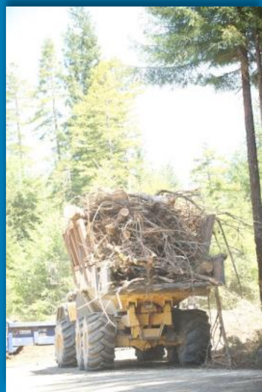
California Biopower Impacts Project

Project Brief – January, 2019



1. Project Overview

The California Biopower Impacts (CBI) Project is supported by the California Energy Commission under Grant Funding Opportunity 16-306. This three-year project – begun in the summer of 2017 – Investigates many of the greenhouse gas (GHG) and other environmental considerations associated with utilization of forest-derived woody biomass and agricultural residues for electricity and process heat generation, as well as investigating project economics and developing policy recommendations.

California's Forest Carbon Plan (Forest Climate Action Team, 2018) identifies insufficient forest management activity rates, limited biomass processing and utilization infrastructure, and unprecedented deterioration of forest health as a few of the critical barriers to managing forests for resilience and net carbon sequestration. In his October 2015 proclamation of a State of Emergency, Governor Brown emphasized that California utilities and state agencies should cooperate to address this emergency. At the same time, residues generated by forest thinning and fuels treatment as well as conventional forestry and agricultural activities have the potential to be transformed from a waste stream into a renewable energy resource.

If managed properly, bioenergy can support sustainable forest management activities while also advancing California's Renewable Portfolio Standard goals. However, there are legitimate concerns surrounding climate, air quality, and ecosystem health implications of improperly managed bioenergy systems. The CBI Project seeks to firmly and transparently establish the environmental performance of bioenergy from forest and agricultural residues.

The key project goals are to:

1. Assess and map technically recoverable forest and agricultural biomass residue in California that could be utilized for electricity and heat generation.
2. Conduct a landscape-level assessment of the fire emission implications of forest residue removal.
3. Develop and implement the California Biomass Residue Emissions Characterization Tool.
4. Characterize and report on key positive and negative environmental impacts of residual biomass mobilization such as changes to soil nutrient balance and carbon stock, and air quality effects from altered black carbon and criteria air pollutant emission profiles.
5. Assess the potential to offset residue mobilization costs for forest management activities through value added supply chains, post-harvest processing, payments for ecosystem services and similar schemes.
6. Consolidate project results into actionable policy recommendations, and disseminate these recommendations to California stakeholder groups.

2. Biomass Residue Base

The residual biomass resource base of interest is from forestry and agricultural activity in the state. Forest harvests were categorized into fourteen different harvest types, covering most common forestry activities as defined by California Forest Practice Rules. The harvest activities modeled were:

- Thin from below (i.e. selecting for small-diameter trees) removing 20, 40, 60, 80, and 100% of total tree basal area[1].
- Thin from above (i.e. selecting for large-diameter trees) removing 20, 40, 60, 80, and 100% of total tree basal area[1].
- Proportional thin (i.e. select equally across small and large diameter trees) removing 20, 40, 60, 80, and 100% of total tree basal area[1].
- Salvage logging: removal of all standing dead trees

For each of the above forest harvest activity types, we modeled the total recoverable biomass residue resource base at the parcel level, divided by residue type and size class. Forest parcels were characterized based on tree list inventory (GNN) data produced by the Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) group at Oregon State University. We have updated these data in California with timber harvest, fire, and tree mortality events, and growth, occurring between 2012 and 2017 using the Forest Vegetation Simulator. Forest data are combined with parcel and riparian management zone data to create a spatially explicit database of forest condition, owner class, and management zone (Figure 1). Tree component biomass for stems, bark, branches, foliage, and roots are calculated by applying national biomass estimators (Jenkins et al., 2003) and the FIA component ratio method to the tree lists.

