Biomass Estimation Methods for CBREC and Related Projects

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OVERVIEW

This document serves to describe the methods used to estimate forest state and residue characteristics from forest treatments used in the C-BREC model. The California Biomass Residue Emissions Characterization (C-BREC) model provides a life-cycle assessment framework for the use of California forest residues, originally focused on electricity generation. The C-BREC model enables robust, transparent accounting for greenhouse gas and air pollutant emissions associated with various management options of residual woody biomass in California. The C-BREC model is being updated to improve accuracy and it's results are relied upon in for multiple active projects exploring the life cycle emission for potential alternative uses of forest treatment residues

The C-BREC model has the ultimate goal of being able to estimate the life cycle climate forcing impacts of utilization of forest residues resulting from a wide range of historic and planned forest activities. The model is dependent on accurate information about the current (pre-treatment) forest state. For this reason, SERC contracted SIG to model the current forest state (in 2025 and 2030) and run a variety of forest silvicultural treatments (11). Results from the forest treatment modeling were processed to build a database of estimated residue masses and characteristics. This was done on a 30 x 30m resolution across all forested areas in California. (This database reports for each of the 30x30m forested lands in California, mass of bone dry wood and mass of carbon in trees cut under 11 different silvicultural treatments (Table 1) and 2 treatment years (2025, 2030).

Generating this database was a joint effort between the team at Spatial Informatics Group (SIG) and the team at Schatz Energy Research Center (SERC). This effort makes use of the best available public domain databases and tools. Broadly the approach is as follows.

- The foundation is TreeMap 2016, a dataset produced by the US Forest Service (Riley et al., 2019) which uses remote sensing (LANDFIRE) to relate Forest Inventory Analysis (FIA) surveyed plots to each forested 30x30m pixel in the western US.
- United States Forest Service (USFS) Forest Vegetation Simulation (FVS), is used to model forest growth, disturbances and silvicultural treatments.
- FVS tree level "cut lists" (estimates of each cut tree size and species) are used in conjunction with FIA National Scale Volume and Biomass Estimators (NSVB) methods to estimate mass and carbon in the harvested trees.

Thanks to the Governor's Office of Planning and Resources for supporting this important work.

FCAT MODELING

SIG built a semi-automated Forest Carbon Accounting Tool (FCAT) which is a command-line tool designed to gauge the potential for mitigating greenhouse gas emissions through fuel treatments. All data sources and models used by FCAT are in the public domain. FCAT employs forest growth, carbon flux, and fire behavior simulations based on pixel-based measurements of vegetation type, structure, and wildland fuels. Its components encompass GIS processing and Forest Vegetation Simulator (FVS) modeling for forest growth.

The FCAT Modeling Process consists of a series of semi-automated microservices:

1. GIS pre-processing to prepare the area of interest (AOI), baseline (e.g., let grow) and project conditions (e.g., implementing fuel treatments), as well as disturbances (e.g., burn scars). The only project-specific data input required in this context are treatment locations and prescriptions while all other inputs (e.g., vegetation and climate data, burn probabilities) are lookup based or derived from datasets in the public domain.

2. Identify every unique combination of TreeMap ID, past disturbance, and modeled treatment. The TreeMap 2016 dataset produced by the US Forest Service (Riley et al., 2019) contains forest stand metrics such as trees per acre, aboveground carbon, and live basal area at a 30m resolution.

3. Build an USFS Forest Vegetation Simulator (FVS) input database:

   a) TreeMap stand data is updated to current forest conditions using the Forest Vegetation Simulator (FVS; USFS, 2020). Updating the forests to current conditions is accomplished by incorporating disturbances such as harvest, forest management practices, and wildfires from 2016 to the current year.
   b) Historical wildfire data from the Monitoring Trends in Burn Severity (MTBS) program and National Interagency Fire Center (NIFC) were compiled to model past wildfires. Non-wildfire disturbance data(such as from harvests and fuel mitigation treatments) was also compiled and is detailed in Kearns et al. (2022). All disturbances (wildfire and otherwise) were cross-walked into severity levels: low, moderate, and high. Generic kcp files corresponding to each severity level for both wildfire and non-wildfire disturbance (examples in Appendix A: Past Disturbance FVS kcps) were utilized to simulate these events within FVS Fire and Fuels Extension (FFE). FVS determines post-disturbance stand characteristics as the stands are grown forward.
   c) Each unique combination of TreeMap ID and disturbance severity was simulated as an individual forest stand by growing the stand forward, applying the disturbance and then growing the stand forward to 2025 and 2030. The results for both years were output in order to be able to simulate ‘proposed’ forest treatments at either year.
   d) Instructions are embedded for simulating disturbances and treatments.

