ANALYSIS OPTIONS FOR FOREST CARBON INVENTORY AND GREENHOUSE GAS LIFE CYCLE ASSESSMENT OF THE CALIFORNIA FOREST LAWS AND REGULATIONS

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EXECUTIVE SUMMARY

It is believed that properly managed forest landscapes can help to mitigate the effects of climate change. Forests convert atmospheric carbon dioxide (CO_2) into carbon and store it in forest biomass and soils. Wood products from harvested forests can also store carbon for long periods of time. When forest residual and slash materials are used as a bioenergy source, instead of leaving it in the forests to burn or decay, forest greenhouse gas emissions (GHG) may be reduced.

Assembly Bill 1504 (AB 1504, Skinner 2010)[1] amends the Z'berg-Nejedly Forest Practice Act of 1973 (i.e., the rules and regulations that govern the management of California's forests) to require that the California Board of Forestry and Fire Protection (BOF) and Department of Forestry and Fire Protection (CAL FIRE) guarantee its regulations governing commercial timber harvesting take into account the capacity of forests to sequester 5 million metric tons (MMT) of carbon/year, consistent with California's climate change mitigation goals for the forest sector established under Assembly Bill 32 (2006).

This report presents two analytical approaches to evaluate the effect of California's forest rules and regulations on forest GHG emissions and carbon sequestration – 1) Forest Carbon Inventory and 2) Life Cycle Assessment. Life Cycle Assessment (LCA) is presented as an approach because it is a standardized analytical method used to comprehensively quantify and interpret energy and material flows to and from the environment over the entire life cycle of a product, process, or service. In this case, California's timberlands and forestlands (and associated wood products) are providing a service of sequestering atmospheric CO_2 and thus helping to mitigate climate change. Through the course of the project however, discussions amongst the Project Team and input provided by the Project's Science Advisory Committee identified the need to first determine if the state's forest sector is meeting AB 1504's target of sequestering 5 MMT of carbon/year. It was reasoned that if the forest carbon inventory analysis determines that California is not meeting the AB 1504 target, then a more in-depth LCA could be performed to better identify which forest practice rules (and within which segment of the forest and wood products stream) were effecting the state's ability to meet the AB 1504 target. Consequently, two questions guided the development of analysis options to address Task 2 of the IFWG work plan and AB 1504 directives:

1. Is California meeting the AB 1504 adopted forest sequestration target of 5 MMT/year?
2. What is the effect of various adopted forest-related rules, practices, policies and laws on carbon sequestration and associated GHG emissions?

The Forest Carbon Inventory option was developed to answer the first question, and is compliant with the Land Use, Land Use Change and Forestry (LULUCF)[2] Tier 3 methods identified by the International Panel on Climate Change (IPCC). The following analytical steps were identified for Forest Carbon Inventory option:

1. Define analysis area and period.
2. Establish baseline forest conditions and carbon stocks.
3. Track fate of carbon in wood removals.
4. Conduct carbon accounting.

[1] Assembly Bill 1504 (Skinner 2010) - http://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml

[2] Land use, land-use change and forestry (LULUCF) is defined by the United Nations Climate Change Secretariat as "*A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities*."

The LCA options identified in this report comply with ISO standards which includes four iterative phases (i.e., Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation) where previous steps can be revisited in an iterative process of refinement. The following summarizes findings and recommendations by LCA Goal and Scope Definition, Inventory Analysis, and Impact Assessment phases.

1. The Goal and Scope Definition Phase - The goal of the Forest Regulation GHG LCA as interpreted from AB 1504 and preceding documents as: "*to evaluate and assess the effect of California's forest rules and regulations on forest GHG emissions, baseline stocking level, and carbon sequestration potential*." The intended audience includes forestry regulators, managers and practitioners, policy makers, stakeholders, as well as the public at large. The scope of the Forest Regulation Carbon LCA is extensive with key goal and scope elements highlighted here:

- A comprehensive list of existing forest rules was compiled and ranked for their potential effect carbon sequestration. We identified 263 existing rules under existing Forest Practice Regulations with carbon relevance, categorizing rules by their focus on timber harvest standards, wildfire, pest control, wildlife, soil erosion, or land conversion. Rules with the greatest carbon impact are highlighted in the report. One notable finding was that there is no searchable database or other easily accessible option to analyze the scale that carbon emission impact assessments currently play under CEQA requirements for timber conversions. To improve understanding on GHG consequences and mitigation practices of timberland conversions in California, we suggest creating a dataset identifying all timberland conversions reported to CAL FIRE and identify the respective GHG mitigation activities approved under CEQA where applicable.
- We identified the need to conduct a 'consequential' LCA, where a comparison of GHG effects would be made between existing California forest with rules and regulations applied and an alternative set of rules and regulations applied. Comparison using either modeled outputs (comparing 'existing rules' vs 'alternative rules') or through comparisons of outputs derived from empirical datasets representing a site with 'existing rules' vs. another site with 'alternative rules' scenarios would be used to identify which rule set results in a greater carbon sequestration benefit.
- The underlying system to be analyzed was organized into three major forest system elements (forest ecosystem, forest operations, and forest products).
- The system boundary was identified in terms spatial, temporal and operational boundaries. The outermost spatial boundary of the LCA is represented by the extent of California forest rules and regulations authority, which can be further stratified by CAL FIREs districts and sub-districts as well as by forest types and forest age classes. Expanding the spatial boundaries to include forest lands managed by other agencies would provide a more complete assessment of forest carbon dynamics. The temporal boundary definition would depend on the analytical approach used, where for modeled comparisons, rules and regulation effects would be measured at a 20 year and 100 year time frame although any time interval and duration could be used to explore shorter or longer term model outputs. For empirical data comparisons, measured outputs would be based on time since different rules and regulations were applied. Operational boundaries were identified as forest, operations, and products.
- A diagram and supporting narrative was constructed to show linkages and fluxes between atmospheric CO_2, carbon pools, non-GHG and GHG emissions.
- An extensive inventory of existing data was compiled and placed into the context of different LCA impact analysis options – both for modeled comparisons and for comparison based on empirical data.

- The implementation of a selected LCA option should be subject to review by the public, stakeholders (including agency managers), and a Board of Forestry (BOF)-external Science Advisory Committee. The report supporting the LCA needs to detail results, data, methods, assumptions and limitations. All assumptions need to be spelled out including description of unit processes and choice of impact categories and especially baseline forest rules impact assumptions. The report needs to provide clear language on the original (i.e., non-CO_2 related) context of the analyzed rules.

2. The Inventory Analysis Phase - The inventory analysis phase (LCI phase) is an inventory of input and output data with regard to the system being studied. A data inventory and a flow model of the forest system was constructed in this report. A comprehensive list of available vegetation, soil, wildfire, climate, timber harvest, and wood product data were compiled as well as forest growth, wildfire, climate, energy models for all activities within the system boundary were identified and listed in Appendix A and B this report.

3. The Impact Assessment Phase – This phase is aimed at evaluating the significance of potential environmental impacts by translating the extensive LCI flows into meaningful environmental measures. In this report, the details of three LCA impact analysis options (Gold, Silver, and Bronze) are presented for consideration by CAL FIRE. For each analysis option presented, we include input provided by stakeholders and the Project's Science Advisory Committee and present details on temporal and spatial considerations, and identify best available data and models to conduct forest inventory and a Life Cycle Analysis. In addition, we identify tradeoffs for each option and gaps in data and model capabilities. Each LCA options presented in this report follow the same generalized analysis steps, including:

1. Document LCA goal and scope definitions and define system boundaries
    a. Define spatial boundaries and stratify analysis area
        i. Functional evaluation unit (e.g. watershed, fire-shed – the area to which output metrics are scaled)
        ii. Reporting units (e.g., state, region, district)
        iii. Modeling units (e.g., specific stand, general forest type)
    b. Define temporal boundaries
        i. Modeled time horizon (e.g., 10, 20, 40, 100 years)
        ii. Analysis summary interval (e.g., annual, 5 year time step, 10 year time step)
    c. Identify process units, inputs and outputs
        i. Included carbon pools
2. Define and document baseline and alternative scenarios (e.g., forest regulation scenarios) and associated assumptions
3. Evaluate and forecast expected future climate and weather regimes
4. Evaluate and forecast expected future forest fire regimes
5. Evaluate and forecast expected future forest disease and disturbance
6. Evaluate and forecast carbon sequestration and emissions for forest ecosystem, under baseline and alternative scenarios, integrating weather, fire regime, and disease analyses (3, 4 and 5 above).
7. Evaluate and forecast expected future emissions from forest operations, under baseline and alternative scenarios.
8. Evaluate and forecast carbon sequestration and emissions from forest products, under baseline and alternative scenarios
9. Conduct carbon accounting for baseline and alternative scenarios, integrating forest ecosystem, forest operations, and forest products analyses (steps 6, 7, and 8 above).

10. Conduct leakage analysis
11. Conduct interpretation and refinements as you move through each step

The 'Gold' LCA option presented in this report represents a full modelling approach. This option uses the finest resolution data possible to evaluate forest carbon stock and flux. Where possible, evaluation would be based on spatially explicit stand-level data, such as field survey or forest inventory data. Single stands or parcels can be evaluated individually, or multiple stands can be evaluated simultaneously as a larger landscape (e.g., watershed) to determine forest carbon sequestration, emissions, and expected wildfire behavior. The analysis uses individual tree growth and yield models such as the US Forest Service Forest Vegetation Simulator (FVS) and extensions to forecast vegetation change over the analysis period, and is linked spatially in GIS to fire behavior prediction models (FlamMap). Fine scaled weather and climate predictions drive the forest vegetation forecasts and fire behavior predictions. Wildfire emissions models (CONSUME and U.S. Forest Service Forest Vegetation Simulator) are used to predict wildfire emissions during the analysis period for each rule scenario, and are calculated using the area based on vegetation projections, forecasted weather scenarios, and changes in expected fire spread and severity. This approach would include a probabilistic assessment of model results and provide robust estimates on CO_2 emission reductions as well as associated confidence estimates.

The 'Silver' LCA option would use a state and transition approach, using the Vegetation Dynamics Development Tool (VDDT). The evaluation unit would be a fireshed, although it could be larger if necessary. The fireshed would be stratified into cells, each assumed to be homogenous, with each cell assigned a class. Each class, representing a vegetation cover type/structural stage combination would be associated with a carbon value using existing tools and data such as growth models (e.g., FVS), or lookup tables (e.g., Carbon Online Estimator). Specificity of the classes and carbon values could be scaled, depending on the scope of the analysis, to represent either specific site conditions, or broad regional forest type conditions. Cells (e.g., spatial locations) would change through time based on transitions such as succession and management actions. Transition pathways can be either deterministic or probabilistic. Carbon values for classes under different climate projections can be accounted for using FVS Climate.

The state and transition method would account for wildfire and other disturbances in a stochastic way, with stands having some probability through time of transitioning to a burned state, with its own carbon value. Assumptions for harvest levels, forest growth, and probability of wildfire or other disturbance would be based on "current" or 2014 levels, a "contemporary" trend average over the last 10 years, and/or a "quarter century trend" which utilizes available data for up to the past 25 years.

The 'Bronze' LCA option represents a generalized approach. The approach for this option would be to utilize existing datasets and models for all analysis, and complete the analysis at the Forest District Level as defined by the current California Forest Practice Rules, then aggregate values at each district to a statewide level. Within the High-Use Sub-Districts and other counties that have additional rules (Marin, San Mateo, Santa Clara, Santa Cruz, Lake, and Monterey), this option would quantify the effects of these additional rules into the analysis. This analysis would generally be non-spatial, with ArcGIS primarily used to extract data from existing datasets and convert into an Excel format. Baseline forest carbon stocks would be based on a lookup table, using the COLE system (Carbon Online Estimator) or similarly broad scaled option. Assumptions for harvest levels, forest growth, and losses due to wildfire or other disturbance would be based on "current" or 2014 levels, a "contemporary" trend average over the last 10 years, and/or a "quarter century trend" which utilizes available data for up to the past 25 years. The

analysis itself could be conducted using a series of Excel based spreadsheet to estimate and summarize current and future carbon stocks over the analysis period under future climate scenarios.

The Forest Carbon Inventory and LCA options presented provide implementable avenues that BOF and CAL FIRE can pursue in the fulfillment of AB 1504 directives.

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INTRODUCTION

Through photosynthesis, California's forests convert atmospheric CO_2 into carbon and can store carbon in forest biomass and soils for long periods of time. Wood products from harvested forests also store carbon for longs periods of time. When forest residual and slash materials are used as a bioenergy source, forests may emit less greenhouse gases (GHG) than when burned through wildfire or managed fire.

It is believed that properly managed forest landscapes can help to mitigate the effects of climate change. California's Forest Sector is the only sector identified as a net GHG sink in the 2008 and 2014 California Air Resources Board (ARB) Scoping Plans. Thus, there is a need to understand the effects of management and natural process on forest carbon emissions and sequestration. Forest inventory and Life Cycle Analysis (LCA) methods can be used to evaluate if forests sequester more carbon than is emitted as CO_2 and other GHGs.

The potential benefits from forest carbon sequestration are, themselves at risk from climate change. Climate science predicts a loss of conifer forest cover in California as a result of forest regeneration failures and stand mortality caused by drought stress, invasive species, and possible increases in insects disease, and wildfires (Moritz et al. 2012, Hurteau et al. 2014b, Silva and Anand 2013, Dale et al. 2001). Thus there is also a need to understand climate change effects on forested landscapes, their sequestration and GHG emission processes and fluxes, as well as management effects on these changing processes. Filling these information gaps will help to support California's climate change policy and inform management decisions for California's forests and improve our understanding of the ultimate fate of carbon and CO_2 emissions in the context of the forest ecosystems, wood products and forest bioenergy utilization.

The origin of this project is linked to Task 2 of a work plan developed by the California Interagency Forest Working Group on Climate Change (IFWG). The IFWG was chartered to provide recommendations and technical information to assist the California Board of Forestry (BOF) in achieving goals and objectives outlined in relation to the climate adaptation strategies referenced in Governor Schwarzenegger's Executive Order 13-08. The charge of the IFWG was to establish a clear list of priorities for forest related climate policy and strategy development. The objective of Task 2 of the IFWG work plan was to determine the effect of California's existing forest [and rangeland] regulations and related programs on meeting the state's GHG goals as adopted in Governor Schwarzenegger's Executive Order S-3-03.

AB 1504 (2010) amends the Z'berg-Nejedly Forest Practice Act of 1973 to require that the BOF guarantee all its regulations governing commercial timber harvesting take into account the capacity of forests to sequester carbon dioxide. AB 1504 (2010), Section 4551 (b) (1) states that "*The board [BOF] shall ensure that its rules and regulations that govern the harvesting of commercial tree species, where applicable, consider the capacity of forest resources, including above ground and below ground biomass and soil, to sequester carbon dioxide emissions sufficient to meet or exceed the state's greenhouse gas reduction requirements for the forestry sector, consistent with the scoping plan adopted by the State Air Resources Board [ARB] pursuant to the California Global Warming Solutions Act of 2006 (Division 25.5 (commencing with Section 38500) of the Health and Safety Code)*". According to an Assembly floor analysis[3] of the AB 1504 (2010) legislation, BOF and CAL FIRE, in consultation with ARB, are to assess the

[3] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200920100AB1504

capacity of its forest regulations and non-regulatory forestry programs to meet or exceed the state's greenhouse gas reduction goals.

In response, CAL FIRE identified a scope of work for a third party to evaluate analysis options (this report) to address directives interpreted from AB 1504 (2010) and Task 2 of the work plan developed by the IFWG. CAL FIRE identified the following core tasks:

- Identify adopted forest regulations and practices that could significantly affect carbon sequestration processes and trends;
- Clarify the temporal framework for analysis;
- Clarify the spatial framework for analysis;
- Evaluate and provide options regarding the best existing data, analytical methods, forest growth models, and climates models;
- Identify gaps in data and analytical methods;
- Place the above listed tasks into the context of a life cycle assessment (LCA) following ISO standards.

Consequently, the purpose of this report is to summarize relevant data and information, and to forward analytical options that can be used to guide a subsequent analysis to help fulfill AB 1504 (2010) requirements. The technical objectives (i.e., excluding stakeholder participation and public outreach efforts) of this project are to:

- Develop practicable analysis options, which can be used guide a follow-on study that answers the question: "*What is the effect of adopted forest-related rules, practices, policies and laws on carbon sequestration (amount and rate) and GHG emissions?"* and *"is California meeting the 5 MMT/year carbon sequestration target for the forestry sector identified in AB 32 and AB 1504?"* It was resolved by the Project Team that answering the "target" question first would provide an understanding of the current status under California's existing forest rules and regulations. If such an analysis indicates (with high confidence) that carbon is being sequestered at or above 5 MMT/year, then it might be reasonable to assume that currently adopted forest practice rules are consistent with AB 1504. Conversely, if the target is not being achieved, or is at risk from future climate change, then a more in-depth LCA study could be conducted to identify policy options to improve forest carbon sequestration and GHG emission reduction outcomes.
- Other objectives of this report are to provide recommendations and rationale for each analysis option for the following: 1) spatial and temporal context, 2) what data, models and assumptions should be used for each analysis option, 3) how the data should be analyzed, and 4) what gaps in data and models exist that limit the ability to immediately implement an analysis option.

This report provides an overview of LCA, and a review of forest practice rules that likely have the greatest effect on forest carbon sequestration and GHG emissions. Also within the context of LCA phases, the report provides temporal and spatial analysis considerations, an exhaustive review of available and relevant data, models and potential gaps. The report concludes with a detailed description of analysis options that BOF and CAL FIRE could use as they proceed in the implementation of AB 1504 directives.