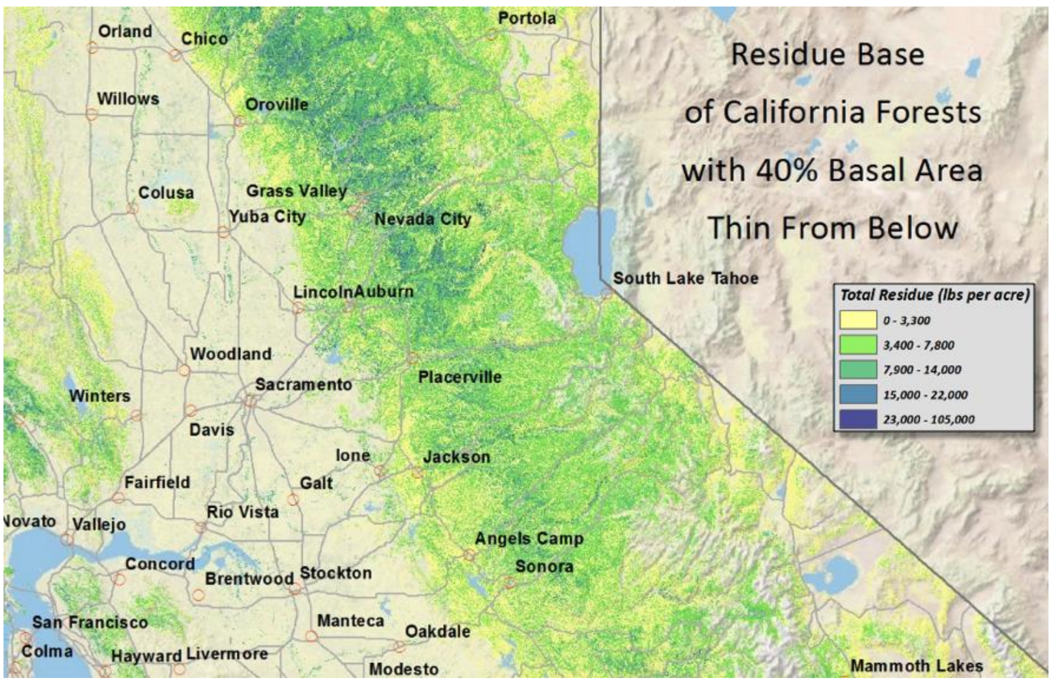


Figure 1: Example residue base data layer across a section of Northern California. This map presents the residue resulting from thinning activity removing 40% of total standing basal area from below (i.e. selecting for small diameter trees). Modeled at 30m^2 spatial resolution.

Agricultural residue base estimates were derived from earlier work by the California Biomass Collaborative (Williams et al., 2015). We focus our analysis on the eight crops that dominate agricultural residue production in California: rice, grapes, almonds, corn, wheat, cotton, and walnuts. Together, these eight crops comprise over 80% of the estimated technically available annual mass of residues in the state. This project does not consider food processing residues as it is assumed the majority of these residues have existing market pathways.

[1] 100% removal case (clear-cut) is the same whether thinned from above, below, or proportionally.

3. Life Cycle Emissions Accounting

Almost a half-century of literature has established life-cycle assessment (LCA) as an effective tool for evaluating the total resource impact of a product or action. The CBI Project is developing an LCA framework specific to the use of California forest and agricultural residues for electricity generation and heating applications. Using this framework, the project team is developing and implement a methodology through the California Biomass Residue Emissions Characterization (C-BREC) Tool to explore the life cycle impacts of different bioenergy pathway scenarios. This transparent, customizable LCA tool, will allow stakeholders in California to evaluate the impacts of different residual biomass energy policy and technology pathways in the state.

3.1. Scope and Boundary

A central assumption underpinning the CBI analytical framework is that the residual material being consumed is a *true waste* in that it would not have been used at all were it not for the bioenergy system. As such, it is assumed the residues are not the driver of the primary forestry or agricultural activity, and therefore the utilization of the residues is not allocated any of the upstream emissions associated with those activities.

For example, we assume that primary forest harvest activities are being conducted for the purpose of sawtimber extraction or improving forest health. The branches, treetops, and foliage that comprise the harvest residue base are typically left to decay or are burned on site. As such, we do not allocate any of the primary harvest emissions – nor any of the forest carbon stock and flow implications of the primary harvest – to the bioenergy pathway. This framework could be integrated with a model of the C stock implications of primary harvest activities to obtain a broader perspective on the environmental impact of forest management and agricultural activities.