4. Execute FVS:R script to automate building and executing FVS key files for various FVS simulations in 5-year time steps over a 40-year time horizon,

A range of forest management treatments were modeled for these years, resulting in a cut tree list for each model run. These cut lists were then utilized to calculate the biomass classes that could be generated from the treatments.

GIS PRE-PROCESSING

The entire state of California was used in this assessment as described by the US census bureau

TreeMap data is a spatial model of trees in continental US' forests provided in a 30 x 30m resolution for the year 2016. TreeMap data is created using a random forest model, a machine learning algorithm, with inputs such as the Forest Inventory Analysis (FIA) (FIA, 2018) and forest cover, height, and vegetation type provided by the LANDFIRE project (Landfire, 2015). Each pixel in the TreeMap dataset contains a wide range of estimates including biomass (Figure 1) and as an input to this process a list of trees estimated to be on the landscape, with descriptive variables including diameter, height and species.

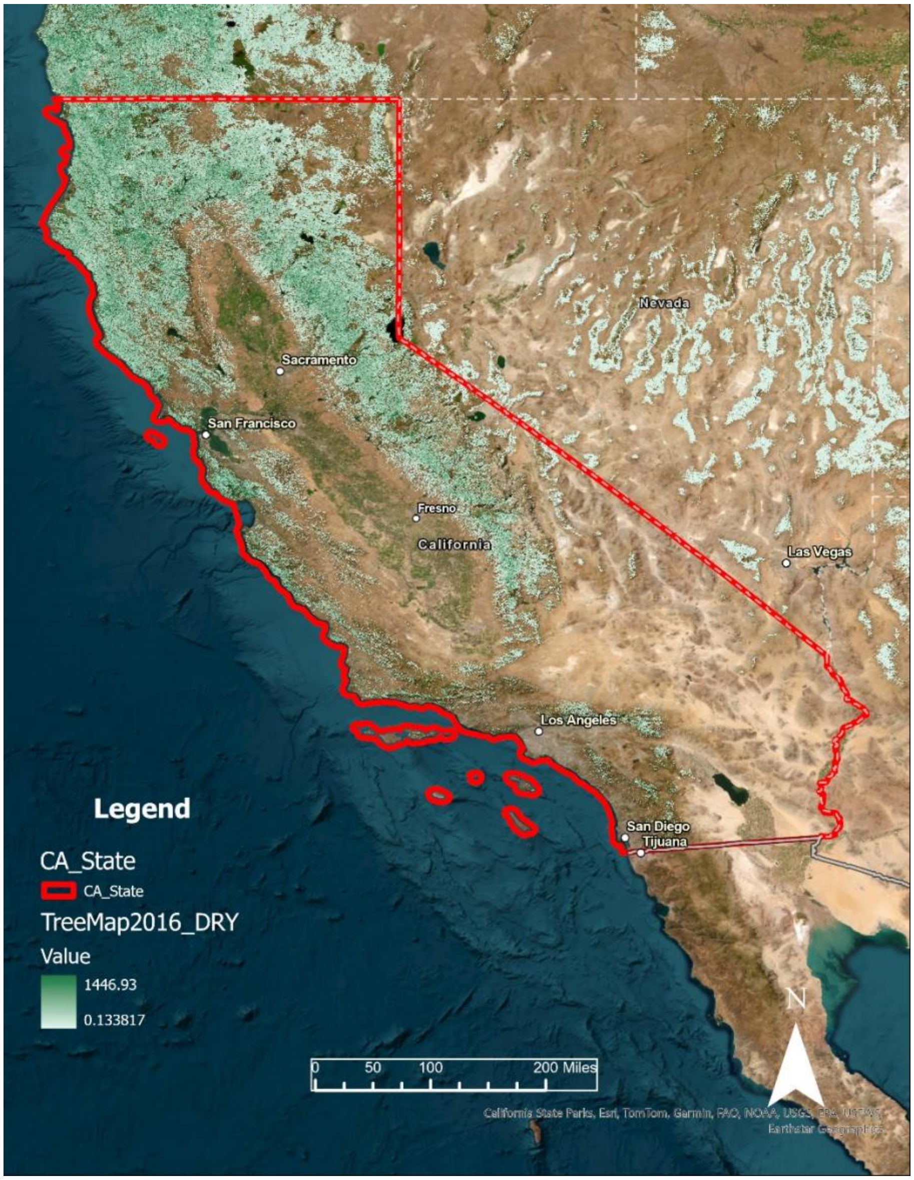

Figure 1. Live Aboveground Biomass in Metric Tons/Acre within the project area using TreeMap 2016 data.

Silvicultural Treatments

Relevant treatments were selected to be re-used from the past simulations in C-BREC, described in section 4.1.1.1 of the Framework (Schatz Energy Research Center, 2021) These included the thin from below treatments, the thin from above treatments, and the clear cut treatment. The thin from below and above treatments included four cut intensities to reduce the basal area by 20, 40, 60 and 80 percent (Table 1).

Two additional treatments that were not included in the previous modeling effort were developed to allow variable treatment intensity dependent on forest density. These treatment parameters were selected in attempt to represent typical forest fuels treatments conducted in California for forest health goals and to improve the resiliency of forests, while maintaining model simplicity (same treatment for the whole state). One of the treatments is a thin from below up to trees with 30” DBH, while preferentially cutting shade tolerant species, with a goal of reaching 55% of the maximum Stand Density Index (SDI). This treatment is referred to as ‘SDI55’. The other new treatment is a thin from below with no diameter limit, and also sets shade tolerant species to be removed first with a goal of reducing stand density to 30% of the maximum SDI. This treatment is referred to as ‘SDI30’.