LIFE CYCLE ASSESSMENT AND ITS APPLICATION TO FOREST RULES AND REGULATIONS

Life Cycle Assessment Overview

A LCA is an analytical method used to comprehensively quantify and interpret energy and material flows to and from the environment over the entire life cycle of a product, process, or service (ISO 2006a, ISO 2006b). The analytical framework provided in ISO standards for life cycle assessments are able to account for complexities inherent in understanding California's forest GHG emissions and carbon sequestration in the context of global climate change. The ISO 14040 LCA standard specifies general LCA principles and frameworks (ISO 2006a), while ISO 14044 LCA standard (ISO 2006b) provides in-depth LCA requirements and guidelines. A LCA based on ISO standards includes four phases (Figure 1):

- The Goal and Scope Definition Phase - An LCA starts with an explicit statement of the goal and scope of the study, which sets out the context of the study and explains how and to whom the results are to be communicated. The scope of an LCA, including the temporal, spatial and system boundaries and level of detail, depends on the subject and the intended use of the study. The depth and breadth of a LCA can differ considerably depending on the goal or goals of the LCA.
- The Inventory Analysis Phase - The inventory analysis phase (LCI phase) is an inventory of input and output data with regard to the system being studied. It involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. It involves collection of the data necessary to meet the goals of the defined study. The input and output data needed for construction of the model are collected for all activities within the system's boundaries, including from the supply chain.
- The Impact Assessment Phase - The purpose of life cycle impact assessment phase (LCIA) is to understand and evaluate the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. This phase is aimed at evaluating the significance of potential environmental impacts by translating the extensive LCI flows into meaningful environmental measures.
- The Interpretation Phase - In this phase, significant issues based on the results of the LCI and LCIA phases of LCA are identified. This phase includes an evaluation that considers completeness, sensitivity and consistency checks through each LCA phase as well as a place to capture conclusions, limitations, and recommendations.

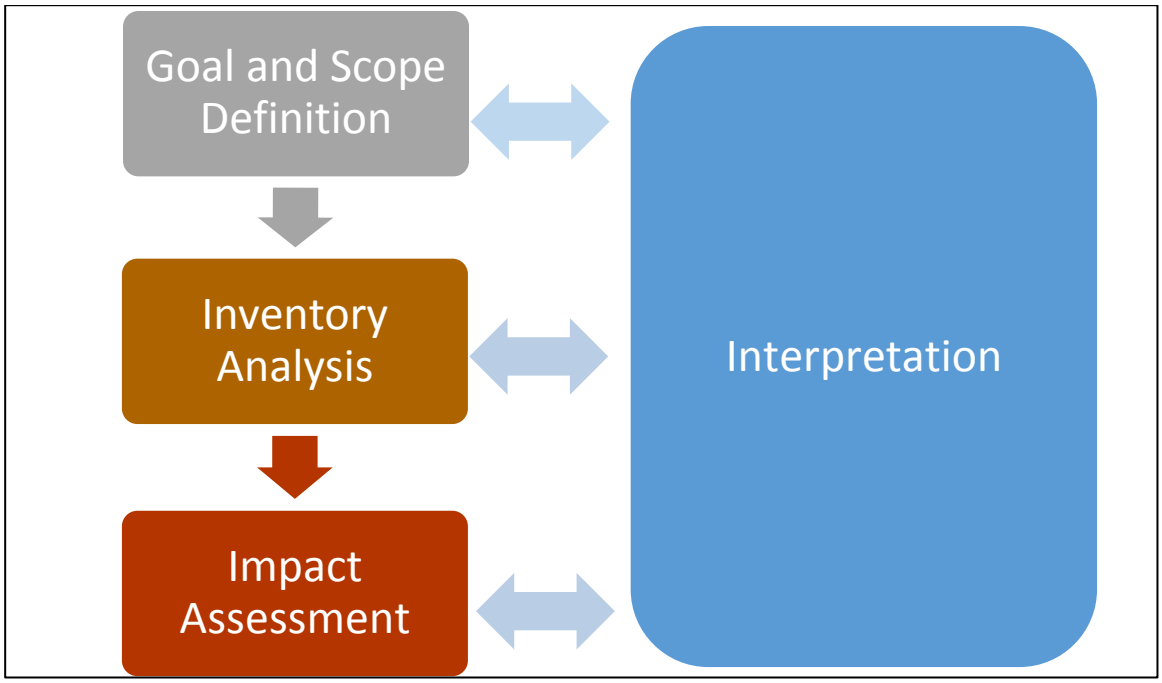

Figure 1: Life Cycle Assessment phases and the interaction with the interpretation phase (adapted from Figure 4 in ISO 2006b). A Life Cycle Assessment is an iterative process where the interpretation phase is used to refine or revise goals and scope (e.g. revised system boundaries), the inventory analysis (e.g., integrate new or different input or output data), or the impact assessment.

The unique nature of assessing the effect of California's forest related rules and regulations on forest land makes some ISO LCA steps less significant while elevating others. For instance, allocation procedures of greenhouse gas (GHG) emissions towards a specific product are of lesser concern since all emissions will be accumulated and related back to the affected acreage. Also, no value choices are applicable nor a definition of several impact categories (the only impact category applicable is net CO_2 emissions). We therefore in this report concentrate on those sections of the scope definition that are project-relevant.

Figure 2 aligns the ISO-specific LCA steps (i.e., Goal and Scope Definition, Inventory Analysis, Impact Assessment including data quality analysis and normalization, and Interpretation) with the project-specific analytical steps of a Forest Regulation Carbon LCA. The iterative nature of the ISO-LCA approach allows for revisiting the goal and scope definitions at multiple points along the analysis chain.

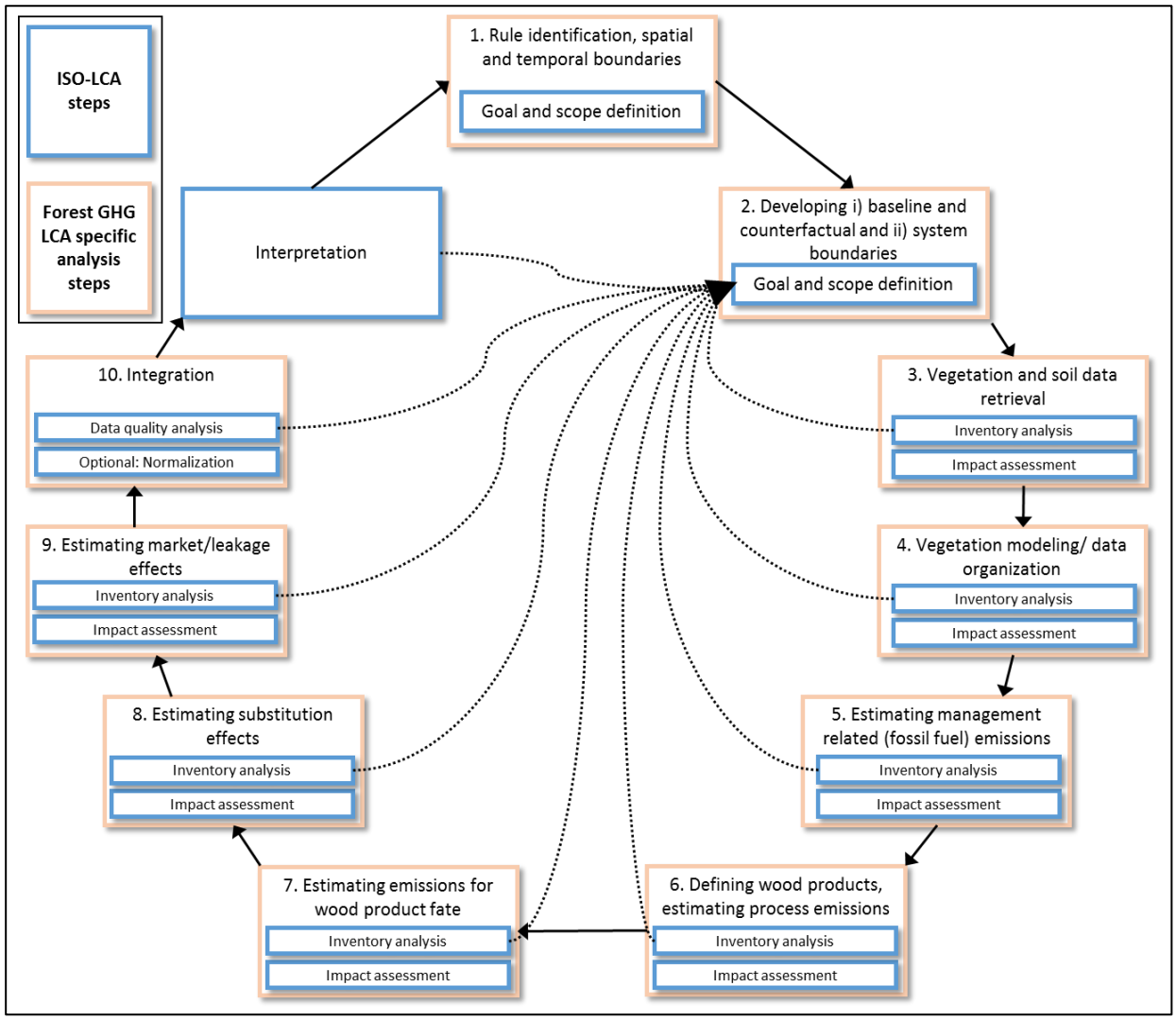

Figure 2. For a given forest management control scenario (e.g., with California forest practice rules applied to a defined assessment area), these are the ISO LCA steps (1. Goal and Scope Definition, 2. Inventory Analysis, 3. Impact Assessment including data quality analysis and normalization, 4. Interpretation) aligned with the project-specific analytical steps of the Forest Regulation Carbon LCA study. The iterative nature of the ISO-LCA approach allows for revisiting the goal and scope definitions at multiple points along the analysis.

Goals and Scope of the Life Cycle Assessment for Forest Rule and Regulations

ISO-standardized LCA steps start with a goal and scope definition. The goal definition should include the intended application, the reasons for carrying out the study, the intended audience, and whether the results are intended to be used in comparative assertions disclosed to the public. The initial goal of this LCA was interpreted from AB 1504 (2010) and Task 2 of the preceding IFWG work plan - to evaluate and assess the effect of California's forest rules and regulations on forest carbon emissions (CO_2), baseline stocking level, and carbon sequestration potential (expressed as million metric tonnes per year [or MMT/yr]). The intended audience includes forestry practitioners, the Board of Forestry (i.e., policy makers responsible for revisions to rules and regulations), stakeholders, as well as the public at large. Since the LCA approach is intended to compare the impact of the currently adopted suite of forest rules and regulation (i.e., baseline scenario) with an 'alternative rule' scenario (for comparative assertions with the baseline), this baseline needs to be clearly defined in nature and methodology.

Input provided by the Science Advisory Committee and Project Team on a draft version of this report expanded the goal to include an analysis option that could be used to answer the question of whether California is meeting the 5 MMT/year carbon sequestration target. Since a LCA is not appropriate for addressing this goal, an additional analysis option (i.e., carbon inventory option) is included in the report.

There are two different types of LCA – "attributional" LCA and "consequential" LCA. Attributional LCA focuses on the processes associated with producing, consuming and disposing a product, frequently with the intent to identify opportunities to reduce a product's environmental impact. In contrast, a consequential LCA "*models the causal relationships originating from the decision to change the output of the product, and therefore seeks to inform policy makers on the broader impacts of policies which are intended to change levels of production*" (Brander et al. 2008). While most LCAs and associated guidelines are of an attributional nature or are geared towards an attributional LCA, a consequential LCA can utilize LCA frameworks built for an attributional use as well. This is an important distinction since the analysis of GHG implications of California forest rules and regulations using LCA methodology falls under the definition of a consequential LCA where a baseline rules scenario would be compared to an alternative rules scenario in terms of carbon sequestration and GHG emissions.

The Forest Regulation Carbon LCA is envisioned as a comparison between an 'existing rules' scenario (baseline) and an 'alternate rules' scenario. The 'Assessment of California Rules and Regulations' section in this report provides an overview of the rules to be analyzed, and the 'Data Requirements' section provides more discussion of the methodological implications of providing datasets for such a comparison. The 'existing rules' (baseline) scenario in this context would be defined as a scenario in which all the current forest rules under consideration remain in effect. The 'alternative rules' scenario in this context would be defined as a scenario in which one would apply a different set of forest rules than the baseline that might yield greater (or fewer) carbon sequestration and GHG benefits. The cost of regulations would also need to be considered when providing the scope of the comparative study. For instance, an alternative rule set could require extensive environmental review/documentation, site preparation and the use of alternative harvest technologies - the cost to comply with this set of alternative rules could theoretically prohibit some property owners from implementing a timber harvest.

ISO LCA standards contain clear language dealing with the potential pitfalls when using a LCA approach to compare several potential scenarios or product alternatives. For instance, ISO 14044 (2006b) states that "*an LCI study alone shall not be used for comparisons intended to be used in comparative assertions which are to be disclosed to the public*". This statement is grounded on the potential sensitivities and intended or unintended biases coming from comparing alternatives solely based on LCA outcomes. It is therefore of paramount importance to carefully select and describe the 'alternate' scenario against which the set of forest-relevant rules and regulations in California should be measured against. Any documentation on CO_2-emission LCA's in the context of California forest rules and regulations needs to provide clear language on the original (i.e., non-CO_2 related) context of the analyzed rule.

In order to identify a suitable baseline, Buchholz et al. (2014) provide an overview on guiding principles that could guide the choice of a baseline including accuracy, comprehensiveness, conservativeness, and practicality – with each of these principles receiving potentially different weightings depending on the assessment's purpose:

"Gustavsson et al. (2000) identified four principles that suggest baselines should be accurate, comprehensive, and conservative, as well as balanced against practicability. Accuracy refers to capturing data uncertainty in a spatial and temporal context. Comprehensiveness refers to data completeness ("Are all carbon pools and fluxes accounted for?") and completeness of GHG emission drivers (socioeconomic and ecological) while conservativeness captures a framework's ability to not overestimate the deviation of a given GHG emission pathway from the baseline. Practicability refers to being simple enough to be widely implemented. These attributes might receive different weightings depending on the accounting framework's purpose. If a planning framework is being developed, comprehensiveness and conservativeness might be paramount attributes for deciding on an appropriate baseline. If a monitoring framework is being developed, accuracy and practicability might receive increased scrutiny."

Besides the consideration mentioned above when choosing a baseline, ISO LCA standards also require that if "*the study is intended to be used in comparative assertions [and] is intended to be disclosed to the public, the final sensitivity analysis of the input and output data shall include the mass, energy and environmental significance criteria so that all inputs that cumulatively contribute more than a defined amount (e.g., percentage) to the total are included in the study*" (ISO 2006b). Considering the complexity of the Forest Regulation Carbon LCA study and the uncertainty associated with large segments of the system, the definition of a threshold value might be warranted. That is, a minimum or maximum difference (by ratio or total value) should be defined before a law can be declared as detrimental or beneficial. For example, the European Commission directive 2009/28/EC mandated that biofuels and bioliquids need to provide at least 35% carbon emissions savings over conventional (fossil) fuels in order to be in compliance with national targets (European Commission 2009). Threshold values may be defined for forest rules and regulations, to declare that they do or do not meet this requirement.

In the context of the Forest Regulation Carbon LCA study, the first practical step is to identify the rules that should be studied on their GHG implications (see prioritization of rules in section 'Assessment of California Rules and Regulations'). Rules might differ in their applicability and significance by district and region. For example, wildfire-relevant rules could receive different attention in the coastal redwood ecosystems than in the mixed conifer ecosystems and Stream Management Zones (SMZ) may receive different scrutiny depending on their location. We suggest that LCA outputs should therefore be reported in a format that allows one to look at results at various spatial scales, ownerships, but also by forest type (e.g., coastal redwood, riparian, oak woodland, montane chaparral, mixed conifer, Douglas fir, red fir, subalpine). Furthermore, definitions and decisions on how to deal with important attributes are other important steps in this stage. Examples include how to define fire-related attributes (fireshed delineation, fire risk, shadow effects) and management alternatives, as well as a decision on using an empirical data-based vs. model-driven approach for the comparative study assessment (see also section 'Life Cycle Impact Analysis Considerations'). The Life Cycle Assessment – Analysis Options section in this report provides a detailed overview on the Forest Regulation Carbon LCA specific analysis steps embedded into a LCA framework that adheres to ISO-standards.

Assessment of California Rules and Regulations

To help establish a baseline for California forest rules and regulations, we identified five distinct sets of with GHG and carbon relevance: 1) Forest Practice Act; 2) the Forest Practice Regulations; 3) the Public Resource Code (PRC) regulating the protection of forest, range and forage lands (prohibited activities [Division 4 Part 2 Chapter 6]; 4) the Wild & Scenic Rivers Act and; 5) The Professional Foresters Laws and Regulations (CPR Code §752). Within these rules and regulations, we identified a total of 263 specific sections that can be analyzed for their carbon emissions impact. Of these 263 rules, the Forest Practice

Act (33 rules) and the Forest Practice Regulations (225 rules) provide the bulk of the identified rules (Table 1). Almost half of the rules (128) applicable to carbon emissions provided a framework to maintain productivity/sustained yield. There were obvious overlap of rules amongst categories. For instance, soil conservation measures would also contribute to water quality protection as well as stand productivity. For a few rules, where a clear categorization was ambiguous because of overlapping controls, the most prominent category within the rule was used to categorize it. The "Definitions, General Rules" category was used to bin very general rules or rules covering several categories with no prioritization.