Life cycle assessment of the harvested residues (Figure 2) includes:

1. Direct emissions from collection, transportation, and conversion of biomass residues into electricity
2. Emissions resulting from changes in wildfire behavior following removal of residues
3. Emissions resulting from changes to soil composition following removal of residues

The emissions calculated above for the harvest case is compared to the reference business-as-usual case, in which residues are not recovered. The reference case captures emissions over time from residues scattered or piled in the field, including:

1. Controlled burn of residues (pile and broadcast burning)
2. Decomposition out to 100 years
3. Emissions from wildfire exposure

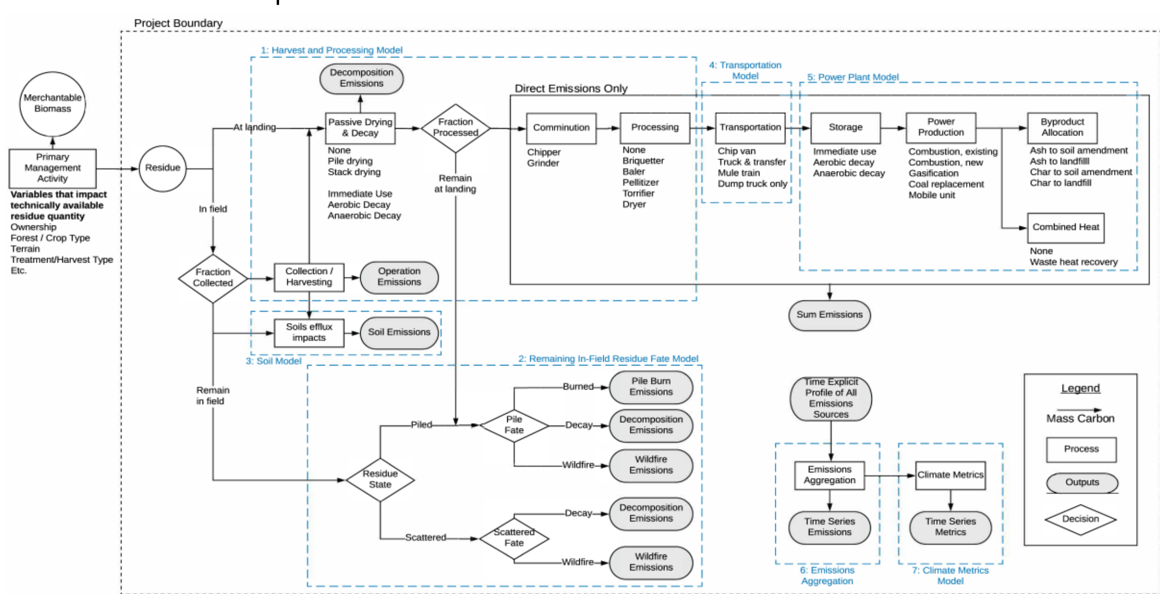


Figure 2: Mass flow diagram of the CBI Project analytical framework

3.1. Accounting for Time

A key challenge in the emissions accounting for the framework described here is the fact that bioenergy emissions occur in one pulse in year zero, whereas the emissions associated with the reference fate of the biomass may occur slowly over decades of biomass decay. One approach to accounting for the time value of this temporary sequestration is through the use of time-integrated climate metrics. Our modeling calculates and reports two climate metrics: the Absolute Global Warming Potential (AGWP) and the Integrated Absolute Global Temperature Potential (iAGTP). The common formulation of these metrics is built by modeling a single pulse of emissions at a single point in time. This project is implementing an “emissions scenario” approach as discussed by (Myhre et al., 2013), elaborated on by (Aamaas et al., 2012), and recently implemented in a few publications related to the emissions profile of biomass (Giuntoli et al., 2015). The result is a time-explicit AGWP and iAGTP that approximate the global radiative forcing and temperature response, respectively, to a time-explicit emissions profile generated by C-BREC. We also calculate the CO_2e emissions based on the time-dependent GWP calculated for each emissions profile.

3.2. Life Cycle Inventory

The C-BREC tool improves on existing frameworks, representing California’s unique bioeconomy context while offering improved spatial resolution, rigorously characterized uncertainty, and a high degree of specification and adaptability regarding counterfactual fate of feedstocks, supply chain characteristics, and end-use technologies. Users are able to specify harvest practices, feedstock collection and handling methods, post-harvest treatments, feedstock management pathways, conversion technologies, and other characteristics based on the comprehensive characterization of project implementation characteristics illustrated in Figure 3.

