific Coast: Pacific Southwest (PSW)	California	0.568	0.568	0.675	0.675
Rocky Mountain: Rocky Mountain, North (RMN)	Montana	0.568	0.568	0.704	0.704
	Idaho				
Rocky Mountain: Rocky Mountain, South (RMS)	Nevada	0.568	0.568	0.704	0.704
	Arizona				
	New Mexico				
	Colorado				
	Utah				
	Wyoming				
South: Southeast (SE)	Virginia	0.609	0.591	0.636	0.553
	North Carolina				
	South Carolina				
	Georgia				
	Florida				
South: South Central (SC)	Texas	0.587	0.581	0.629	0.570
	Oklahoma				
	Arkansas				
	Louisiana				
	Mississippi				
	Alabama				
	Tennessee				
	Kentucky				
West: Includes RMN, RMS, PWE, PSW except where stated otherwise		0.568	0.568		

To continue, projects must first determine the Assessment Area that best corresponds with the project location. Start by identifying the geographic Supersection for the project by reviewing the Supersection maps available at: http://www.arb.ca.gov/cc/capandtrade/protocols/usforest/usforestprojects_2014.htm. Once you have identified the correct Supersection, consult the Assessment Area Data File (available from the same webpage) to identify the Assessment Area that best corresponds to the project based on the dominant vegetation present in the "forest type" category within the spreadsheet.

Once the Assessment Area has been determined, go to the "Supersections_HWP" tab in the Assessment Area Data File to obtain the default percentages in each wood product class. As seen in the table below, the wood products generated in the Sierra Nevada Assessment Area are 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_2e produced in softwood lumber = 0.97 X 1,934.2 tonnes = 1,876.2 tonnes.
CO_2e produced in plywood = 0.03 X 1,934.2 tonnes = 58.0 tonnes.

Based on table 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)

CO_2e stored in softwood lumber = 1,876.2 tonnes X 0.463 = 868.7 tonnes.

CO_2e stored in plywood = 58.0 tonnes X 0.484 = 28.1 tonnes.

The total carbon stored in in-use wood products is 896.8 tonnes of CO_2e.

Example #4 – Emission Reduction from Generating Renewable Energy

Begin by applying the emission reduction factor of -0.24 MTCO2e per bone dry ton (BDT) from ARB and CalRecycle's published biomass conversion study (ARB, 2013). The emission factor is based on the difference between the non-biogenic emissions associated with biomass conversion and the utility emissions from the combustion of fossil fuels such as natural gas. This emission factor does not account for the collection or transportation of biomass. The CA-GREET model provides appropriate emission factors for those processes as discussed in ARB's Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Forest Waste (ARB, 2009). To calculate biomass collection emissions, apply an emission factor of 0.059960 MTCO2e per BDT collected. To calculate transportation emissions, apply an emission factor of 0.001999 MTCO2e per mile traveled between the project site to the biomass facility. This methodology assumes that the wood waste is delivered to a biomass energy facility that produces electricity through combustion of the biomass in a boiler to produce steam which is then used to power a turbine-driven generator. If the biomass facility uses a different process (e.g., gasification) or produces a different form or power (e.g., ethanol) quantification methods should be modified.

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