SDI is calculated in FVS for the California forest variants using the Zeide (1983) calculation as a default. The Zeide calculations account for an aggression bias in Reinecke’s (1933) calculation, in order to be more representative in uneven-aged forest stand conditions which we concluded was better to use for entire state of California. The SDI calculation used in FVS are further explained in Dixon (2024).

For all of the forest treatments all of the pre-harvest slash is modeled to be removed. This was done in order to isolate the slash generated from the forest treatment from pre-existing slash in the forest. For each of the 11 treatments modeled, there are two versions, one that occurs in 2025 and one that occurs in 2030. In totality, there are 22 treatments and examples of FVS treatment kcps are attached in Appendix A.

Table 1. Description of the Forest Silvicultural Treatments.

Treatment name	Thinning description
Remove 100%	Clear-cut 100% of standing trees
Thin from Below by 20%	Remove 20% of basal area starting with the smallest BDH trees
Thin from Below by 40%	Remove 40% of basal area starting with the smallest BDH trees
Thin from Below by 60%	Remove 60% of basal area starting with the smallest BDH trees
Thin from Below by 80%	Remove 80% of basal area starting with the smallest BDH trees
Thin from Above by 20%	Remove 20% of basal area starting with the largest BDH trees
Thin from Above by 40%	Remove 40% of basal area starting with the largest BDH trees
Thin from Above by 60%	Remove 60% of basal area starting with the largest BDH trees
Thin from Above by 80%	Remove 80% of basal area starting with the largest BDH trees
55% Maximum SDI	Thin from below up to 30" DBH, preferentially cutting shade tolerant species, to reach the goal of 55% maximum SDI
30% Maximum SDI	Thin from below with no diameter limit, preferentially cutting shade tolerant species, until reaching 30% maximum SDI

Modeling Forest growth and yield

Using the above treatment descriptions, FCAT was run on the entire states forested areas for the 11 defined silvicultural treatments in both 2025 and 2030. The full suite of outputs available from FVS are possible to output however the outputs used for CBREC modeling purposes are the Cut-list (which reports quantity and characteristics of trees harvested), Tree-list (Which reports quantity and characteristics of trees remaining after harvested), and the potential fire outputs. The Cut-list is the only output needed for residue mass and carbon estimation, other outputs are used with-in fire modeling efforts.