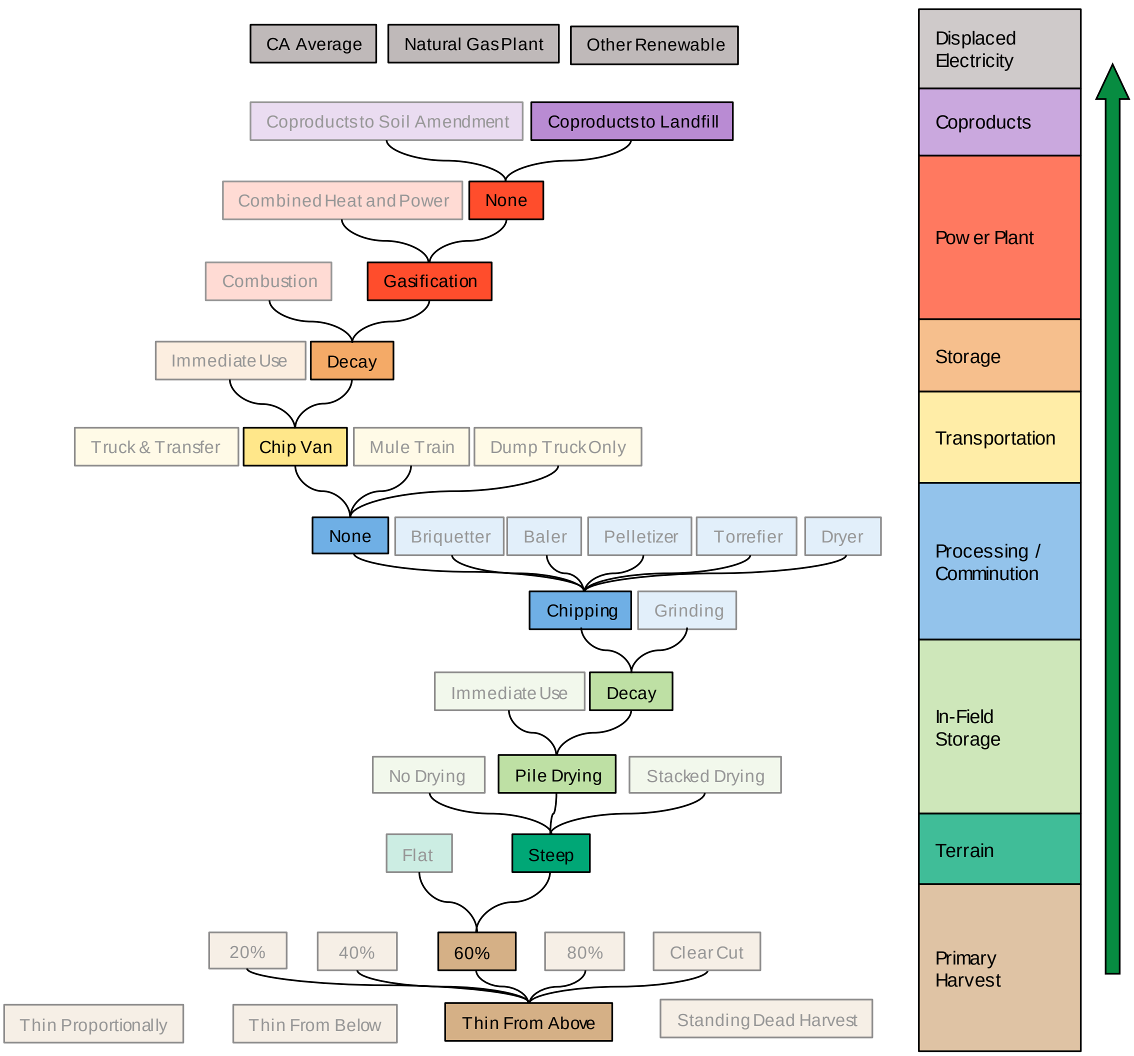


Figure 3: Example pathway for life-cycle inventory calculation in the C-BREC accounting framework.

4. Reference Biomass Fate

The “reference case” or “counterfactual fate” of the biomass describes the emissions associated with a given ton of biomass residue if it is not removed from the field for energy production.