The Forest Practice Act (PRC Division 4, Part 2 Chapter 8)[4] provides a general set of definitions and regulations, and applies to private lands and non-federal public lands (except state parks) only. The Forest Practice Act mandates the preparation of Timber Harvesting Plans (THP) by a California Registered Professional Forester (RPF) for each harvesting activity. Timber Harvest Plans are the main monitoring and enforcement tool for the Forest Practice Act. We identified 33 rules under the Forest Practice Act with carbon relevance, with the following likely having the greatest influence:

- Maximum Sustained Production of High Quality Timber Products - 4513 (b)
- Stocking standards for point count and basal area - 4561 (a) and (b)
- Fire protection zone rules - 4562
- Control of soil erosion - 4562.5
- Nonindustrial Timber Management Plan - Article 7.5
- Conversions - Article 9

The Forest Practice Regulations[5] are the most specific set of regulations in a California forestry context and apply to private land and non-federal public lands (except state parks) only. The Forest Practice Regulations are intended to provide field personnel with working rules for their use. We identified 225 rules under the Forest Practice Regulations with carbon relevance, with the following likely having the greatest influence:

- Harvest Standards
  - Maximum Sustained Production of High Quality Timber Products - 913, 933, 953
  - Resource conservation standards for minimum stocking - 912.7
- Wildfire/Pest Control/Wildlife:
  - Treatment of logging slash to reduce fire hazard - 917.2, 937.2, 957.2
  - Burning of piles and concentrations of slash - 917.5,937.5,957.5
  - Protection of Residual Trees - 917.7,937.7,957.7
  - Fire Protection - 918, 938, 958
  - Emergency notice for fuel hazard reduction - 1052.4
- Soil Erosion
  - Tractor operations - 914.2(c), 934.2(c), 954.2(c)
  - Timber operation, winter period - 914.7, 934.7, 954.7
  - Use of heavy equipment for site preparation - 915.1,935.1,955.1
  - Treatment of vegetative matter - 915.2,935.2,955.2
  - Reduction of soil loss - 916.7, 936.7, 956.7
- Conversion - Article 7

[4] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=04001-05000&file=4511-4517
[5] http://calfire.ca.gov/resource_mgt/downloads/2014_FP_Rulebook_w_TRA_No.1.pdf

Table 1: Summary of the number of rules and regulations by rule category that were reviewed for their likely role in carbon sequestration.

	Rule Categories								
	Conversion	Cultural	Definitions, General Rules	Productivity & Sustained Yield	Soil Conservation	Water Quality Protection	Wildfire Prevention	Wildlife and Habitat	Grand Total
Forest Practice Regulations (Rules)	3	9	18	121	21	17	13	23	**225**
Forest Practice Act (FPA)	2		21	7	1	1	1		**33**
Professional Foresters Laws and Regulations			2						**2**
Protection of Forest, Range and Forage Lands; Prohibited Activities							1		**1**
Wild & Scenic Rivers Act			2						**2**
Grand Total	**5**	**9**	**43**	**128**	**22**	**18**	**15**	**23**	**263**

Protection of forest, range and forage lands: Prohibited activities - Relevant articles in the California Public Resources Code (PRC), Division 4, Part 2, Chapter 6 cover wildland fire preparedness measures outlined in Article 1[6] and Article 2[7]. While the general nature of these articles prevent a detailed analysis of their carbon emission implications, the effect of these rules is to prevent direct emissions from human-caused wildfires. While these articles may prevent emissions from fires in the near-term, implementation of the articles may contribute in the long-term to fuel buildup over time, potentially resulting in higher severity fires and thus greater carbon emissions. The Forest Regulation Carbon LCA study is intended to shed light on this question. Wildfire prevention rules covered in the Forest Practice Act (summarized above) would likely result in a similar outcome but are more detailed than PRC Division 4, Part 2, Chapter 6.

The Wild and Scenic Rivers Act (16 USC 1271-1287) - Public Law 90-542[8] affects forest-related carbon emissions in its entirety, however quantifying the carbon emission consequences of the act would be difficult. The only specific rule within the Wild & Scenic Rivers Act with tangible carbon emission consequences is the definition of special treatment areas (5093.52(i)) which poses a constraint on harvesting activities. While this rule could lead to increased stocking levels and therefore carbon storage on a given acreage, the broader carbon emission implications are less known. Reduced harvest levels could also impact the quantity of wood products derived from the affected acreage, potentially limiting carbon stored in wood products, product substitution benefits, and leading to leakage effects. While each of these segments is associated with a high degree of uncertainty, a final statement on the carbon emission benefits of a rule limiting harvest activities is premature with benefits likely only measurable on a case by case basis. The Forest Regulation Carbon LCA study is intended to shed light on this question.

The Professional Foresters Laws and Regulations[9]*,* requiring Registered Professional Foresters (CPR Code §752) to manage forests, can affect forest-related carbon emissions in its entirety, though more indirectly.

Conversion of Timberland - Since 1990, about 16,447 acres of private timberland were converted to non-timberland, peaking around 2002 (FRAP 2010). The conversion of timberland is regulated under 14 CCR 1100 which provides three possible ways to convert timberland in California:

- 14 CCR 1103 requires a permit to convert timberland. The harvesting of timber must occur per a timber harvesting plan, and the conversion permit covers the conversion activities (those things that occur after the timber has been removed). The timber harvesting plan undergoes a CEQA functional equivalent review, and the analysis contained in the plan should assess the project's effects on greenhouse gas emissions. The conversion activities undergo conversion-specific CEQA analysis (14 CCR 15064.4), which should also analyze the project's effects on greenhouse gases. However, the analysis is not required per regulations contained in the Forest Practice Rules.
- 14 CCR 1104.1 provides for a less-than-three-acre conversion exemption (14 CCR 1104.1), which is intended for small-scale conversions. No assessment of the conversion's effects on carbon

[6] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=04001-05000&file=4411-4418
[7] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=04001-05000&file=4421-4446
[8] http://www.ferc.gov/legal/fed-sta/wsr-act.pdf
[9] http://bofdata.fire.ca.gov/professional_foresters_registration/about_seebox/professional_foresters_laws_and_regulations.pdf

are required with the exemption, since it is exempt from the timber harvesting plan requirement.

- 14 CCR 1104.2 allows larger scale conversions for subdivision development on lands not zoned as timberland production zone. This is considered an exemption and no conversion permit is required. As with a regular conversion permit, timber operations occur per a timber harvesting plan, which should address the project's effect on greenhouse gases. Again, this is done per the requirements contained in CEQA.

There is no searchable database or other easily accessible option to analyze the scale that carbon emission impact assessments currently play under CEQA requirements for timber conversions. This might be partly due to the fact that the CEQA requirements do not specify a certain format how a carbon emission impact analysis would need to be done and/or how to mitigate undesirable carbon emission impacts. A proposed bill SG 455[10] as an amendment to PRC 4621[11] suggested a standardized mitigation strategy for timberland conversions in 2011 but was not chaptered.

The lack of GHG-mitigation specific language in CEQA may be partly responsible for the current absence of a standardized GHG impact assessment of timber- and forestland conversions which in turn results in a lack of metadata to study the scale and efficacy of GHG emissions derived from timberland conversions. To improve understanding on GHG consequences and mitigation practices of timberland conversions in California, we suggest creating a dataset identifying all timberland conversions reported to CAL FIRE and identify the respective GHG mitigation activities approved under CEQA where applicable. To complete this dataset, we suggest analyzing the GHG consequences of timberland conversions that fall under the exceptions outlined above.

Regulations, Policy and Plan Documents of Potential Relevance but not Further Screened - A public and stakeholder meeting was held on September 5, 2014 to receive input on which regulations might affect carbon sequestration, amongst other input requested for this project. Much of the stakeholder input revolved around regulations from other agencies (i.e., not BOF and CAL FIRE) which have the potential to affect carbon sequestration. Because these regulations and agencies were not within the scope of this project or within the scope of AB 1504 (2010), they were not evaluated as part of this project. Nonetheless, stakeholder input is documented here in recognition that there are other local, state and federal regulations, policies and planning efforts that may also impact carbon sequestration and, with additional screening could theoretically be included in a more comprehensive life cycle assessment.

On a federal level, the Clean Water Act, Endangered Species Act, Clean Air Act, and the National Environmental Policy Act can all affect forest carbon sequestration and GHG emissions but their impact is less tangible due to their broader legal focus compared to the rules reviewed above. These are not within scope of the AB 1504 (2010) mandate. On a state level, the California Environmental Quality Act (CEQA), the Porter-Cologne Water Quality Control Act and the California Endangered Species Act are succinctly covered by the rules identified above in terms of their GHG implications. Likewise, other federal and state regulation and programs designed to protect/conserve land for wildlife and other natural resources, such as California Fish and Wildlife Code, Natural Communities Conservation Plans (NCCP, California Fish and Game Code §2800), Habitat Conservation Plan (HCP, Federal Endangered Species Act - Section 10(a)(1)(B)), and federal Safe Harbor Agreements could affect forest carbon sequestration and carbon emissions, though not part of the AB 1504 (2010) mandate. Pesticide

[10] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB455
[11] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=04001-05000&file=4621-4628

regulations were also not further analyzed due to their secondary nature in terms of carbon emission impacts. Stakeholders at this meeting were also clear on the need to coordinate this effort with the Forest Carbon Plan that is being prepared by the Forest Climate Action Team and lead by the California Department of Forestry and Fire Protection.

Two non-binding policy documents with GHG relevance are the National Fire Plan 2014[12] as well as the state-level Strategic Fire Plan 2010[13]. The State has annual unit-specific fire plans with project priorities listed, including active and planned projects going back 10 years[14]. Since 2010, these fire plans have been linked to the State Strategic Fire Plan. Tracking the implementation of these plans may be important for carbon accounting. In particular, state and federal fire policy related to initial attack goals are relevant. By having a policy of extinguishing most fires before they are large (e.g. CA governor's budget 2014-15 Program 3450 Section 11.30: "CAL FIRE's goal is to contain 95 percent of all wildfires to 10 acres or less")[15] there is an effect on reducing near term emissions, but potentially increasing medium to long term emissions due to increasing fire severity resulting from fire exclusion. The Forest Regulation Carbon LCA study is intended to shed light on this question. For identical reasons, federal policy on managed fires would be relevant as well. However, since these state and federal fire policies are dispersed across many policy directives, a screening for specific rules was not possible. Wildfire response directives influence GHG emissions from wildfire directly through response time and suppression objectives, and indirectly through growth rates and future wildfire risk associated with fire return intervals.

System Boundaries and Functional Units

Within the California forest carbon context, the underlying system to be analyzed through an LCA can be organized into three major forest system elements (forest ecosystem, forest operations, and forest products) and their interactions with the atmosphere (Figure 3). Separating the wood product stream in this practical way helps to clearly define sequestration and GHG emissions accounting boundaries and facilitates identification of system specific emissions in understandable way to a broader audience. Depending on the LCA goal and scope definition (see above), some elements or sub-elements (e.g., direct forest product effects, indirect forest product effects) as well as impact indicators (e.g., CO_2 emissions only, non-CO_2 GHGs, albedo effect) might be included or excluded, affecting completeness and policy relevance, and scientific certainty of the outcomes (see also Figure 8, Cherubini 2013). By building on the concepts illustrated in Figure 3, the following sections will provide options to build such an accounting framework adhering to ISO LCA standards while at the same time considering available tools, models and datasets.

The definition of system boundaries for LCA accounting frameworks is not standardized in the literature. For instance, Eve et al. (2014) details accounting boundaries as physical, temporal, activity, and material boundaries. The ISO LCA standards restrict system boundary definitions to unit processes (activity boundaries; e.g., forest ecosystem carbon pool) and category indicators (material boundaries; e.g., CO_2 flows from wood processing) (Figure 3). Temporal boundaries are to some extent covered as part of the category indicator definitions. Both spatial and temporal boundaries deserve a special focus in forest carbon accounting compared to other LCA efforts due to the augmented complexity of forest ecology and the market sector.

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[12] http://www.forestsandrangelands.gov/strategy/thestrategy.shtml
[13] http://cdfdata.fire.ca.gov/fire_er/fpp_planning_cafireplan
[14] http://cdfdata.fire.ca.gov/fire_er/fpp_planning_plans and http://osfm.fire.ca.gov/fireplan/fireplanning.php
[15] http://www.ebudget.ca.gov/2014-15/StateAgencyBudgets/3000/3540/program_description.html

The definition of the system boundary needs to specify the unit processes and the input and outputs considered. ISO defines the unit process as the smallest element considered in the life cycle inventory analysis for which input and output data are quantified. Inputs and outputs are defined as product, material or energy flow that enters or leaves a unit process, respectively. In the case of a Forest Regulation Carbon LCA study, these unit processes could include:

- The forest ecosystem including the sub-units such as wildfire-related processes and soil carbon exchange processes;
- The handling of slash, covering harvest-related processes and fate such as on-site burning vs. feedstock for bioenergy production including fossil fuel emissions (direct and indirect fossil fuel emissions during handling of slash, avoided fossil fuel emissions in the energy sector);
- The handling of roundwood covering harvest-related processes including losses and leakage. In this case leakage would be the displacement effects when roundwood consumption is greater than roundwood production in California; where wood comes from other places with different, forest practices – practices that perhaps generate more fossil fuel emissions or result in greater environmental impacts;
- The manufacture and processing of wood products (comprising direct and indirect fossil fuel emissions) and including sub-units such as product substitution;
- The handling of residues occurring during the processing of wood products including avoided fossil fuel emissions in the energy sector if used as a bioenergy feedstock;
- The fate of wood products including avoided fossil fuel emissions in the energy sector if used as a bioenergy feedstock.

For a Forest Regulation Carbon LCA, inputs and outputs are restricted to energy (elementary flow) and products (product flow) throughout the production chain. Material consumption in the sense of an end-point reporting unit (e.g., amount of wood processed) is not the focus of this LCA. Nevertheless, to fully account for upstream fossil fuel emissions such as the production and maintenance of harvesting or manufacturing equipment, the fossil fuel emissions associated with the use of associated materials in the production process are of relevance.

In addition to defining inputs and outputs, the beginning and end of process units should be described. Also, the system boundaries should also assign the inputs and outputs to each unit process to ensure adequate incorporation and avoid double-accounting. This will assist in linking inputs and outputs to the functional unit in the indicator aggregation step.

A process diagram is a crucial part of the system boundary definition. Figure 4 and Figure 5 are examples of a process diagram identifying the process units and impact indicators associated with California forests and wood products. Figure 4 provides an example for more focused approach excluding non-CO_2 GHG impact indicators and excluding the accounting of product and energy substitution scenarios. In contrast**,** Figure 5 draws the systems boundary wider in terms of impact indicators and sub-unit processes (product substitution in the energy and wood products sector). These flow diagrams describe the overall understanding of the system, describe boundaries in terms of unit processes and category indicators, as well as what category indicator is associated with which unit process for a forest management control scenario. To run a comparative analysis describing two forest management policy scenarios, each scenario would follow the same system diagram, but the inputs (and associated values) would differ. For instance, an alternative rule set might result in more roundwood products to be extracted from a forest ecosystem compared to the existing rule (baseline) scenario. Both scenarios

would be run separately using the same pools and flows, varying only in inputs and outputs quantity and subsequently the carbon pool size.

The functional unit will be tied directly to the goal of a Forest Regulation Carbon LCA study and will provide a reference to which the input and output data are normalized. In the case of the rules or regulations-specific analysis, since the rules and regulations are tied to the land base, a land area unit such as acre or hectare is advisable. For each step along the multitude of modeling and calculation exercises within each unit process (e.g., forest ecosystem carbon pool, slash carbon pool, etc.), this functional unit will become the normalizing factor to trace back sequestration and CO_2 emissions to changes triggered by a given set of rules on one given acre of land.

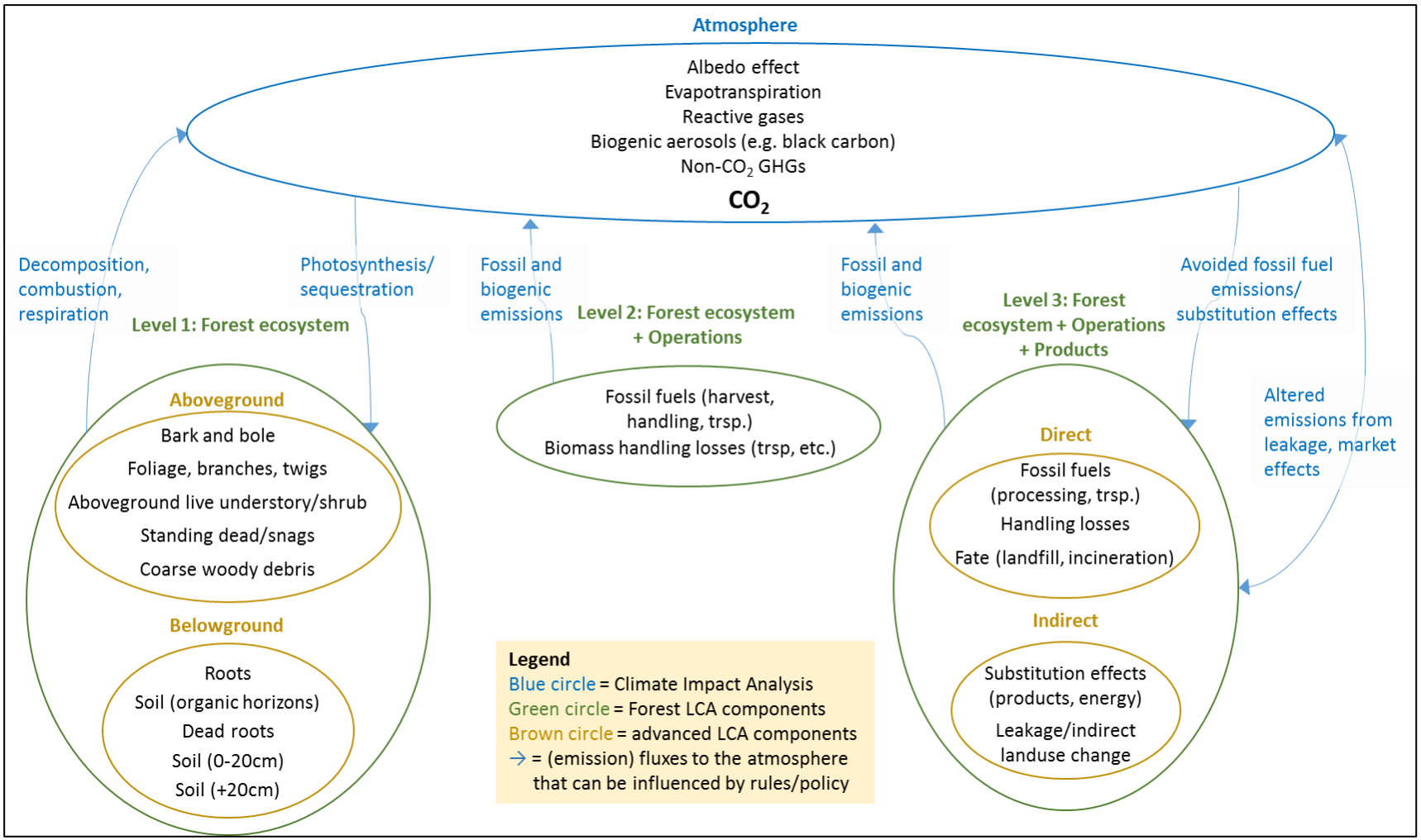

Figure 3. Forest system elements (forest ecosystem, forest operations, and forest products) and their interactions with the atmosphere. Depending on the policy question being asked, some elements or sub-elements (e.g., direct forest product effects, indirect forest product effects) as well as impact indicators (e.g., CO_2 emissions only, non-CO_2 GHGs, albedo effect) might be included or excluded, affecting completeness and policy relevance, and scientific certainty of the outcomes.