BIOMASS ESTIMATION

The Schatz team implemented the FIA NSVB biomass estimation method (Wesfall Et al. 2024) using the FVS Cut-list outputs prepared via the above described FCAT modeling. This newly updated method was implemented in python.

The general approach is to take a Cut-list (a list of tree species and sizes determined to be cut under a particular treatment) and use the updated FIA equations to estimate the biomass quantity of different size classes of debris for each tree category (i.e. rows in the Cut-list). As each of these tree categories can represent varying number of trees in a given forest stand the FVS output of “trees per acre” is used as a scaling factor to actually estimate biomass and carbon on a per acre basis for the stand.

Biomass equations specific to each species and region were available for most trees appearing in our cutlists, but not all. When a tree species and region combination was encountered that did not appear in the update, the biomass breakdown was usually performed using an updated Jenkins-class specific equation. “Woodland species,” which are shrublike trees such as junipers and mountain mahogany, were not included in the FIA NSVB update. For such trees, the Jenkins allometric equations were used (Jenkins Et al. 2003)

In all cases except for woodland species, the size breakdown was calculated using the following method:

a. Total volume of wood inside the bark in the main trunk is estimated and converted to a weight.
b. Total bark weight is estimated.
c. Total branch weight is estimated.
d. Total biomass weight is estimated.
e. Total foliage weight is estimated.
f. Branch, bark, and wood inside bark weights are added, and the result is divided by the estimated total biomass weight. The resulting "harmonization factor" is used to adjust the estimates for the weight of the bark, branch, and wood inside bark.
g. The harmonized weight of the wood inside the bark is divided by its estimated volume to calculate a harmonized wood density.
h. The harmonized bark weight is divided by the estimated bark volume to get a harmonized bark density.
i. If DBH <= 4, the total weight of biomass is placed in the "0-4 inch" size class.
j. If 4<DBH<=6 inches, a stem/trunk taper equation is used to calculate the height at which the trunk reaches 4 inches. The fraction of the total stem wood and bark volume above the 4 inch breakpoint are estimated, and converted to weights using the harmonized densities. These are summed in the "top" category. The branch and top weight are combined into the "0-4" category, while the fractions of the total trunk volume of bark and wood from the portion of the trunk between 1 ft (assumed to be the stump height) and the breakpoint in height are converted to weights and summed in the '4-6 inch' category.
k. If 6<DBH<=9 inches, the taper equation is used to calculate the height of breakpoints at 4 inches and 6 inches of diameter. Fractions are calculated as in section (j).
l. If DBH>9, the taper equation calculates the height of breakpoints at 4, 6, and 9 inches in diameter. Fractions are calculated as in section (j).

For woodland species, the total biomass weight and the portion of this weight being foliage are estimated using the Jenkins allometric equations. The foliage portion is subtracted from the total, and the resulting amount is placed into the 0-4 size class. It's important to note that foliage is included in the Jenkins definition of biomass, while the FIA approach excludes foliage from the definition of biomass.

DATA ACCESS

These data are hosted by the Schatz Center at https://drive.google.com/drive/folders/1MYNxFvL9amPN80ue2TRGyCH_aX5qaDqO?usp=sharing. This folder contains three files in addition to this documentation:

BREC_ID.TIF: A raster file that reports ID values at a 30mx30m resolution for the state of California.

Residue_by_treatment.csv: Tabular data that reports the amount of biomass generated for each ID (matching the IDs in the TIF) from a variety of different forest treatments and two years of treatment. Treatment codes are used which relate to the actual treatments as follows.

Treatment Name	Code Used
Clearcut	RM100
20% thin from above	TFA_20
40% thin from above	TFA_40
60% thin from above	TFA_60
80% thin from above	TFA_80
20% thin from below	TFB_20
40% thin from below	TFB_40
60% thin from below	TFB_60
80% thin from below	TFB_80
55% Maximum SDI	SDI55
30% Maximum SDI	SDI30

The treatment code is followed by the harvest year (ie. The clearcut applied in 2025 is RM100_2025).