4.1. Fire Methodology

We modeled emissions from wildfire and prescribed burns using the "activity" fuels equations from Consume (version 4.2, Prichard et al., 2006), software created by the US Forest Service. The activity fuels equations were developed for fuels that were "resulting from or altered by forestry practices such as timber harvesting or thinning" (p.141, Prichard et al., 2006), and are thus directly applicable to this use case. The activity fuels equations calculate consumption and emissions estimates for scattered (i.e., non-piled) fuels. The activity equations provide estimates of fuel consumption for each fuel size class, weighted by combustion phase: flaming, smoldering, and residual. The consumption estimates are then multiplied by species-specific emissions factors (e.g. CO, CO_2) taken from the Bluesky modeling framework (Larkin et al., 2010). The activity equations also apply different emissions coefficients for 1,000 hour timelag fuels and larger depending on the state of decay, which is characterized as either sound or rotten. The general workflow for estimating emissions is illustrated in the equation below, where $emissions_{cp}$ is the emissions by combustion phase, BC_{cp} is the biomass consumed by combustion phase for fuel size class i of decay class j, and EF_{cp} is the emissions factor for each pollutant, which are also weighted by combustion phase:

$$emissions_{cp} = \sum_{i=1}^{m}\sum_{j=1}^{m} BC_{cpij} \times EF_{cp}$$

We also estimate charcoal production during combustion using data taken from Pingree et al. 2011.

We use Fuel Characteristic Classification System (FCCS) (Riccardi et al., 2007) data to represent the initial fuel loads. FCCS data are available in raster format through Landfire.gov. Additional fuel loading resulting from treatments is derived from our biomass resource base projections and is added to the original fuel loading data. We estimate the emissions impact of residue removal by running Consume with and without this additional fuel on site. To calculate emissions from piled fuels, we multiply the total mass consumed by specific pile emissions factors (Tables 4 & 5, Prichard et al., 2006). We are assuming 90% consumption, the default value used by Consume (Prichard et al., 2006). We partitioned the consumed portion by combustion phase, assigning 70% flaming, 15% smoldering, and 15% residual, following examples outlined in Wright et al. 2017. Fuel consumption and emissions estimates are delivered in spatially explicit (raster) format for integration into the C-BREC model framework.

Both emissions and fire behavior models require inputs for fuel moisture (1, 10, 100, and 1,000 hour) and mid-flame wind speed. To estimate these inputs, we are using 4km resolution GRIDMET data, the University of Idaho gridded surface meteorological data set (Abatzoglou, 2013; Abatzoglou and Brown, 2012). GRIDMET does not supply 1- and 10-hour fuel moisture, so we calculated these using equations taken from the National Fire Danger Ratings System (NFDRS) (Cohen and Deeming, 1985). GRIDMET provides wind speed values at 30m, so we use treatment-specific wind adjustment factors (WAF) (Andrews, 2012). We calculated spatially-explicit WAF for each silvacultural treatment, adjusting for TPI and post-treatment trees per acre. For wildfire simulations, we calculated the 97th percentile conditions for all climate variables constrained to the months of June through September for all years from 2000 to 2017. For prescribed fire simulations, we calculated the 37.5th percentile conditions for all climate variables constrained to September and October (the typical fall prescribed fire season) for the same time period as the wildfire scenarios. Slope is estimated using data products from the National Elevation Dataset. Figure 4 details the basic process flow for the fire emissions module.

4.2. Decomposition

The decay model is built on a simple negative exponential decay model (Olson, 1963). Decomposition mechanisms are characterized through a single decay constant $k_{x,y,i}$ for each residue size class x, disposition y, and spatial location i, which are adjusted with a climate modifier α_i:

$$M_n = \sum_{x,y,i} M_{0_{x,y,i}} e^{-k_{x,y,i}\alpha_i t}$$

The literature on biomass decomposition identifies three main drivers for decay rate variability. These are species composition, size class and disposition of material, and climatic factors.