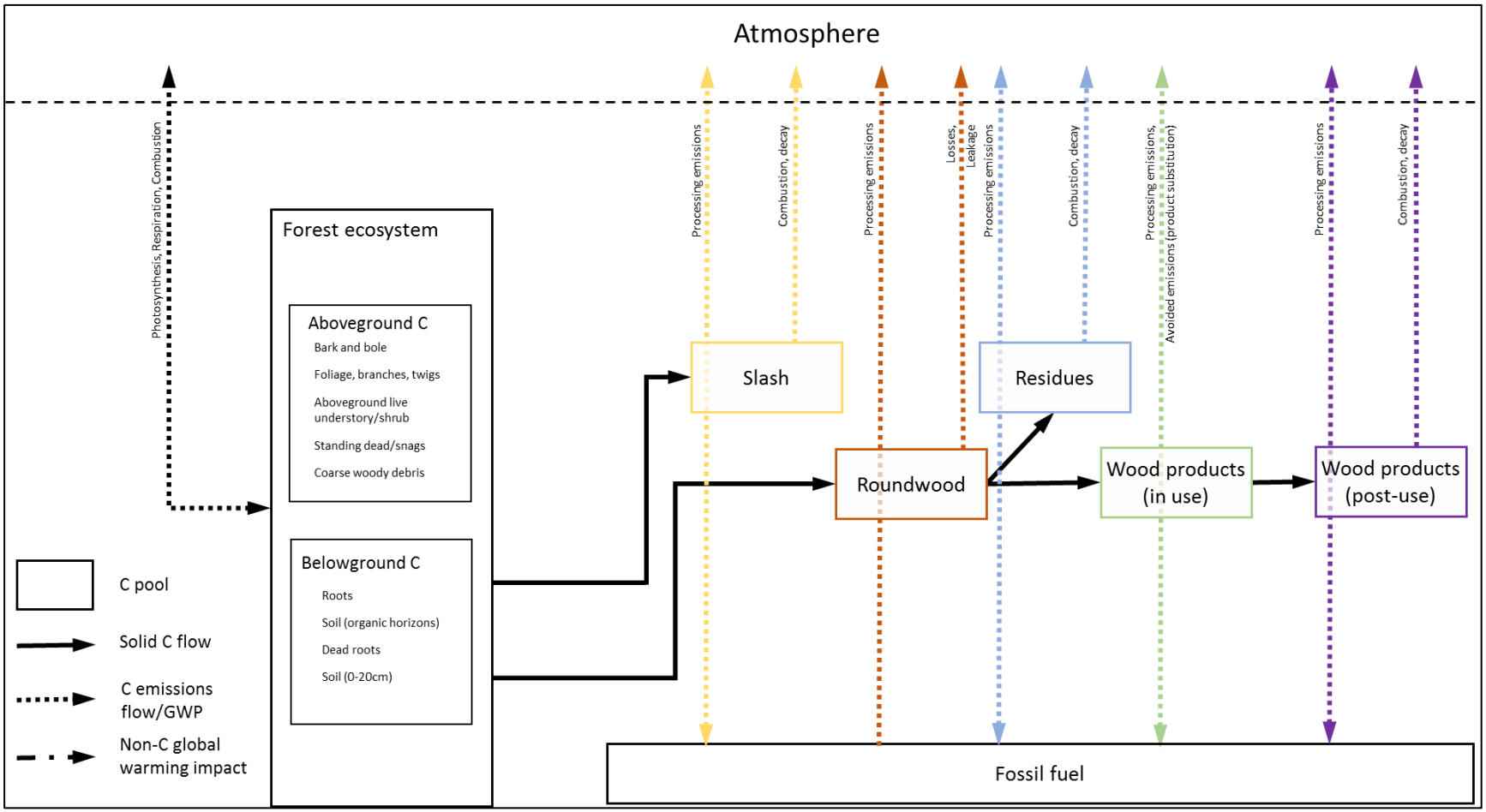

Figure 4. An example of a focused LCA system boundary excluding some impact indicators (all non-CO_2 GHG impact categories), and sub-unit elements (e.g. mineral soil, product substitution, avoided emissions in the energy sector) that are associated with high uncertainties. Reversed arrows indicate global warming counter-effects through, for example, carbon sequestration through photosynthesis. The magnitude of the flows (arrows) will vary depending on the application.

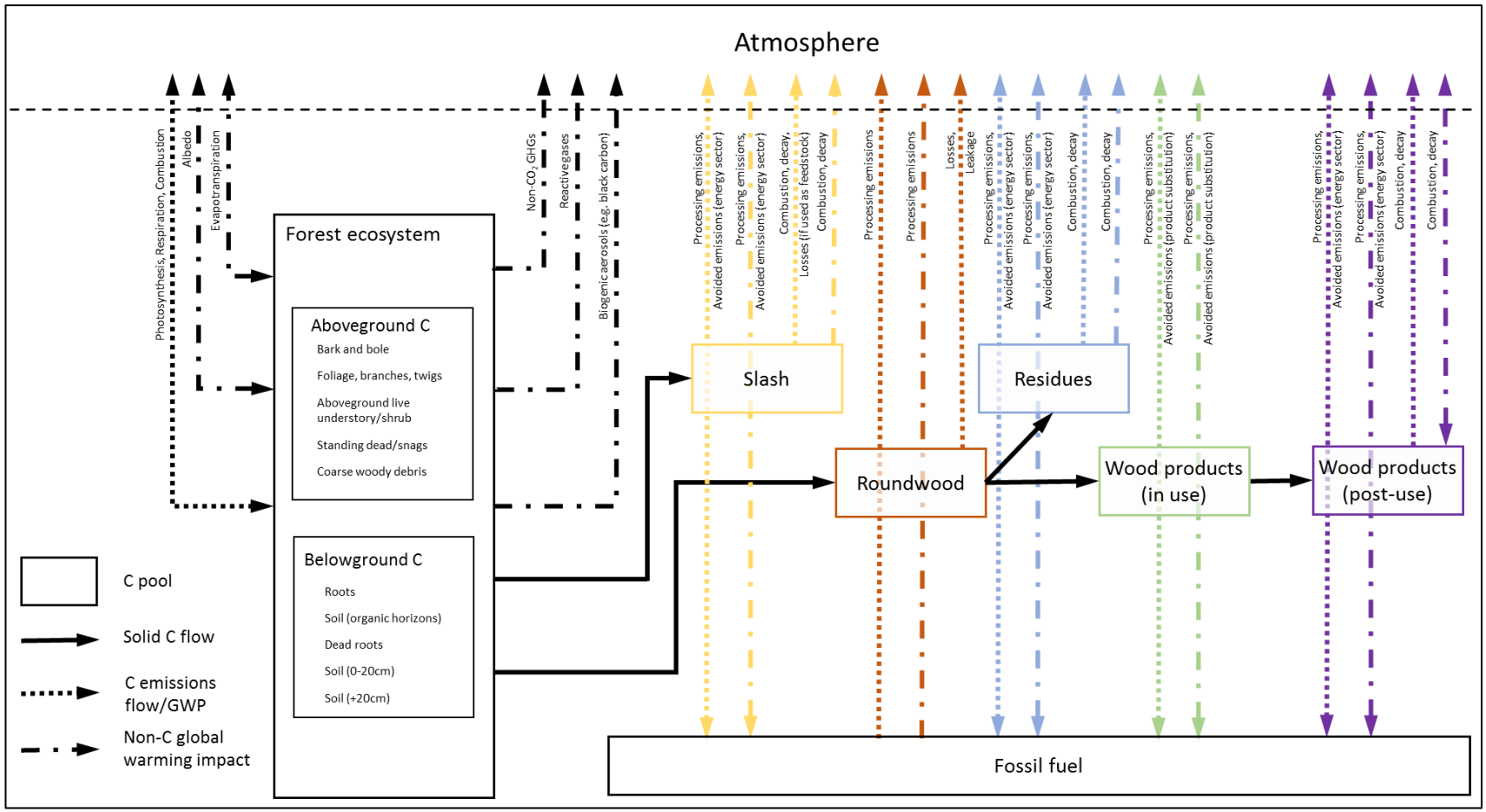

Figure 5. An example of a fully integrated system boundary including all known impact indicators (all GHGs, albedo, evapotranspiration, reactive gases, biogenic aerosols as well as all sub-process units (e.g., mineral soil, leakage, product and energy substitution) irrespective of the uncertainties associated with their quantification. Reversed arrows indicate global warming counter-effects through carbon sequestration, avoided emissions, or other avoided global warming impacts. The magnitude of the flows (arrows) will vary depending on the application.

Principles for System Boundary Choice - The identification and explanation of criteria used in establishing the system boundary is an important primary step. For instance, an argument for drawing smaller system boundaries could be to reduce scientific uncertainty (e.g., Figure 4) while compromising completeness (or ability to draw inferences). This can be done by defining the unit process (e.g., include/exclude leakage) as well as the level of detail required for data retrieval (e.g., using lookup tables that provide default values for leakage vs. site-specific modeling based on empirical data).
ISO LCA standards (ISO 2006b) provide some guiding principles to decide on 'cut-off' criteria for the initial inclusion of inputs and outputs. Cut-off criteria are:

1. **Mass:** When using mass as a criterion would require the inclusion of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled. In the context of the Forest Regulation Carbon LCA study, it could be argued that the loss of biomass during the manufacturing process is insignificant due to the high level of biomass utilization (for energy) and can be ignored.

2. **Energy:** When using energy as a criterion for inclusion in the LCA, one might decide to only require the inclusion of inputs that cumulatively contribute more than a defined percentage (5%) of the product system's energy inputs. In the context of the Forest Regulation Carbon LCA study, it could be argued, that the upstream energy inputs required to produce and maintain the harvest equipment are insignificant considering the larger picture and could be ignored.

3. **Environmental Significance:** Decisions on cut-off criteria should be made to only include inputs that contribute more than a defined amount to the total process chain. This criterion assists in avoiding overburdening the analysis process with many analysis-intensive but insignificant assessment steps. In the context of the Forest Regulation Carbon LCA study, since only carbon emissions are considered, environmental significance aligns closely with energy-related cut-off criteria. It could be argued that the environmental significance (i.e., carbon emissions) of producing harvest equipment is insignificant when looking at the overall picture.

Choosing the 'right' system boundary for a carbon accounting framework is not self-evident (Ascui and Lovell 2011). Marland et al. (2013) stressed the importance of recalling 'the question being asked' when deciding on carbon accounting frameworks. By identifying three potential frameworks of: 1) operational control and financial responsibility; 2) atmospheric impact and comparative evaluation, and; 3) resource renewability, the authors describe the underlying drivers when choosing one system boundary over another for an accounting stricture (Figure 6). While a wider system boundary is more inclusive in its impact assessment, it also can add additional analysis efforts that are irrelevant to the original purpose of the LCA. For instance, a wide LCA boundary might include upstream impacts that are beyond the sphere of influence or mandate of the entity commissioning the LCA.

With LCA being one of the most rigorous and inclusive of all (carbon) accounting frameworks (EPA 2011a, p 2), the insights offered by the carbon accounting literature can be applied to the Forest Regulation Carbon LCA study. In this context, the ISO LCA 14044 (ISO 2006b) states that "*LCA is one of several environmental management techniques (e.g., risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) and might not be the most appropriate technique to use in all situations. LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in this International Standard can be applied to these other aspects.*"

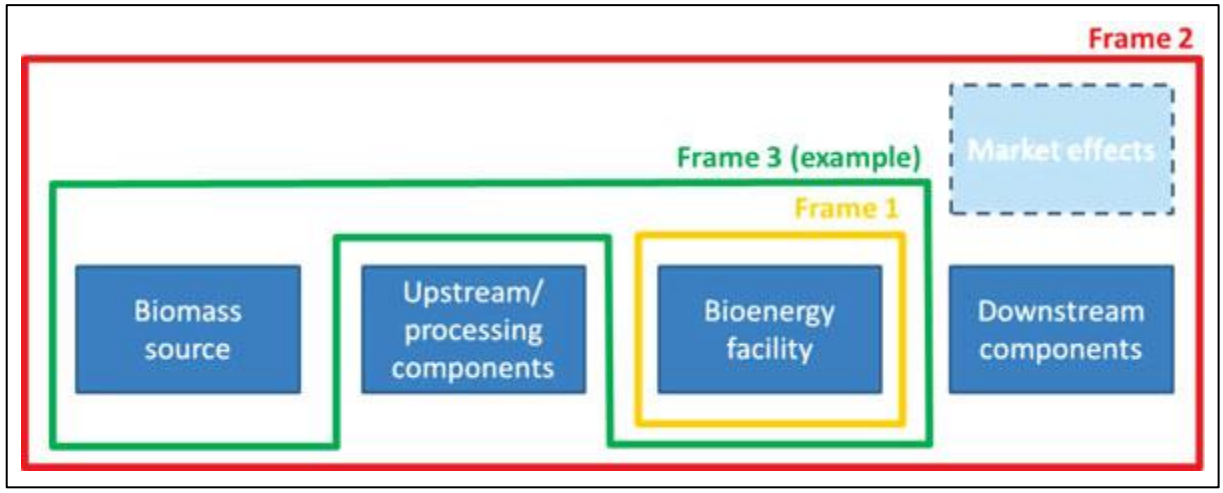

Figure 6. Potentially useful framework for entity-scale carbon accounting. Frame 1 includes only the entity, Frame 2 is a life cycle assessment that includes or excludes off-site market effects, and Frame 3 attaches some attributes of the fuel source (e.g., renewability) to the consuming entity (source: Marland et al. 2013).

To decide on a system boundary that responds to the charge question, there is a host of literature on guiding principles partly drawing from related accounting fields such as financial accounting standards (Table 2). Each new accounting framework will be unique in how to include and weight each principle based on the charge question. For the Forest Regulation Carbon LCA study, 'ease of use' as well as 'comparability' and 'consistency' are of minor importance since this is a unique and state-wide effort with a larger than usual budget compared to usual LCA applications. In contrast, predictive value, accuracy/representational faithfulness and transparency/verifiability are of major importance considering the statewide and profound impacts (feedback value) that rule violation would have (i.e., a finding that current rules do not support the AB 1504 (2010) mandate).

Table 2: Guiding principles for choosing a system boundary (unit processes and impact categories) for carbon accounting frameworks including LCA.

Principle			
Marland et al. (2013)	Eve et al. (2014)	Sevdalina et al. (2003, in Skog 2008)	Description
Predictive value			Data associated with acceptable degrees of uncertainty.
Feedback value			Data will impact current actions.
Timeliness	Ease of use, Cost-effectiveness		Eve et al. (2014): Measure of the complexity of the user interface and underlying data requirements. A measure of the relative costs and benefits of additional efforts to improve inventory estimates or reduce uncertainty. For example there is a balance between the relative costs and benefits of additional efforts to reduce uncertainty.
Comparability	Comparability	Comparability	Eve et al. (2014): For the guidelines to be comparable, the estimates of emissions and sequestration being reported by one entity are comparable to the estimates being reported by others. For this purpose, entities should use common methodologies and formats for estimating and reporting inventories. Consequently, in general, the methods specify one method for any technology or management practice (i.e., methods suggested in this report do not allow users to select from a menu of methods). Skog (2008): Estimates reported by parties in inventories should be comparable among parties.
	Consistency	Consistency	Eve et al. (2014): The methods used to generate inventory estimates should be internally consistent in all its elements and the estimates should be consistent with other years. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. Consistency is an important consideration in merging differing estimation techniques from diverse technologies and management practices. Skog (2008): Estimates are consistent in all their elements with estimates of other years. That is, the same methods are used for the base and all subsequent years, and consistent data sets are used to estimate emissions and sinks
	Completeness	Completeness	Eve et al. (2014): The methods must account for all sources and sinks, as well as all GHGs to the greatest extent possible. Completeness also means

Principle			
Marland et al. (2013)	Eve et al. (2014)	Sevdalina et al. (2003, in Skog 2008)	Description
			full coverage of sources and sinks under the control of the entity. Completeness is an important consideration to be balanced with ease of use in reporting appropriately for an entity that may have a minor activity or an activity with severely limited data availability. Skog (2008): Estimates cover all sources and sinks, as well as all gases, included in the IPCC guidelines as well as other existing relevant source/sink categories that are specific to individual parties and, there- fore, may not be included in the IPCC guidelines. Completeness also means full geographic coverage of sources and sinks of a Party.
Neutrality			Information must be free from bias.
Representational faithfulness	Accuracy	Accuracy	Eve et al. (2014): A relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. Skog (2008): Relative measure of the exactness of an estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable.
Verifiability	Transparency	Transparency	Eve et al. (2014): The assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of information. Skog (2008): Assumptions and methods are clearly explained to allow replication and assessment by users of the information.

Temporal Scale Considerations

Measurement and Reporting Frequency **–** For a given monitoring program, measurement frequency (i.e., how frequent empirical data are collected) is often different than the reporting frequency (i.e., how frequently data are summarized and reported to an audience).