Biomass estimates are reported in bone dry imperial short tons per acre. These estimates are disaggregated by size class. The naming structure includes the size class at the end, as described below (where X represents the code_year name combination):

“X9_plus” Reports the density of logs greater than 9 inches.
“X6_9” Reports the density of logs between 6 and 9 inches.
“X4_6” Reports the density of logs between 4 and 6 inches and branches.
“X0_4” Reports the density of logs under 4 inches including branches
“foliage” Reports the density of foliage.

Carbon_by_treatment.csv: reports the amount of carbon in biomass cut at each ID (matching the IDS in the .tif). This file is structured following the residue by treatment data, using the same treatment names and column names but only reporting mass of carbon rather than bone dry wood. The mass of carbon is also reported as imperial short tons per acre. This utilizes the same treatment names and variable names as described above.

REFERENCES

Dixon, G. E. (2024). *A User's Guide to the Forest Vegetation Simulator*.

FIA. (2018). *Forest Inventory and Analysis national core field guide. Volume 1: Field data collection procedure for Phase 2 plots. Version 7.0* (p. 453). USDA Forest Service.

Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A. 2003. National scale biomass estimators for United States tree species. Forest Science. 49: 12-35

Kearns, E. J., Saah, D., Levine, C. R., Lautenberger, C., Doherty, O. M., Porter, J. R., Amodeo, M., Rudeen, C., Woodward, K. D., Johnson, G. W., Markert, K., Shu, E., Freeman, N., Bauer, M., Lai, K., Hsieh, H., Wilson, B., McClenny, B., McMahon, A., & Chishtie, F. (2022). The Construction of Probabilistic Wildfire Risk Estimates for Individual Real Estate Parcels for the Contiguous United States. *Fire*, *5*(4), Article 4. https://doi.org/10.3390/fire5040117

Landfire. (2015). *LANDFIRE Program: Data Products—Vegetation—Existing Vegetation Type*. https://www.landfire.gov/evt.php

Rebain, S. A., Reinhardt, E. D., Crookston, N. L., Beukema, S. J., Kurz, W. A., Greenough, J. A., Robinson, D. C. E., & Lutes, D. C. (2022). *The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation* (p. 417). United States Department of Agriculture Forest Service.

Riley, K. L., Grenfell, Isaac C., Finney, M. A., & Shaw, J. (2019). *TreeMap 2016: A tree-level model of the forests of the conterminous United States circa 2016*. https://www.fs.usda.gov/rds/archive/Catalog/RDS-2021-0074

Schatz Energy Research Center. (2021). *C-BREC Model Framework*. https://schatzcenter.org/pubs/2021-biomass-R2.pdf

USFS. (2020). *Forest Vegetation Simulator (FVS)*. https://www-fs-fed-us/fvs/index.shtml

Westfall, James A.; Coulston, John W.; Gray, Andrew N.; Shaw, John D.; Radtke, Philip J.; Walker, David M.; Weiskittel, Aaron R.; MacFarlane, David W.; Affleck, David L.R.; Zhao, Dehai; Temesgen, Hailemariam; Poudel, Krishna P.; Frank, Jereme M.; Prisley, Stephen P.; Wang, Yingfang; Sánchez Meador, Andrew J.; Auty, David; Domke, Grant M. 2024. A national-scale tree volume, biomass, and carbon modeling system for the United States. Gen. Tech. Rep. WO-104. Washington, DC: U.S. Department of Agriculture, Forest Service. 37 p. https://doi.org/10.2737/WO-GTR-104.