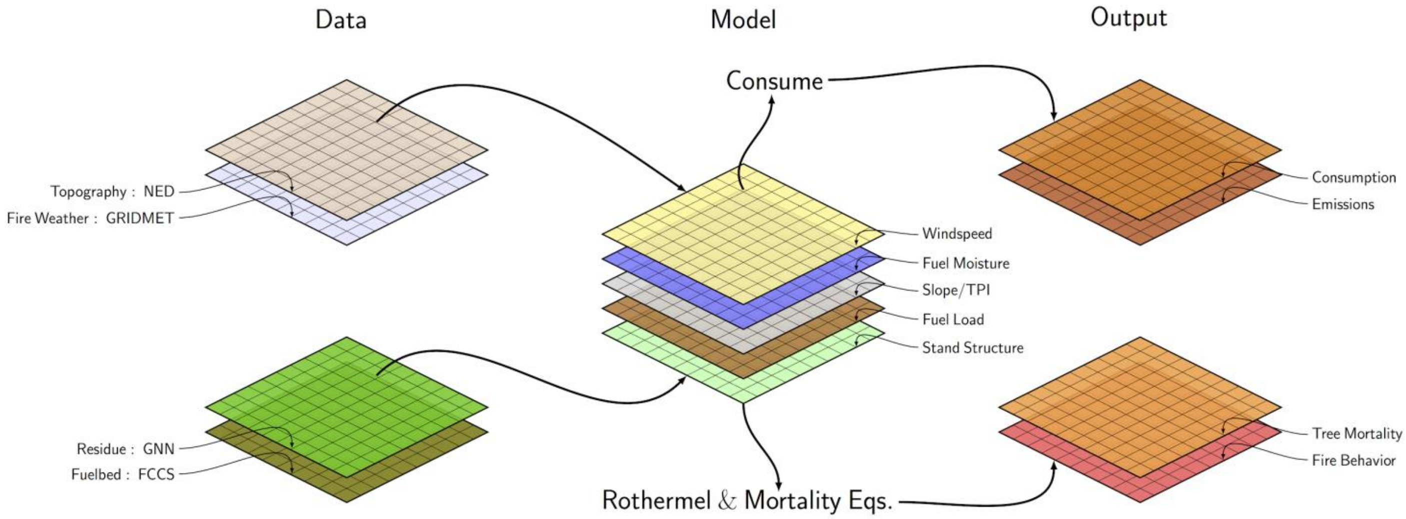


Figure 4: Raster processing flow diagram for fire modeling.

Species Composition: We have established a database of decay constants that vary by species and size class. These values come from literature sources and synthesize numerous meta-analyses of decay (Laiho and Prescott, 2004; Mackensen and Bauhus, 1999; Weedon et al., 2009; Yin, 1999). These values are being used to vary the rates of residue decomposition based on the species composition at a given location.

Size Class and Disposition: Decomposition rate of biomass in the forest varies by size class and between scattered and piled material (Edmonds et al., 1986; Erickson et al., 1985; Wagener and Offord, 1972), with material in contact with the ground exposed to conditions and organisms that hasten decay. Decay constants are varied by the following size classes: CWD – standing (CS), CWD – down (CD), fines (F), and litter (L). Where material is piled, we assume a consistent size and geometry for the piles and treat the bottom fraction of the total material as though it were scattered because it is in contact with the ground. The resulting set of spatially explicit decay constants is shown in Table 1.

Table 1: Set of decay constants and associated climate modifier provided for each 30m raster cell across the state.

Location i	Snag	Piled			Scattered			α_i
	$k_{CS,i}$	$k_{CD,p,i}$	$k_{F,p,i}$	$k_{L,p,i}$	$k_{CD,s,i}$	$k_{F,s,i}$	$k_{L,s,i}$	

Climate: Temperature and moisture are the two most important climatic factors that affect the decay of biomass (Sierra Carlos A. et al., 2015). Temperature controls the rate of heterotrophic cell respiration while moisture can be a limiting factor of decay if material becomes too dry. To capture these effects, we apply a mechanistic model that alters the exponential decay constant in a given area based on the historical temperature and soil moisture of the area. A variation on the Demeter equations for climate effects was used to derive α_i as the product of a temperature function and a moisture function (adapted from (Foley, 1995)):

$$\alpha_i = f(T) * f(M)$$

A 10-year average from 2007 through 2017 for 100-hour fuel moisture and mean daily temperatures are used from GridMET (Abatzoglou, 2013) to obtain spatial variability in temperature and moisture.

5. Model Capabilities

The California Biomass Residue Emissions Characterization (C-BREC) Tool (Figure 5) enables robust, transparent accounting for the GHG and air pollutant emissions associated with residual biomass energy systems in the state. This entirely open-source tool is being built using the R programming language, and implemented online in Python. Users specify the following key project characteristics to begin using the tool:

- Location of residue generation
- Type of forestry or agricultural activity being conducted and primary harvest method
- Location of residue utilization
- Reference fate of unremoved biomass (piled, scattered, burned)
- Key supply chain characteristics such as any post-harvest treatment, end-use technology, etc.