The measurement and reporting frequency for forest related GHG emissions and carbon sequestration is technically not a required element of a LCA scope. However, per the scope of work detailed for this project – "*to identify the reporting frequency for re-analysis in the context of key target dates for 2020 and 2050*" - it is addressed here because of its relevance for understanding the status and trends associated with AB 32 targets for net carbon emissions and the data could be used to validate LCA associated model assumptions and outputs at a future date. Within the context of the Forest Carbon Inventory Option the measurement and reporting frequency is relevant for decision makers to understand if the 5 MMT/year carbon sequestration target prescribed by AB 1504 is being achieved.

The frequency of forest measurement and reporting is typically driven by legislative directives or agency policy and other technical considerations (e.g., variability of indicator values in space and time). For example, California legislation has established GHG emission reduction targets that span multiple economic sectors as well as a carbon sequestration rate target for the "natural and working lands" sector (formally referred to as the "forest" sector). California Assembly Bill 32 of 2006 (AB 32) requires California to reduce its annual GHG emissions to 1990 levels by 2020 (to about 427 MMT CO_2e) — a reduction of approximately 15% below emissions expected under a "business as usual" scenario[16]. According to Executive Order S-3-05, by 2050, the state adopted a target to reduce CO_2e emission by 80% of 1990 level (or about 85 MMT CO_2e/year). Part 2 of AB 32 (Section 38530 (b)(1)) established annual monitoring and reporting requirements[17] for greenhouse gas emissions from all sources – starting with measurement and reporting of carbon emission levels from the largest sources. ARB is responsible for maintaining and updating California's GHG inventory which tracks GHG emissions from 2000 forward. The ARB GHG emissions inventory provides estimates of the amount of GHGs emitted to the atmosphere by economic sector (except the forest sector) within California. AB 32 does not establish a forest carbon sequestration measurement and reporting requirement. However, to understand the net annual forest sector GHG emissions within the state (GHG emissions – forest carbon sequestration = net GHG emissions), annual carbon sequestration measurement and reporting would be necessary to be compatible with the California GHG Inventory schedule.

The US EPA produces an annual report called the Inventory of U.S. Greenhouse Gas Emissions and Sinks. This report tracks total annual U.S. emissions and removals (sinks) by source, economic sector, and greenhouse gas going back to 1990. This report relies on US Forest Service - Forest Inventory and Analysis (FIA) data to assess above ground carbon stock changes and Natural Resources Conservation Service' National Resources Inventory (NRI) for carbon associated with cropland, grassland, and settlements. The FIA program includes the measurement of a fixed proportion of the plots in each State, each year, known as annual inventory. The base federal program implemented for all states includes sampling levels of 15% per year in the eastern US and 10% per year in the western US. Sampling at this

[16] ARB has recalculated the 1990 GHG emissions level with the AR4 GWPs to be 431 $MMTCO_2$, therefore the 2020 GHG emissions limit established in response to AB 32 is now slightly higher than the 427 $MMTCO_2$ in the initial Scoping Plan.

[17] AB 32 (Section 38530 (b)(1)) *"Require the monitoring and annual reporting of greenhouse gas emissions from greenhouse gas emission sources beginning with the sources or categories of sources that contribute the most to statewide emissions."*

frequency means that all plots within California are collected over a 10 year period. FIA currently reports in five year periods and produces acceptable levels of certainty down to a forest type level in most cases (e.g., Christensen 2008). Similar to FIA, since 2000, NRI data have been gathered annually, though major releases of data are reported at 5-year intervals.

In March 2015, the US Forest Service published regional carbon assessment whitepapers on how much carbon is stored in the Nation's forest ecosystems and harvested wood products (USDA Forest Service 2015). These reports provide information from FIA data on carbon stocks and trends for seven different forest ecosystem carbon pools – 1) above-ground live tree, 2) below-ground live tree, 3) standing dead, 4) understory, 5) down dead wood, 6) forest floor and 7) soil organic carbon – for the baseline period 1990 to 2013 (and 2005 to 2013, truncation of the longer baseline). The regional reports provide annual estimates of carbon stored in harvested wood products over longer time periods (depending upon data availability) and could serve to inform CALFIRE's forest carbon inventory and analysis needs.

The California Department of Forestry and Fire Protection - Fire and Resource Assessment Program (FRAP) is charged with assessing the amount and extent of California's forests and rangelands, analyzes their conditions and identifies alternative management and policy guidelines. California law (PRC 4789) mandates FRAP to prepare periodic assessments of California's forest and rangeland resources. Most recently FRAP has produced these assessments in 2003 and 2010, and is in the process of preparing an assessment for 2015. These assessments are completed using data generated internally or through partnerships with other agencies. These assessments are primarily used to identify key resource issues and report the status and trends of forest lands in the state, roughly on a 5-year reporting interval.

ARB is required to produce a Scoping Plan every five years. Scoping Plans describes the approach California will take to reduce greenhouse gases (GHG) to achieve the goal of reducing emissions to 1990 levels by 2020. The 2014 Scoping Plan updates the initial Scoping Plan (2008) with new strategies and recommendations. The Update defines ARB's climate change priorities for the next five years and sets the groundwork to reach California's long-term 2050 climate goals. The 2014 Scoping Plan also recommends that quantitative planning targets be set (other than those suggested in AB 1504 (2010)) to increase net forest carbon storage in California for the near-term, mid-term, and by 2050; and that forest carbon inventory and assessments should be continually maintained and refined to support this effort.

The existing frequency of forest-related measurement and reporting efforts managed by FRAP, FIA, NRI, ARB and US EPA may be the most cost-effective way to generate reliable data that can inform whether carbon sequestration goals are being achieved. The measurement and reporting frequency across the different programs reviewed ranges from 1 to 5 to 10 years. A five year reporting interval with annual forest carbon inventory appears most reasonable for CAL FIRE given considerations for alignment with other statutory measurement and reporting requirements, data availability, current staff capacity, cost effectiveness and responsiveness to AB 32 carbon emission reduction target dates.

Timeline Needed to Measure the Effect of California Forest Rules and Regulations **-** When projecting impacts of rules and regulations, 20 to 100 year time projections are not unusual (IPCC 2013a). A multitude of forestry-focused literature exists on how to include time in emission estimates (e.g. Kendall et al. 2009, O'Hare et al. 2009, Levasseur et al., 2012). However, for modeling forest dynamics it is important to consider a large enough spatial scale to capture variability and to reduce overall uncertainties from stochastic events. Detecting trends within a stand might take decades due to the slow response of individual trees to site-specific growing conditions and stochastic events (insect

outbreak, extreme weather or wildfire). Some research suggests that long term trends might be better captured by including a sufficient spatial scale even within short time intervals (Blois et al. 2013, Pickett 1989). The same might hold true for stochastic events – when investigating a large-enough region, the pulse created by these events can be subdued sufficiently to recognize trends. The point here is that a small area of investigation will require a longer time span to reveal the effects of a treatment (e.g., the application of existing or alternative forest practice rules) whereas a larger area of investigation would not because a larger area is more likely to capture variability in the system and as a result reduce uncertainty in modeled outputs. There is no literature available on the extent that space can be substituted for time in the context of modeling the effect of California forest rules and regulations. Significant uncertainties around some carbon pools such as (mineral) soil are both derived from data and methodological uncertainties and therefore affect both short and long-term measurement and modeling intervals. It is therefore advisable to coordinate modeled outputs with ARB GHG emission reduction target dates, recognizing that shorter or longer term modeling intervals could be helpful to resolve treatment effects (i.e., application of forest practice rules) between or after ARB target dates.

Spatial Scale Considerations

Land management and authority considerations - AB 1504 is intended to ensure that California forest rules and regulations do not impact forest's ability to sequester carbon and help to achieve GHG reduction targets. AB 1504 only applies to forestlands and timberlands regulated by BOF and CAL FIRE (i.e., lands managed by the state, private entities, and NGOs). California forest rules and regulations do not apply to forests managed by federal authorities. Federal forest lands in California include lands managed by the USDA - Forest Service (USFS), USDI - National Parks Service (NPS) and Bureau of Land Management (BLM). Lands administered by the USFS and BLM are managed to accommodate multiple land use objectives. These include timber management, recreation, wildlife and fisheries resource conservation as well as water quantity and quality stewardship. The National Park Service is charged with preserving natural qualities and values within a park's boundary. Differences in land use directives between national parks and lands managed by the USFS or BLM could result in differences in carbon emission and sequestration outcomes. While none of these federal lands fall under the jurisdiction of the AB 1504 (2010) mandate, their extent makes them relevant under state-wide conditions and thus should serve as the primary spatial boundary at least for monitoring applications.

Despite these differences in land management approaches, forests are categorized as:

- **Timberland** - Forest land that is producing or capable of producing in excess of 20 cubic feet per acre per year of commercial wood at culmination of mean annual increment excluding reserved forest lands; this definition can be used in some instances interchangeably with 'commercial forest',
- **Forestland** - Land that is at least 10 percent stocked by forest trees of any size, or land formerly having such tree cover, and not currently developed for a non-forest use,
- **Reserved** - Land permanently reserved from wood products utilization through statute or administrative designation, and
- **Non-stocked** - A stand-size class of forest land that is stocked with less than 10 percent of minimum full stocking with live trees.

Based on FIA data, FRAP estimates that over half of the live tree volume in California is located on public lands (FRAP 2010). By focusing on unreserved National Forest timberland, private forests (unreserved), and reserved National Forests, an analysis would capture close to 90 % of all forest acreage as well as tree volume. Though contested through recent FIA data, FRAP (2010) also states that "*Intensively managed forests, as found on many private timberlands, will likely have growth underestimated and*

mortality overestimated [...]. Therefore, the private lands estimates should be considered a lower range of possible results, particularly for the coast redwood region and for plantations." Nevertheless, when attempting to find analytical efficiencies at a state-wide scale, a strong argument could be made to: a) focus on the forest categories consistent with the categories listed above and; b) include federal forest lands in a full analysis due to its high level of forest ownership in CA. Forest rules and regulations are applied differentially to district and sub-districts for lands under the regulatory authority of Cal Fire and BOF. Differences in the district and sub-district application of rules and regulation should be accounted for when assessing the effect of forest rules and regulations on carbon sequestration and GHG emissions.

Rangeland is not included under the mandate of AB 1504 (2010) and should therefore probably not be included in a Forest Regulation Carbon LCA. However, over half of California (approximately 60 million acres) are classified as rangeland with a mean soil carbon volume of 47 to 63 metric tonnes carbon per acre for non-woody and woody rangelands, respectively (Silver et al. 2010). FRAP (2010) states that "*the Natural Resource Conservation Service has estimated erosion due to wind on non-federal pasture land in California at 0.4 tons per acre per year.*" If only half of all California rangeland experiences wind erosion at this rate, the subsequent carbon emission rate caused by wind only (ignoring other drivers of soil carbon emissions) would be higher than the current forest carbon sequestration rate as estimated by FRAP (2010, Table 1.2.5). Considering also other drivers of carbon dioxide emissions from rangelands such as the fact that "*over 100,000 acres of grazing lands were lost to urbanization between 1990 and 2004 with an estimate of 750,000 additional acres by 2040*" (Kroeger et al. 2009, cited in FRAP 2010), there is a strong argument to be made to include rangelands in a statewide carbon LCA. Inclusion of rangelands in the life cycle assessment was also recommended by stakeholders at the September 5, 2014 public/stakeholder meeting on the implementation of AB 1504.

Forestlands that are not managed for commercial value may be administered by federal, state or private land owners. These lands are often managed for resource conservation or preservation. Non-commercial National Forests comprise a high proportion of California's forests in terms of acreage (11%) and tree volume (13%; FRAP 2010) and consequently represent a significant capacity to sequester carbon. Perhaps due to this fact, stakeholders recommended at a September 5, 2014 public/stakeholder meeting that these lands be considered within the context of the forest carbon life cycle analysis. If non-commercial private forestland is included in the assessment, we suggest that non-commercial National Forests be prioritized because they represent a large proportion of land area and volume, and thus potential for carbon sequestration.

Hardwood forests represent 38% of California's forested landscape but represent only 24% of total tree volume (

Table 3, Table 4). Slightly over half of the hardwood volume is located on private land (

Table 3, 13% of total volume). Hardwood timberland (i.e., commercial hardwood forests) contains around 60% of total live tree volume for both National Forests and private forest lands. Disregarding

timber quality aspects and the current small size of an in-state hardwood market in California, the productivity and volume of hardwood forests per se does not exclude potential future harvest activities (e.g., the application of fuel reduction policies or an emerging biomass for energy market). National Forests are the only significant ownership category in terms of tree volume (and therefore carbon stocks) – 10% of the tree volume on National Forests are unreserved hardwoods (Table 5).

Table 3. California forest types by ownership: Acres and percent area of forestland (FIA 2014).

	Softwood		**Hardwood**		**Non-stocked***	
	Acres	**Percent of total**	**Acres**	**Percent of total**	**Acres**	**Percent of total**
Total	**19,165,811**	**59%**	**12,337,534**	**38%**	**750,559**	**2%**
National Forest	11,382,933	35%	3,567,744	11%	479,283	1%
National Park Service	1,199,429	4%	201,631	1%	25,685	0%
Bureau of Land Mgmt.	925,190	3%	572,403	2%	59,847	0%
Fish and Wildlife Service	3,603	0%	568	0%	-	0%
Dept. of Defense	28,121	0%	64,519	0%	-	0%
Other federal	23,333	0%	95,856	0%	-	0%
State	310,818	1%	382,173	1%	5,791	0%
County and Municipal	56,631	0%	307,370	1%	-	0%
Other local Government	7,913	0%	12,058	0%	-	0%
Private	5,227,840	16%	7,133,211	22%	179,953	1%

* A stand-size class of forest land that is stocked with less than 10 percent of minimum full stocking with live trees.

Table 4. California forest types by ownership: Net volume of live trees in cubic feet on forest land (FIA 2014).

	Softwood		Hardwood		Non-stocked	
	Cubic Feet	Percent of Total	Cubic Feet	Percent of Total	Cubic Feet	Percent of Total
Total	**77,584,483,842**	**76%**	**24,156,106,998**	**24%**	**66,924,771**	**0%**
National Forest	48,044,529,128	47%	7,298,399,069	7%	40,257,320	0%
National Park Service	6,304,019,448	6%	514,284,751	1%	6,095,285	0%
Bureau of Land Mgmt.	955,511,362	1%	850,790,823	1%	1,562,433	0%
Fish and Wildlife Service	2,862,149	0%	1,254,944	0%	-	0%
Dept. of Defense	12,355,130	0%	76,786,877	0%	-	0%
Other federal	4,829,056	0%	40,289,599	0%	-	0%
State	2,938,379,437	3%	1,177,959,390	1%	-	0%
County and Municipal	232,238,433	0%	710,952,203	1%	-	0%
Other local Government	2,744,400	0%	36,581,830	0%	-	0%
Private	19,087,015,297	19%	13,448,807,508	13%	19,009,734	0%

Table 5. Net volume of live trees in cubic feet on National Forest land (FIA 2014).

	Not Reserved		Reserved	
	Cubic Feet	% of Total	Cubic Feet	% of Total
Softwoods	35,293,054,839	64%	12,751,474,287	23%
Hardwoods	5,383,191,076	10%	1,915,207,993	3%
Non-stocked	36,716,581	0%	3,540,739	0%

According to FIA there are limited private forestlands under a reserved status in California [18] and there are large areas of hardwood carrying significant tree volume on unreserved National Forests. Thus it could be argued that hardwood forests, which represent a significant proportion of California's forest volume, could be significantly impacted. Stakeholders suggested at the September 5, 2014 public/stakeholder meeting that hardwood forest be included in the life cycle assessment.

Since forests differ in total carbon storage and potential carbon fluxes by forest type, ownerships and protected status, we recommend categorizing forests accordingly in the LCA data inventory phase. For forest types, we recommend using the CalVeg forest types for a more nuanced reporting beyond hardwoods/softwoods (see also section 'Goals and Scope of the Life Cycle Assessment for Forest Rule and Regulations').

[18] See http://gis1.usgs.gov/csas/gap/viewer/padus/Map.aspx. Also, FIA reports no reserved private forest land.

Life Cycle Inventory Considerations

A life cycle inventory (LCI) is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. The Life Cycle Inventory builds on the goal and scope definitions and contains the collection and calculation of data (Figure 7). This process is likely to involve several iterative steps to adjust data collection and calculation efforts or study scope (e.g., adjusting the system boundary) based on preliminary outcomes. While this section provides an overview on the ISO standard to perform a LCI and reference to data, models and associate gaps for the Forest Carbon LCA, detailed options on the LCI in the context of a Forest Regulation Carbon LCA are provided in 'Analysis Options' section of this report.

Collecting data

The collection of data in the LCI phase according to ISO LCA standards entails the following steps (ISO 2006b):

- Drawing unspecific process flow diagrams that outline all the unit processes to be modelled, including their interrelationships. Process flow diagrams are included in the goals and scope section of this report and could be refined in the LCI phase of a real-world Forest Carbon LCA.
- Describe each unit process in detail with respect to factors influencing inputs and outputs.
- Listing of flows and relevant data for operating conditions associated with each unit process.
- Developing a list that specifies the units used.
- Describing the data collection and calculation techniques needed for all data. Appendix A and B of this report list available models and data, respectively for a Forest Carbon LCA. The 'Analysis Options' section places data and models into the context of an implementable LCA.
- Providing instructions to document clearly any special cases, irregularities or other items associated with the data provided.

Building on the system diagram developed for the scope of the LCA (see above Figure 4), the additional steps required in this phase are unit process-specific diagrams. These include detailing the internal mechanisms of each unit process, including inputs and outputs considered. Identifying the category indicators affected is another important step (e.g., CO_2 only, all GHGs, expanded global warming impact indicator set). Other activities include describing linkages to each unit process, including measurement units (e.g., tons of wood processed) as well as the data quality requirements, such as data sources (i.e., lookup tables, original datasets, modeling applications, etc.). While the ISO-specific scope of work only specifies the unit processes to be included (include/exclude leakage, influence of wildfire), this step requires a clear definition on how to produce relevant data to be included. For example, this step would describe the full approach on how to model wildfire interactions which is one of the most influential and uncertain elements in the Forest Carbon LCA effort (see 'Analysis Options' section).