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APPENDIX A

Treatment FVS Kcps

Thin from Above Treatment example with removing 20% of basal area

```
* remove all slash
YardLoss      2025      0      0      1
* Thin from above
ThinBBA       2025  Parms(BBA*0.8,1,0,999,0,999)
```

Thin from Below Treatment example with removing 20% of basal area

```
* remove all slash
YardLoss      2025      0      0      1
* Thin from above
ThinABA       2025  Parms(BBA*0.8,1,0,999,0,999)
```

Clearcut Treatment example

```
* Clearcut/Coppice: CBREC
ThinDBH      2025      0      0      1.0      0.0      0.0      0.0
ThinDBH      2025      0    999.0    1.0      0.0      0        0.0
```

Forest Health Treatment example

```
*creating a species group of shade tolerant species
SpGroup    shadetol
WF GF IC DF

* remove all slash
YardLoss      2025      0      0      1

* SpecPref: Change the species preference for removal.
* Making shadetolerant species the first to be removed
SpecPref      2025     Parms(shadetol,15)

Compute          0
MAXHEALTH= 0.55
* before-thin max SDI- for reference only
BSDI_MAX = BSDIMAX
END

* Thin from below
* Thin to 55% of maximum SDI
* cutting efficiency = 1
* 0-30 DBH
* 1= thin from below within the diameter range
```

ThinSDI 2025 Parms((MAXHEALTH*BSDI_MAX),1.,All,0.,30.,1.)

Forest Resiliency Treatment example

```
SpGroup    shadetol
WF GF IC DF

* remove all slash
YardLoss       2025       0       0       1

* SpecPref: Change the species preference for removal.
* Making shadetolerant species the first to be removed
SpecPref       2025     Parms(shadetol,15)

Compute          0
MAXRES= 0.30
* before-thin max SDI- for reference only
BSDI_MAX = BSDIMAX
END

* Thin from below
* Thin to 30% of maximum SDI
* cutting efficiency = 1
* no DBH limit DBH
* 1= thin from below within the diameter range
ThinSDI        2025     Parms((MAXRES*BSDI_MAX),1.,All,0.,999.,1.)
```

Past Disturbance FVS kcps

Past Wildfire severity level 1 example

```
* Args: Wind, Moisture, Temp, MortCode, PAB, Season
FMIN
SimFire       2020   Parms(5, 3, 65., 1, 50, 1)
End
```

Past Wildfire severity level 2 example

```
* Args: Wind, Moisture, Temp, MortCode, PAB, Season
FMIN
SimFire       2020   Parms(10, 2, 70., 1, 75, 2)
End
```

Past Wildfire severity level 3 example

```
* Args: Wind, Moisture, Temp, MortCode, PAB, Season
FMIN
SimFire      2020   Parms(20, 1, 80., 1, 100, 3)
End
```

Mechanical Removal example

```
* residual BA, thinning efficiency, min dbh, max dbh, min ht, max ht
ThinBBA      2022     125     0.9     8     20     0.0     999.0
* fall all snags to 15 in dbh
Fmin
SalvSP       2022     All     0
* smallest dbh, largest dbh, yrs dead, *hard*/soft, proportion of eligible felled, proportion of felled left in stand
Salvage      2022     0.     15.     5.     1     0.9     0.
* assume mastication and/or pile burn is called separately
End
```

Mechanical Addition example

```
* transfer one size class to another
* reduce fuel depth by 25% (FFE Table 3.7) to simulate mastication
* Args: Treatment, Harvest, Mult
FMIN
FuelTret     2022   Parms(2, 3, .75)
* masticate and leave all 0-12" dead trees
* Args: Species, Cut (0)/Leave (1)
SalvSP       2022   Parms(ALL,0.)
* Args: MinDBH, MaxDBH, YrsDead, Hard/Soft, PropFell, PropLeft
* 101 = up to 101 years old, 0 = hard + soft
Salvage      2022   Parms(0., 12, 101., 0, 1., 1.)
```

```
END
* 100% of tree biomass is left behind to be masticated
YardLoss      2022   Parms(1,1,1)
* cut all trees at least 1 ft tall and between 0-12 in dbh with 100% efficiency
* target residual TPA is 109 overstory trees > 12 in dbh (no effect on Rx)
* Arguments: ResTPA, CutEff, SmDBH, LgDBH, SmHt, LgHt
ThinBTA       2022   Parms(0., 1.0, 0., 12., 1., 999.)
FMIN
* nothing larger than 12" is masticated
* all 6-12" fuels are moved to 3-6" class
FuelMove      2022   Parms(5,4,0,1,999,0)
End
```