For a given project profile, The C-BREC model generates an emissions time-series, reporting net emission values for several different time-explicit climate metrics. This modeling approach also enables us to evaluate the sensitivity of the results to various key input parameters, enabling us to target policy recommendations and subsequent research efforts.

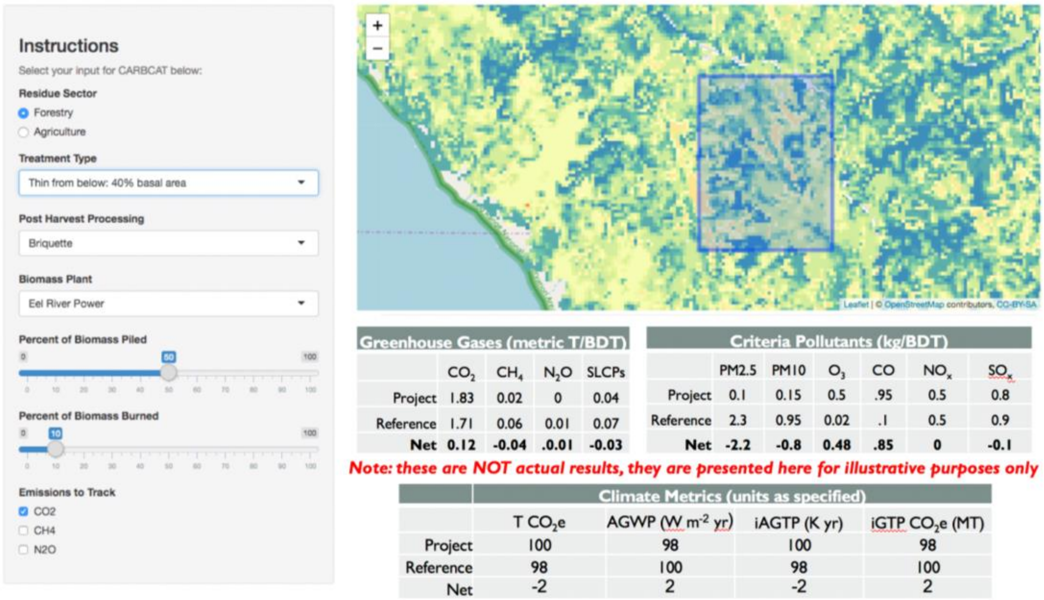


Figure 5: Preliminary mock-up of online C-BREC tool interface.

6. Follow-up Work

Preliminary research and early results are enabling identification of key literature gaps and sensitivities:

a) *Empirical studies of targeted emissions sources:* Based on preliminary evaluation of model sensitivities, we believe that potential for methane emissions from biomass decomposition could be an important driver of net overall climate performance. This applies both in the open chip piles sometimes present in biomass energy supply chains as well as in the reference fate of the field piling of residues. Our team has one grant in hand as well as one proposal under consideration for field measurement of these emissions.

b) Integration with broader land-use modeling frameworks: This project considers forest management and agricultural activities as exogenous to the biomass residue supply chain. As such, we do not quantify any carbon cycling implication of these activities. We have recently submitted a project proposal in partnership with Lawrence Berkeley National Laboratory that would facilitate the integration of our model with their ongoing natural and working lands carbon accounting model (CALAND) to more comprehensively characterize the climate implications of land-use decisions in the state.

c) *Air emissions health burden:* Our research will generate a substantial, spatially disaggregated database of criteria air pollutant emissions associated with mobilization and utilization of biomass residues as well as their counterfactual fate in the field. It is beyond the scope of this research to evaluate the human health burden associated with these emissions, but our results will create interesting avenues for such research, and we are eager to pursue them.

d) *Residue pile-burn database:* One key driver of the net performance of biomass residue energy systems is the extent to which these residues would also have been burned deliberately in the reference system. Despite the air quality, forest management, and climate implications of this practice, there is no organized effort to track it in the state. A careful, statewide survey of forest operators would enable better understanding of the extent of residue burning in California as well as the major drivers of residue management decisions.

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