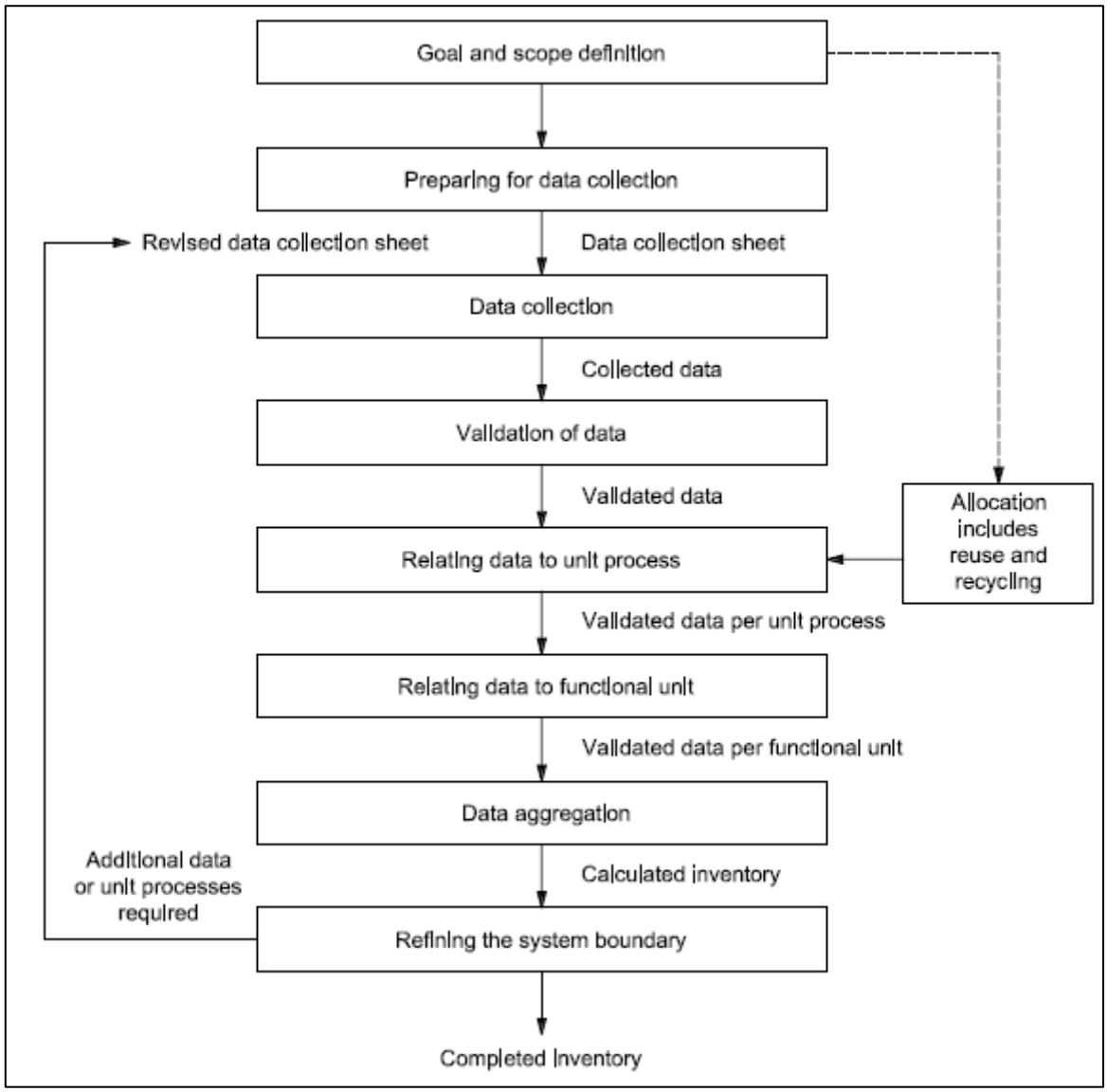

Figure 7: Simplified procedures from life cycle inventory analysis (source: ISO 2006b).

Data Gap Analysis

While a variety of datasets are available to conduct components of such an LCA analysis (see Appendix B), there is no single, fully integrated, "seamless" dataset available today which can be used for this application. In addition, there are very limited datasets available to assess soil carbon, and comprehensive datasets on volume lost in fire or converted from forestland to some other type are absent. While the FIA program would likely pick up both issues over time, the ten year FIA re-measurement cycle would produce delayed insight in carbon emitted through conversion and/or fire and may not support annual reporting intervals very well. With respect to LCA modeling, there are fewer reliable datasets or models available for assessing leakage, wood products, wood product in-use post-use fate, or substitution benefits.

Development of custom datasets can be time consuming and expensive. Utilizing existing models and datasets would be an advisable approach. While such models and datasets exist at the state-level for forests (e.g., FIA for datasets, FVS for models), no quantitative and regularly maintained model and

dataset exists for rangeland condition and vegetation structure. The following steps outline methods how to use existing datasets or deal with data gaps in the context of evaluating forest carbon emissions through a LCA:

1) In terms of determining the extent of current forest land conversions and associated carbon consequences, there is no searchable database or other easily accessible option to analyze the scale that GHG-impact assessments currently play under CEQA requirements for timber conversions. This might be partly due to the fact that the CEQA requirements do not specify a certain format how a GHG impact analysis would need to be done and/or how to mitigate undesirable GHG impacts. A proposed bill SG 455 as an amendment to PRC 4621 suggested a standardized mitigation strategy for timberland conversions in 2011 but was not chaptered.
2) Break the steps of the LCA analysis into discrete components, which utilize existing models, where available. Utilize the model data parameters to further investigate where reliable statewide or other datasets are available
3) Where datasets are not available, or not at an appropriate scale to be used in the assessment, determine if other datasets that are at a broader scale or accuracy may be utilized for a more "coarse grained" analysis until detailed datasets may be developed.
4) Develop customized datasets to address "gaps" in existing data: This approach may be used for specific areas of assessment where there are no readily available or reliable data. As with model development, building custom base datasets may take substantial time (1-3 years) to develop, and may not provide finer resolution, if the background spatial data needed to build new datasets is of poor quality or at a broader scale than needed.
5) Create a fully integrated seamless dataset to assess GHG Life Cycle Analysis of the California Forest Practice Law and Regulations: Such a dataset would combine existing data, modified existing data, and new custom datasets into a single geodatabase which would be used for this and future assessments. A similar effort can be seen in development, distribution, and updating of the LANDFIRE dataset (Rollins 2009). This would likely prove to be a challenging, costly, and time consuming effort, but if it provides datasets that are consistent, readily usable, and annually updated, may save time from other analysis efforts in the future.
6) A statewide collection of LiDAR data for forested ecosystems would provide improved estimates of above ground forest carbon pools. Currently, there are disparate LiDAR collection efforts by various local jurisdictions across California that could be inventoried and may reduce the cost of an overall statewide effort.

Model Gap Analysis

The list of models in Appendix A identifies the best existing analytical methods, forest growth models, and climate models which may be utilized to develop an approach to GHG Life Cycle Analysis of the California Forest Practice Law and Regulations. While a variety of models are available to conduct components of such an analysis, there is no single, fully integrated, "seamless" model available today which can be used for this analysis. In addition, there are limited models available to assess soil carbon including soil respiration, and radiative forcing effects (albedo, evapotranspiration, etc.); only basic model components on decay functions and non-CO_2 emissions and; there are no variants available in FVS to model carbon dynamics in "late-seral" redwood forest ecosystems. With respect to LCA modeling, there are limited options available for assessing leakage, wood products LCA, and substitution benefits.

The limitation of model availability is not uncommon in quantifying forest ecosystem dynamics, most notably fire, drought, climate change or insect-induced disturbances lack reliable modeling techniques.

Models are typically developed for specific purposes where there is wide application, demand, and potentially commercial values at stake or insured values at risk. Examples of this include development of FVS for forest management use, FLAMMAP for fire hazard and risk assessments, and CACTOS for commercial timber production planning. Often, ecosystem functions that do not provide commercial value or that are difficult to accurately quantify, such as soil carbon, are not readily developed into models that can be easily used for planning and analysis. Though this poses a quandary with respect to developing an easily repeatable, science based, modeling approach to assess GHG's, there are a few general approaches which may be taken as described in detail below.

1) Break the steps of the LCA analysis into discrete components, which utilize existing models, where available: This approach would allow assessments to be conducted using existing, and often peer reviewed, models (i.e. FVS, FLAMMAP, ARCFUELS) which have been already tested in a variety of management based and research projects.
2) Develop a base set of assumptions which may be used in place of modeling for assessments of soil carbon, where the data and modeling capacity does not currently exist. This may include providing assumptions of soil carbon gain or loss, as it relates to silvicultural practices across different vegetation, soil, and climate type found in California.
3) Develop customized models to address "gaps" in existing model capabilities: This approach may be used for specific areas of assessment where there are no readily available or reliable models. This would likely take substantial time (1-3 years) to develop, and may not provide additional accuracy beyond using an "assumption based" approach as described in #2.
4) Create a fully integrated seamless model that assesses GHG Life Cycle Analysis of the California Forest Practice Law and Regulations: Such a model could incorporate aspects or potentially code of the existing models, but development would likely require a multidisciplinary team of scientists and subject matter experts working closely with programmers to develop a user friendly model. This would likely prove to be a challenging, costly, and time consuming effort, which may yield no greater accuracy than using existing models in a "modular" approach utilizing as described in #1 and #2 above.

The choice of models to use should be based on the type of assessments, including scale, accuracy, and uncertainty which will be conducted. These assessments in turn are based on the specific questions which need to be answered with respect to an LCA analysis based on policy, law, and public input.

Calculating data

This step includes data validation, relating the data within a unit process and relating outcomes to a functional unit. For instance, calculation outcomes can be compared to published data on similar efforts. The output then needs to be assigned to a unit process (e.g., wood products processing) and put in relation to the functional unit (e.g., on a per acre basis). Preliminary results might warrant a reiterative process including the refinement of the system boundary (Figure 7). Performing this step can be synchronized with a sensitivity analysis that considers inclusion/exclusion of unit processes, inputs/outputs, or category indicators.

Life Cycle Impact Analysis Considerations

The Life Cycle Impact Assessment (LCIA) phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. Impact assessment should address ecological, resource depletion and human health effects. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. In terms of impact types, ISO standards require a description of the impact

categories, category indicators and characterization models included within the LCA study. Since AB 1504 (2010) limits the extent of this effort to the capacity of forests to sequester CO_2, MMT of net CO_2 emissions sequestered per year are the only impact category for a Forest Regulation Carbon LCA study (LCIA methods are detailed in the 'Analysis Options' section of this report).

If a broader analysis approach is chosen to account for overall Global Warming Potential (GWP) of forest regulations, all category indicators would need to be normalized to net MT CO_2e using first level (calculating impacts) and second level (normalizing to CO_2e) characterization models. This step also entails the choice of category indicators. While net CO_2 emissions are at the core of this LCA effort, other greenhouse gases (CO, CH_4, etc.), reactive gases, biogenic aerosols (e.g., black carbon from wildfires), surface energy, albedo and evapotranspiration are other processes that can have a global warming impact (Bonan 2008). Cherubini et al. (2013; Figure 8) report on the multitude of reporting indicators to measure potential climate impact of a scenario. Choosing a set of category indicators requires a balance between increasing policy relevance (i.e., choosing a framework that is as all-encompassing as possible) and scientific certainty. This effort includes determining not only the GWP of certain processes but also "*the choice of end points (emissions, concentration, radiative forcing, change in temperature, etc.), the type of measures (instantaneous or time-integrated) and the treatment of time*" (Cherubini 2013).

There is no scientific consensus to date on what emissions and climate forcings should be included nor what effect should be considered to be the assessment end point in a comprehensive impact assessment study. Besides defining what indicators should be used for a full GWP accounting, there is also no consensus on how to assess radiative forcing which can be measured in instantaneous effects, GWP, or Absolute GWP (see also Kendall et al. 2009 and O'Hare et al. 2009).

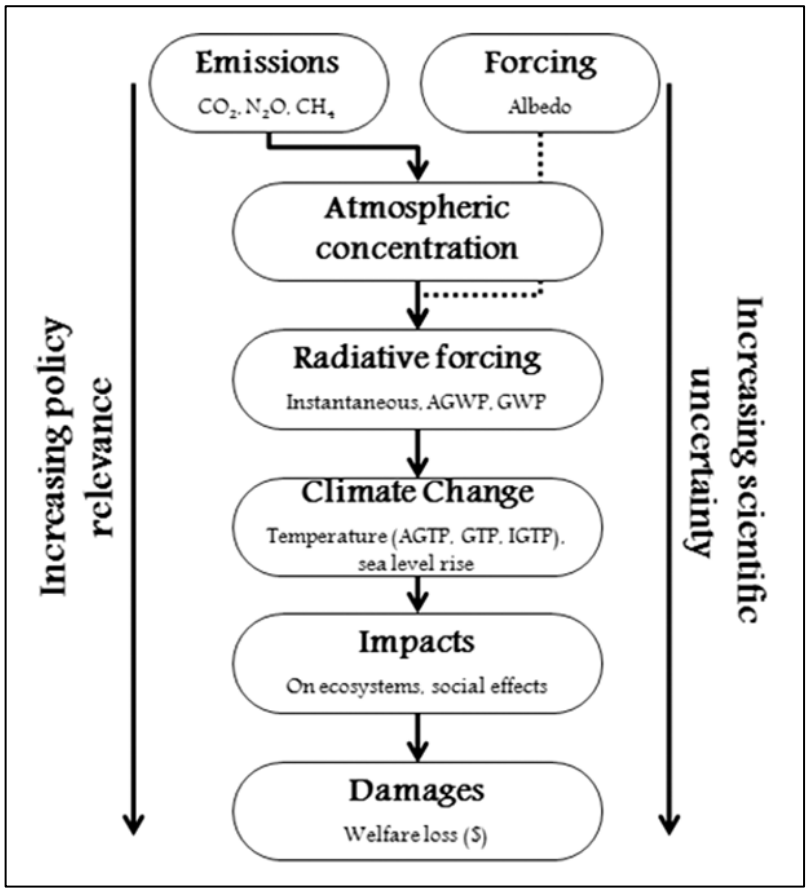

Figure 8: Cause-effect chain of the potential climate impact emissions and climate forcing (Source: Cherubini 2013).

Data Requirements

Since the Forest Regulation Carbon LCA study intends to compare the LCA implications of two (or more) scenarios (e.g., application of existing rules vs. alternative rules), the 'comparative assertions' stipulations of the ISO LCA standards apply, stressing the importance of data quality requirements.

There are two conceivable approaches to produce an 'alternative rule' scenario: an empirical/data-driven approach as well as a model driven approach. While an empirical approach can compare the carbon global warming implications using measured data from differently regulated but comparable regions (e.g., Oregon for parts of Northern California), the model-driven approach would investigate the impact of a given rule set for the same region (e.g., California's forest and rangelands) by feeding forest ecosystem and market software models with empirical inventory data and based on a set of assumptions. Both methods have weaknesses and uncertainties (empirical approach: how to compare one region with another; model-driven approach: how to ensure applicability of model and assumptions?) and might differ in their accuracy, comprehensiveness, conservativeness, and practicality (Buchholz et al. 2014).

Empirical Approach

An empirical approach to determine a rule's or regulation's carbon emission consequences compares two existing datasets on their differences. The differences are derived from one dataset covering a geography in which existing California rules are applied while the other 'alternative' dataset covers a geography that is comparable in its characteristics (e.g., forest types) to limit the impact of unrelated determinants but is not affected by California rules. This 'alternative' dataset can be derived from a

different region (e.g., Oregon and California Douglas fir forests) or from a different point in time prior to policy implementation. The second retro-active option would use historic datasets gathered during a pre-rule era and compare conditions with current/existing 'with rule' conditions. Both options eliminate uncertainty derived from modeling exercises but are also subject to data uncertainty derived from comparing two, potentially inconsistent datasets. In both empirical data analysis options, uncertainties also emerge due to the absence of a 'control dataset' that would allow a ceteris paribus (with other things the same) analysis.

Model-driven Approach

If a modeling approach is chosen over an empirical approach to determine a rule scenario carbon emission consequences, the inherent uncertainty in establishing future scenarios to be modeled is difficult to overcome. A common approach is to model simultaneously a range of possible outcomes with several scenarios. Johnson et al. (2010) state that "*for models used to inform policy, scenarios should be designed that bear in mind the policy levers over which decision makers have control. For instance, scenario choices for geographic region and prior land use are useful because policy makers could provide incentives to grow biomass only in areas and on lands where life cycle emissions would be more favorable.*"

A major impact factor on scenario outcomes in California-specific ecosystem modeling are fire-related modeling assumptions. In a recent retrospective study, Gonzalez et al. (2015) found that between 2001 and 2010, "*wildfires on 6% of the state analysis area produced two-thirds of the live carbon stock loss*." The outcomes of ecosystem carbon dynamic studies are dependent on the probability of occurrence, size, and severity of wildfire (Campbell et al., 2011; Hurteau et al., 2014a). Given the influence of projected changes in climate on forest growth (Silva & Anand, 2013) and disturbance frequency and effect (Westerling et al., 2011; Moritz et al., 2012; Hurteau et al., 2014b), disturbance dynamics are likely to become even more influential in evaluating forest management opportunities over meaningful temporal scales.

When choosing a model-driven approach, different considerations apply when selecting time scales for evaluation purposes. While short term trends should be captured, long term trends including highly uncertain components such as climate change, land management options (e.g., wildfire management), mineral soil carbon (Buchholz et al. 2014) or land conversion become critical as well. In this context, projections over 20 to 100 years produced in conjunction are not uncommon (IPCC 2013a). These projections need to explicitly consider uncertainties and assumptions in evaluating carbon sequestration consequences of forest (and rangeland) management options. Accounting for this uncertainty, using prevailing tools and methods can be technically achieved by employing a range of models and baselines in parallel and/or reporting sufficiently on uncertainties (e.g., by reporting results in terms of likelihood and stating model/assumption biases and gaps).

Value Choices

Since a normative judgment was made from the onset within AB 1504 to only consider net CO_2 emissions, no LCA-specific value choices are applicable nor a definition of several impact categories (the only impact category applicable is net CO_2 emissions).

Data Quality Requirements

Data quality requirements should further address (ISO 2006b):

1. Time-related coverage: age of data and the minimum length of time over which data should be collected;

2. Geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;
3. Technology coverage: specific technology or technology mix (less relevant for the Forest Regulation Carbon LCA study);
4. Precision: measure of the variability of the data values for each data expressed (e.g., variance);
5. Completeness: percentage of flow that is measured or estimated;
6. Representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e., geographical coverage, time period and technology coverage);
7. Consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
8. Reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
9. Sources of the data (see Appendix B);
10. Uncertainty of the information (e.g., data, models and assumptions; see Appendix A and B).

For time-related coverage, the 'Temporal Scale Consideration' section provides insights on consideration for temporal scales of analysis. For geographical coverage, results reported by CalVeg ecosystem types (Coastal redwood, riparian, red fir, etc.) are advisable based on the literature and stakeholder input. Review the 'Spatial Scale Considerations' section for more suggestions on choosing spatial scales and stratification options. Concerning 'Technology Coverage' and 'Uncertainty of the Information', a large variation in data availability and therefore precision, completeness, representativeness, consistency and reproducibility can be expected. Some analytical steps and sub-steps will be covered by several models or datasets while others (e.g., mineral soil carbon, leakage, product substitution) exhibit considerable gaps in detailed information and are fraught with uncertainty - potentially posing a significant impact on overall results. These limitations need to be spelled out in detail as part of the LCA (see 'Analysis Options' section).

Type of Critical Review

Third party review of the LCA is recommended. Early-on stakeholder inclusion can be crucial not only when releasing study results but also when setting the LCA scope. We recommend including double blind expert reviews of the technical content of an LCA as well as a stakeholder driven review process of the scope and policy-relevant sections of an LCA process.

Type and Format of the Report

A report in accordance with ISO LCA standards needs to be transparent and should present details of the results, data, methods, assumptions and limitations identical in scope with IPCC standards (IPCC 2013a). The following items should be considered when preparing third-party reports:

- Modifications to the initial scope together with their justification;
- System boundary, including type of inputs and outputs of the system as elementary flows, and decision criteria;
- Description of the unit processes, including decision about allocation;
- Data, including decision about data, details about individual data and data quality requirements; and choice of impact categories and category indicators.

ANALYSIS OPTIONS

We used our understanding of available data sets and models (and associated gaps) as well as standardized LCA elements to frame analysis options, within the temporal and spatial parameters identified. Analysis options presented below are designed to address two primary questions: 1) Is California achieving the AB 1504 forest carbon sequestration goal?; and 2) what is the effect of forest rules and regulations on net forest carbon sequestration? One option (the forest carbon inventory option) is presented to answer the first question, while several options are presented to answer the second question. These options are broadly labeled as:

- Forest Carbon Inventory Option
- Gold LCA Option
- Silver LCA Option
- Bronze LCA Option
- Alternative Options – These options deviate considerably in suggested methodologies (empirical approach & economic modeling approach) to the gold, silver, and bronze LCA options and are currently presented in their basic concept idea only. The intent is to stimulate further conversations on alternative methods to measure the impact of forest rules on carbon emissions and sequestration.

All options presented here provide valid avenues for forest carbon inventory and LCA, integrating several different tools and data together into different recommended analysis methodologies.

Forest Carbon Inventory Option

While producing forest rule scenario outputs and results, the LCA options outlined below are all characterized by considerable effort in terms of time and cost to produce estimates as well as subject to substantial data and model uncertainties (see section 'Data Requirements'). As an alternative and based on responses from CAL FIRE and the Scientific Advisory Committee, this carbon inventory option would focus on a forest carbon inventory potentially leading in the future towards a forest carbon LCA. A first critical step for informed decision making in the context of CO_2 emission consequences of California's rules and regulations could be to utilize existing forest inventory data and align efforts to existing reporting obligations to the furthest extent possible (Table 6):

- Instead of tracing the CO_2 emission consequences of a baseline rule scenario vs. alternative rule scenario, the analysis could be restricted to answering the question of whether current forest carbon pools are meeting the AB 1504 target of sequestering 5 MMT carbon/year.
- Limiting the analysis to an inventory approach would significantly reduce uncertainties originating from process models. Only forest carbon pools with high confident estimates would be included (forest ecosystem, forest products in-use, forest products post-use).
- Aligning efforts with existing inventory reporting obligations (e.g., AB 32 Section 38530 (b)(1); see also section 'Temporal Scale Considerations') would enable cost-effective and high-frequency annual reporting on overall performance towards achieving the AB 1504 target.

In an LCA context, by providing inventory numbers only, this option would provide all necessary steps with the Goal and Scope Definition phase as well as the LCI phase, while the Impact Assessment and Interpretation phase would be left to the decision makers. That is, if current conditions (or several years of monitoring) indicate that the 5 MMT/year target is not being met, adjustment to policy could be made or one of the LCA analysis option could be conducted to identify which rules are driving the

observed conditions. As a consequence, a functional unit (acres, see section 'System Boundaries and Functional Units') is not needed since only an overall performance against the state-wide sequestration target is to be determined. Further, the category indicator would be carbon sequestered rather than net CO_2 emissions.

Table 6: Overview of Analysis Considerations for the Carbon Inventory Option.

	Pool				
Analysis Considerations	**Forest**	**Operations**	**Products**	**Fate**	**Leakage**
Temporal Scale	Annual	Annual	Annual	Annual	N/A
Spatial Scale	Statewide	Statewide	Statewide	Statewide	N/A
Empirical Data	FIA, BOE, National Forest Health Monitoring Program, CalFire Timber Harvest Plan GIS and Database, Timber Products Output Database, ARB Excel Spreadsheet 'Carbon Tables 20140128.xls'	N/A	Timber Products Output Database, ARB, CalFire	CalRecycle, ARB	N/A
Relevant Models	N/A	N/A	Custom-built models	Custom-built models	N/A
Data Gaps/ Uncertainty	Some FIA parameters modeled rather than measured (e.g., dead roots, stumps)	N/A	CA specific processing data, lack of roundwood 'processing' pool data	Few empirical data available (mostly model based)	N/A
IPCC Tier 3 Compliant	Yes	N/A (IPCC Energy Sector)	Yes	N/A (IPCC Waste Sector)	N/A
Strategy to Improve	Correlate results with remote sensing data	Conduct industry surveys	Conduct industry surveys	Conduct landfill surveys	Conduct CA – specific leakage analysis

Integrated Framework, Tools, and Data

Define analysis area and period

The analysis would be conducted on private and public forest lands as covered by the FIA program, results will be specified down to a forest type (using FIA classification scheme), county, and ownership (FIA) level. The unit measured is 'biophysical carbon from forest' associated with tree growth including above and below carbon pools, roundwood, slash, residues, as well as wood products in-use and post-use (see Figure 4). The focus of analysis lies on the periodic measurement of the size of the pools measured in total carbon stored which will allow estimates on emission flows by means of comparing consecutive periodic assessments. This approach focusing on measurable units (carbon), pools rather than fluxes, and a narrow selection of carbon pools that can be best assessed by empirical data. This approach would only use a few modeled data inputs, which enables a comparatively greater accuracy of estimates of total pool size. For this FIA-driven approach, annual reporting is possible since FIA is based on a continuous inventory approach with a subset of plots measured every year. This option can be compared in its approach to the IPCC Tier 3 inventory approach under the premise that "*verifiable and transparent activity data are available and that the methodologies used are at least as detailed or accurate as […] Tier 2*", i.e., lookup table values (IPCC 2013b).

Tools: N/A

Data: latest FIA data and previous periods, including forest type, ownership, and county

Establish baseline forest conditions and carbon stocks

For the forest ecosystem pool, this approach will rely largely on FIA data including the above- and below-ground live and dead carbon pools. Data accuracy can be augmented by: 1) timber harvest data from BOE, 2) adding data on timberland conversions which are currently not centrally available but are encouraged to be collected annually (see section 'Assessment of California Rules and Regulations'), and 3) data from the National Forest Health Monitoring Program on large-scale impacts such as drought or insect calamity and the USDA Region 5 Fire Severity Database on wildfire impacts. A spatially explicit analysis on harvest activities can be added through the CAL FIRE Timber Harvesting Plan GIS and database.

For FIA data, the statistical accuracy of stocks and changes to stocks is designed for state-level targets with reasonable reporting accuracy at regional scales, such as a state the size of California. Conversion of timberland, which may be concentrated in certain geographic areas over specific time periods, will not likely be accurately estimated by a sole reliance on FIA. Once forestland is removed from the FIA population it is no longer tracked despite the fact that various levels of functioning forested ecosystems can still be in place post-conversion.

FIA, BOE, and CAL FIRE data retrieval can be automated, to a large extent, for annual reporting. For FIA, a readily usable access query has been established with a manual at CAL FIRE for annual updates to the above and below ground carbon pools including all relevant reporting categories (ownership, location, and forest type).[19] Data can be correlated for verification purposes with remote sensing data (e.g., Battles et al. 2014)

[19] See documents provided to CAL FIRE by Tim Robards 'Carbon Tables 20140128.xls' and 'CA_Download20141124.mdb'

Methods to estimate slash quantities and fate can be based on ARB efforts to quantify emissions from logging residues in California[20] using annually updated BOE harvest and other data. Data can be verified through the Timber Products Output Database (TPO; 'logging residues'; slash fate is not determined in the TPO database).

Tools: ArcGIS, CAL FIRE Microsoft Access Database 'CA_Download20141124'

Data: FIA, USDA Region 5 Fire Severity Database[21] and CAL FIRE Incident Information[22], which covers both public and private lands, Board of Equalization (BOE) harvest data, CAL FIRE Timber Harvesting Plan GIS and database (including fire or other salvage), timberland conversion data, ARB Excel Spreadsheet 'Carbon Tables 20140128.xls' (slash), TPO database

Track fate of carbon in wood removals

For the roundwood pool, the primary data source will be BOE harvest data, which can be augmented with CAL FIRE Timber Harvesting Plan GIS and database (including fire or other salvage) to be spatially explicit. There is a lack of data on an approximation of continuously existing roundwood pool in sawmill wood yards (e.g., in months of supply). As a default value and in the absence of reliable data, we recommend to assume a quarter (i.e. three month equivalent, see section below on the residue pool) of the annual roundwood supply as a proxy for a stable roundwood pool at the mill.

For the industry residue pool, total annual residue production can be calculated based on BOE harvest data adjusted by state-wide mill efficiency data such as provided by CAR[23] and verified with data from the Timber Products Output Database. For an approximation of continuously existing residue pool, due to the absences of reliable data, we recommend to assume a three month equivalent of the annual residue accumulation as a proxy for a stable residue pool (EPA 2014l[24].

For the wood products in-use and post-use carbon pool, we suggest aligning methods to CAR (Harvested Wood Products Calculation Worksheet) and congruent ARB efforts[25]. In light of the absence of a California-specific dataset on in-use wood products fate, methods that ultimately rely on national lookup tables for in-use and post-use wood products (Smith et al. 2006) are the closest proxy towards producing inventory numbers for this carbon pool. IPCC guidelines (2013b) suggest ISO 15686 (ISO 2008, 2011) as a standard series approach for country specific reference of service and half-life values of a product. However, no ISO 15686-compliant dataset for wood products in California exists. Data can be verified through the Landfilled Carbon data from CalRecycle with the caveat that the CalRecycle does not make this data available on a yearly basis and would include imported (non-California) wood products as well.

Tools: CAR Harvested Wood Products Calculation Worksheet

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[20] See Buchholz, T. and Robards, T. 2013. Emissions from logging residues from California forests. Report to the State of California Air Resources Board, Sacramento, CA, 11p.; based on Excel spreadsheet 'ARB - emissions from logging residues 2013-06-12.xls'

[21] http://www.fs.usda.gov/detail/r5/landmanagement/gis/%3Fcid%3Dstelprdb5361974

[22] http://cdfdata.fire.ca.gov/incidents/incidents_current

[23] Harvested Wood Products Calculation Worksheet http://www.climateactionreserve.org/wp-content/uploads/2010/02/Harvested-Wood-Products-Calculation-Worksheet.xlsx

[24] See Appendix G - Illustrative Biogenic Process Attributes

[25] See documents provided to CAL FIRE by Tim Robards 'CA HWP 20150120.xls' with reference to Buchholz, T. and Robards, T. 2012. Carbon time series of wood products from CA forests consumed and discarded instate. Report to the State of California Air Resources Board, Sacramento, CA, 15p; based on Excel spreadsheet 'CA wood in CA landfills 2013-04-22.xls.

Data: Board of Equalization (BOE) harvest data, CAL FIRE an ARB documents on landfilled and in-use data, Smith et al. (2006), Landfilled Carbon data from CalRecycle

Carbon Accounting

The total annual net carbon sequestration of the forestry sector can be done by aggregating the carbon pools described above. If spatial data on forest as well as harvest pools were added, this can be broken down by county, ownership class, and vegetation (CALveg, FIAveg). At a disaggregated reporting level (e.g., on a county basis), it is important to report forest ecosystem carbon pool numbers with FIA-derived confidence estimates. While BOE data comes with high confidence levels, uncertainty around in-use, post-use, slash, and residue pools cannot be quantified to a satisfying degree to date. Comparison of current to previous inventory data will allow for determining trends in annual carbon sequestration rates in California's forestry sector.

Tools: Excel, Access

Data: Outputs from previous steps

Tradeoffs of Utilizing This Approach

The carbon inventory option provides a time and cost-efficient approach towards establishing carbon pool inventory numbers that can be used to determine if AB 1504 sequestering target is being achieved. This option does not provide rule and regulation specific impact analysis and contains only segments (goal and scope definition, life cycle inventory) of a full LCA option. It does not allow one to understand how current forest policies, or how a change in policy or new set of regulations would affect carbon pools in near and especially long-term future, and offers limited insights in terms of current trend estimates. Trends will only transpire after several (annual) reporting iterations occur. Restricting the assessment boundaries to carbon pools (e.g., no emission estimates, no non-carbon related climate forcing variables such as evapotranspiration, albedo, methane, etc.) as well as a subset of potential carbon pools (e.g. no leakage, no wood product substitution) increases confidence levels of the results, but only provides a limited picture of the overall climate impact of current forest management. A strong focus on empirical data on the forest ecosystem pool using FIA makes this option less dependent on modeling approaches though several carbon pools in FIA are also modeled rather than measured (e.g., carbon in stumps and dead roots, EPA 2011b, USDA Forest Service 2015).

While methods to temporarily bridge gaps are discussed, critical gaps include an absence of data particularly for in-use and post-use wood product pools but also include residue and slash pools. These data gaps are not California-specific but universal.

The carbon inventory option provides a snapshot in time and cannot be used to forecast future conditions. Nevertheless, this option provides the necessary baseline data to forecast future conditions related to forest carbon pools and emissions and therefore includes necessary steps towards a full LCA (modeling) option.

In order to be compliant with Land Use, Land Use Change and Forestry (LULUCF)[26] Tier 3 methods of the International Panel of Climate Change (IPCC), an inventory option on the forest ecosystem carbon pools needs to "*provide estimates of greater certainty than lower tiers and have a closer link between biomass and soil dynamics*" (IPCC 2006). Applied datasets and models should be well documented and audited.

[26] Land use, land-use change and forestry (LULUCF) is defined by the United Nations Climate Change Secretariat as "*A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities*."

This condition applies to all models and datasets suggested in all options in this report, making all options Tier 3 compatible. For harvested wood products (HWP), IPCC guidelines suggest the use of product specific lookup tables for the HWP pool in general (Tier 2), type-specific HWPs (e.g., respective half-life estimates)(Tier 2), customized HWP pools based on industry data (HWP in-use pools), and market surveys (HWP in-use pools as affected by half-life, HWP post-use pools; IPCC 2013b). HWP pools post-use such as in landfills is not considered specifically in any of the LULUCF IPCC Tiers but is accounted for in the IPCC Waste Sector (IPCC 2006).

Life Cycle Assessment Options

In contrast to options that rely on inventory data gathered in the past (and can be used for the forest carbon inventory option), forward modeling options explore potential future pathways of carbon emissions through models that compare future scenarios based on assumptions (i.e., assumption associated with the effect of existing or alternative forest practice rules). These assumptions can be largely based on empirical data. The Gold, Silver, and Bronze options described below outline LCA approaches that would rely heavily on process models to trace carbon emission and sequestration consequences of a given set of forest rules or regulations. The general stepwise framework to be followed for each LCA analysis option is as follows:

1. Document LCA goal and scope definitions and define system boundaries
    a. Define spatial boundaries and stratify analysis area
        i. Evaluation unit (e.g. watershed, fireshed – the area to which output metrics are scaled)
        ii. Reporting units (e.g., state, region, district)
        iii. Modeling units (e.g., specific stand, general forest type)
    b. Define temporal boundaries
        i. Modeled time horizon (e.g., 10, 20, 40, 100 years)
        ii. Analysis summary interval (e.g., annual, 5 year time step, 10 year time step)
    c. Identify process units, inputs and outputs
        i. Included carbon pools
2. Define and document baseline and alternative scenarios (e.g., forest regulation scenarios) and associated assumptions
3. Evaluate and forecast expected future climate and weather regimes
4. Evaluate and forecast expected future forest fire regimes
5. Evaluate and forecast expected future forest disease and disturbance
6. Evaluate and forecast carbon sequestration and emissions for forest ecosystem, under baseline and alternative scenarios, integrating weather, fire regime, and disease analyses (3, 4 and 5 above).
7. Evaluate and forecast expected future emissions from forest operations, under baseline and alternative scenarios.
8. Evaluate and forecast carbon sequestration and emissions from forest products, under baseline and alternative scenarios
9. Conduct carbon accounting for baseline and alternative scenarios, integrating forest ecosystem, forest operations, and forest products analyses (steps 6, 7, and 8 above).
10. Conduct leakage analysis
11. Conduct interpretation and refinements as you move through each step

Gold Option - Full Modeling Approach

This option uses the finest resolution data possible to evaluate forest carbon stock and flux. Where possible, evaluation is based on spatially explicit stand-level data, such as field survey or forest inventory data. Single stands or parcels can be evaluated individually, or multiple stands can be evaluated simultaneously as a larger landscape (e.g., watershed) to determine forest carbon sequestration, emissions, and expected wildfire behavior. The analysis uses individual tree growth and yield models such as the US Forest Service Forest Vegetation Simulator (FVS) and extensions to forecast vegetation change over the analysis period, and is linked spatially in GIS to fire behavior prediction models (FlamMap). Fine scaled weather and climate predictions drive the forest vegetation forecasts and fire behavior predictions. Wildfire emissions models (CONSUME and FVS [U.S. Forest Service Forest Vegetation Simulator]) are used to predict wildfire emissions during the analysis period with and without management actions, and are calculated using the area based on vegetation projections, forecasted weather scenarios, and changes in expected fire spread and severity. This approach would include a probabilistic assessment of model results and provide robust estimates on CO_2 emission reductions as well as associated confidence estimates (Table 7).

System Boundaries

LCA Goal: Compare baseline regulations and alternative regulations to determine which rule set is expected to result in a greater forest carbon benefit.

Spatial Boundaries: The evaluation unit (EU) for this option would be the fireshed. Firesheds define an area of land of a scale that allows the ecologically relevant integration of wildfire risk, wildfire hazard, and forest carbon accounting. They are conceptually analogous to a watershed. The vegetation growth, wood product LCA, and emissions portion of this analysis methodology can be spatially scaled from a single stand or small parcel up to large watersheds. However, wildfire models used in this option require larger areas of analysis that can capture an expected near-worst case scenario fire. The EU for this option should therefore be of a scale that allows the ecologically relevant integration of wildfire risk, wildfire hazard, and forest carbon accounting such as watersheds, firesheds, or ARB supersections[27]. All firesheds or a subset of representative firesheds can be selected for analysis in each Reporting Unit (described below).

Within a fireshed, forest vegetation can be classified and quantified using various methods, including (ideally) field survey and inventory, aerial imagery analysis, and most-similar-neighbor type analysis. Where stand-specific data are absent for a fireshed, FIA data can be substituted for stands of similar forest type, site class, and history. Stand data for the fireshed is used directly in the forest growth, fire behavior and emissions models. Results from each framework element is geo-summarized into common units (e.g., CO_2 per acre).

Reporting Units: Fireshed analyses can be summarized at the Forest District level. As appropriate, counties with additional rules (e.g., San Mateo, Santa Cruz, Marin, and Lake), and the High Use Subdistrict will be analyzed at the county or sub-district level. Further summaries can be made by ownership and forest type.

Temporal Boundaries: The temporal analysis period can be 10 or 20 years or longer, and may be broken into increments (e.g., 5-10 year steps) where the models allow. Total length of the analysis period will depend largely on the forest growth models, since uncertainty increases with longer time frames. The

[27]ARB supersections maps: http://www.arb.ca.gov/cc/capandtrade/protocols/usforestprojects.htm

data driving the forecasting is derived from forest growth (e.g., FVS) and climate models. Other predictions are deterministic and based on these data. Forest growth models should be calibrated against empirical growth data. A suggested analysis period is 40 years, with 10 year time steps.

Carbon pools: As forest growth models for estimating biomass/carbon such as FVS are best at estimating above ground live and dead carbon. In terms of the forest ecosystem, evaluation should be restricted to these forest ecosystem pools.

Tools: GIS, Database/spreadsheet

Data: Boundary data (FRAP, and others), vegetation type classifications, FIA data, available field survey and inventory data, District and subdistrict boundaries (FRAP), Ownership data including public versus private lands (FRAP), Spatial location of all commercial timberlands (FRAP)

Scenarios

The baseline and alternative scenarios should be clearly identified, with assumptions. For each rule scenario considered, specific differences in management and their equivalent modeling parameters are identified and defined, to be used in modeling vegetation, wildfire and emissions. The baseline scenario should be specific to the fireshed being analyzed, but may also be jurisdictional. Jurisdictional baselines can be established that represent a set of firesheds, a forest district, or a region. Alternative scenarios will be developed that represent exclusion or alteration of one or more rules chosen for analysis.

Tools: GIS, Database

Data: Forest regulations

Expected climate and weather

Expected climate and weather to be used in forecasting models (vegetation and fire) should be established. Daily temperature, humidity, wind speed, and fuel moistures are the critical weather inputs for fire behavior modeling. The baseline climate is defined using weather data recorded by the most appropriate RAWS (remote automated weather station) or combination of RAWS and processed by Fire Family Plus. General Circulation Model (GCM) data will be used in FVS (Climate-FVS extension) to account for climate change in forest vegetation modeling. Downscaled climate predictions from Scripps Institute will be used to modify expected weather parameters in wildfire behavior modeling. Expected frequency of certain types of fire weather events (e.g., moderate, high, and extreme) can be used in conjunction with fire emissions modeling to better estimate potential wildfire emissions.

Tools: Fire Family Plus, Climate analysis tools, databases

Data: Historical weather station and gridded weather data (RAWS, GCM), PRISM, Downscaled climate projections

Expected fire regimes

The probability of fire impacting any given acre on the fireshed should be analyzed by examining pre-historic fire frequency (e.g., from tree ring studies), historic and contemporary records of fire (e.g., fire perimeters, fire return interval departure maps), and future fire management expectations. Fire behavior and severity analysis can be performed with the MTT model used to estimate conditional probability of high-severity fire (greater than a defined flame length) across the landscape by simulating 10,000 fires per landscape/time step. Additionally, the exogenous probability of fire can be analyzed using habitat niche modeling techniques (Maxent algorithm – see Parisien and Moritz 2009).

Tools: FlamMap

Data: Literature, contemporary fire history data, climate data

Expected disease and disturbance

An analysis can be performed to evaluate the potential for disease and other disturbance impacts on the landscape. Diseases and disturbance specific to the unit of evaluation (e.g., Fireshed) should be identified, and their expected effects over time should be enumerated for specific forest types. Input parameters for specific forest growth and development models (e.g., FVS) should be specified.

Data: Literature

Forest ecosystem carbon sequestration and emissions

Establish baseline forest conditions and carbon stocks - A dynamic baseline for forest carbon stocks is established for each fireshed by forecasting changes in forest carbon using FVS and its climate and fire extensions, or similar tree growth models. Using stand-level vegetation data within the analysis area, FVS is used to project forest vegetation change, accounting for species specific growth, mortality, regeneration and other dynamics, and can calculate biomass and stored carbon. Any management actions which should be included as part of the dynamic baseline can be simulated. Disturbance agents other than fire (e.g., insects, disease) can be simulated in FVS. Per-acre carbon volumes are calculated for the entire analysis area at defined time steps over the analysis period, to be used in carbon accounting. Projected stand-level vegetation and fuel characteristics are output, to be used in wildfire behavior emissions modeling.

Tools: FVS and extensions, or similar (FPS, FORSEE)

Data: FIA, available field survey and inventory data, weather and climate analyses from above

Forecast expected vegetation change under alternative scenarios

Similar to derivation of the dynamic baseline, FVS is used with stand-level data to project forest growth and development under alternative scenarios over the analysis period. FVS allows its growth, mortality, and regeneration parameters to be calibrated so as to match historically observed and expected patterns. FVS capably models complex forest management prescriptions and tracks the resulting changes in stand carbon as well carbon removed during management actions. Per-acre values for stored carbon and carbon in wood removals are output and used in carbon accounting. Projected stand-level vegetation and fuel characteristics are output, to be used in wildfire behavior emissions modeling.

Tools: FVS and extensions

Data: FIA, available field survey and inventory data

Forecast expected impacts from wildland fire

Expected changes in fire behavior and severity over time are evaluated using projected vegetation and fuel characteristics from FVS. Expected fire behavior and severity under baseline and management scenarios are quantified using the FlamMap fire behavior model and compared, using several metrics, including expected average fire size and flame length probabilities. Changes can be due to natural vegetation change or management actions. For example, fuel treatments become less effective through time as forest growth moves treated areas back towards pre-treatment conditions, unless maintained. Outputs from FVS are used to generate fire behavior modeling landscapes for input into the FlamMap software program. While the Fire and Fuels Extension to FVS has limitations, it can be used to triangulate results and screen for unusual outcomes. Therefore, changes in expected stand-level fire behavior over time or between management scenarios may be compared using outputs from the Fire and Fuels Extension to FVS. The Minimum Travel Time (MTT) model of fire spread in FlamMap is used to estimate changes in expected fire size and behavior under different management scenarios.

Direct wildfire emissions are calculated. Direct wildfire emissions are defined as the emissions observed or expected for each unit of area on the landscape, if that unit burned instantaneously and independently. Reductions (benefits) in direct emissions from treatment are a direct result of reduction

in fuel loads and arrangements (and resultant fire behavior) within those treatment areas. Total direct emissions are estimated using FVS and CONSUME models, summarized at the fireshed scale (per unit-area), and are independent of any effect of treatment on wildfire spread. Stand-level FVS outputs can be summarized across landscapes using FVS and GIS software. Fire behavior predictions from FVS-FFE can be converted into estimates of stand-level smoke emissions using CONSUME. These estimates of emissions can then be summarized across landscapes. FVS can be used to estimate rates and changes in rates of carbon sequestration before and after wildfires.

Indirect wildfire emissions are then quantified. Fuel treatments and other management actions can not only reduce fire intensity and emissions within themselves, but also modify fire spread, intensity, effects, and emissions within the greater fireshed area. The treatment shadow is the effect of fuel treatments on fire within the greater fireshed area. Mean expected fire sizes and flame length probabilities are used to characterize the change in fuel treatment effectiveness over time. This information is used to quantify the additional emissions reductions realized outside the treatments themselves.

Long-term changes expected from high severity wildfire (e.g. vegetation type conversion) are quantified over the analysis period. High severity fires in forests, particularly uncharacteristically severe crown fires, have the potential for high levels of tree mortality, result in vegetation type redirections (type conversions) from forest to grassland or shrub types. GHG's stored in forested areas that redirect are eventually lost as emissions from decomposition. The literature is examined, as well as maps of historical fire severity (MTBS) to determine what percentage of the landscape might be expected to redirect under high severity fire. This information is used to quantify additional emissions avoided from fuel treatment. Wildfires produce not only immediate smoke emissions but cause major changes in carbon sequestration rates for subsequent decades. FVS tracks snags as well as down dead woody material through time.

Tools: FVS and extensions, FlamMap, CONSUME
Data: FIA, available field survey and inventory data, LANDFIRE, MTBS

Forest Operations Analysis

Understanding the fate of biomass removed from the fireshed, and ultimately how much winds up as carbon sources vs. sinks is a critical component of this framework. The approach used in this option is highly detailed, and region-specific. The following elements are considered:

Harvesting, transporting and processing emissions

- Potential LCA models focusing on industrial process emissions including SIMAPro or GABI as well as California-specific data.
- Data required includes:
    - Typical use logging equipment by harvest method (chainsaw-based, tractor-based, or cable-based), landing site equipment, hauling distance. Processing emissions using a representative mix of California mills and tailoring emission estimates by wood product

Wood removal analysis

Wood products (in-use and post-use)

Cascading use for CA conditions based on industry data (Morgan et al. 2012, Board of Equalization, retrieving and updating CA industry data (e.g. on sawmill efficiencies); product half-lifes and post-use fate based on CA specific industry and landfill-surveys.

Bioenergy emissions and Product substitution

Analyzing the impact of product substitution using dynamic product substitution benefits for both bioenergy and wood products based on recent literature analysis (e.g., York 2012, Bird 2013)

Tools: SIMAPRO, GABI, Excel

Data: FRAP 2010, Morgan et al. 2012, customized, CA industry data

Carbon Accounting

All GHG losses or savings are summarized for the entire fireshed on a per-unit-area basis. For each alternative scenario (vs. baseline) at each time step, net carbon loss from management action is examined, offset by sequestration from forest growth and development, and benefits realized from wood products, biomass utilization, and operations. The benefits expected from both avoided-direct and avoided-indirect wildfire emissions are examined, as well as avoided redirection emissions, and modify these benefits by the probability of fire actually occurring on the landscape. These losses and savings are summed up to determine the effect of fuel treatment on the carbon balance at each time step.

Tools: Database

Data: From analysis

Economic Analysis

Leakage modeling is performed using FASOM-GHG or other economic modeling approach

Tools: FASOM-GHG

Data: From analysis - input data from wood removals from previous steps

Tradeoffs of Utilizing this Approach

This methodology scales from the stand level to the larger landscape levels (i.e., watershed, fireshed). Forest ecosystem carbon derives from individual tree growth models (FVS). Since FVS is a stand-level model it is most accurate at the stand level with more variability captured as stands are aggregated to the landscape level. Larger levels of aggregation and summary will increase uncertainty when plot or stand data from e.g. FIA are extrapolated across larger areas. Additional uncertainty arises in translating forest growth model outputs into fire behavior inputs, and coupling with nationally mapped data (e.g., LANDFIRE) with few options at hand to validate results or quantify uncertainties. While fire behavior can be modeled to the highest level of certainty only on the stand level, fire model output only becomes meaningful at the landscape level where more variability will enter in terms of fire behavior such as shadow effects, ignition risk, weather data, etc. Therefore, this stand-level approach up-scaled to a landscape-level approach provides the most accurate assessment of forest ecosystem carbon and potential fire effects, as they are each assessed individually from the most detailed forest data using specialized models.

Modeling of the growth and development for each stand within firesheds individually, developing projected fire behavior landscapes, and modeling fire upon them makes this option the most intensive in terms of data and analysis time.

For analyzing wood removals, there is probably only limited additional certainty gained from running LCA software since processing emissions are expected to be of minimal impact relative to other elements. Also, California-specific process-emissions might vary from international datasets used in FASOM-GHG. This approach would be the most time and labor intensive. These restrictions also apply to some extent to the silver and bronze options and the FASOM-GHG option detailed below.

Table 7. Overview of Analysis Considerations for the Gold LCA Option.

	Pool				
Analysis Considerations	**Forest Ecosystem**	**Operations**	**Products**	**Fate**	**Leakage**
Temporal Scale	40 yrs	40 yrs	40 yrs	40 yrs	40 yrs
Spatial Scale	Stand-Fireshed. Fireshed, aggregated to District	Stand	Statewide	Statewide	Statewide
Empirical Data	Local/site field inventories, FIA, historical weather	FRAP (2010)	Morgan et al. (2012); Board of Equalization	CalRecycle, ARB	York (2012), Bird (2013)
Relevant Models	Tree/Stand growth models (e.g. FVS); GCMs; Fire Behavior Prediction	GaBi/SimaPro	Custom-build models on product life	No models available	FASOM
Data Gaps/ Uncertainty	Uncertainty in models (e.g. growth models), Uncertainty in source data (e.g. Inventory or LANDFIRE)	CA-specific Processing Data	CA-specific processing data	Little empirical data available (largely model based)	Lacking literature, especially with CA relevance
IPCC Tier 3 Compliant	Yes	N/A (IPCC Energy Sector)	Yes	N/A (IPCC Waste Sector)	N/A
Strategy to Improve	Calibrate models with empirical data, increase site-specific data	Industry Surveys	Industry Surveys	Landfill surveys	Improved CA-Specific Leakage Analysis

Silver Option: State and Transition Approach

This option would use a state and transition approach, using the Vegetation Dynamics Development Tool (VDDT). The evaluation unit would be a fireshed, although it could be larger if necessary. The fireshed would be stratified into cells, each assumed to be homogenous, with each cell assigned a class. Each class, representing a vegetation cover type/structural stage combination would be associated with a carbon value using existing tools and data such as growth models (e.g. FVS), or lookup tables (e.g. Carbon Online Estimator). Specificity of the classes and carbon values could be scaled, depending on the scope of the analysis, to represent either specific site conditions, or broad regional forest type conditions. Cells (e.g., spatial locations) would change through time based on transitions such as succession and management actions. Transition pathways can be either deterministic or probabilistic. Carbon values for classes under different climate projections can be accounted for using FVS Climate.

The state and transition method can also account for wildfire and other disturbances in a stochastic way, with stands having some probability through time of transitioning to a burned state, with its own carbon value. Assumptions for harvest levels, forest growth, and probability of wildfire or other disturbance would be based on "current" or 2014 levels, a "contemporary" trend average over the last 10 years, and/or a "quarter century trend" which utilizes available data for up to the past 25 years. Current burn probabilities for various California vegetation types are listed by Safford et al. (2011). The analysis would follow the general steps below (see also Table 8).

System Boundaries

Spatial Boundaries: This analysis option can be considered semi-spatial, in that each cell (spatial location) is modeled independently with its own transition pathway. As such, size of the cells and specificity of the classes and carbon values assigned to each cell can be scaled, depending on the scope of the analysis, to represent either specific site conditions, or broad regional forest type conditions. Similar to the full modeling approach, the fireshed can serve as a reasonable evaluation unit over which results can be summarized to the acre. All firesheds or a subset of representative firesheds can be selected for analysis in each Reporting Unit, described below.

Reporting Units: Firesheds or other evaluation units can be summarized at the Forest District level. As appropriate, counties with additional rules (San Mateo, Santa Cruz, Marin, and Lake), and the High Use sub-districts can be analyzed at the county or sub-district level. Further summaries can be made by ownership and forest type.

Temporal Boundaries: The temporal analysis period can be 10 years or longer, and may be broken into increments e.g., 5 or 10 year time steps. VDDT is flexible in this regard, but because carbon value assignments may inherit from FVS, COLE, or other growth estimates, 10 year increments may be the shortest feasible. Total length of the analysis period (e.g. 40 years) will also depend largely on the choice of models used, since uncertainty in biomass-carbon estimates increases with longer time frames. Forest growth models should be calibrated against empirical growth data. A suggested analysis period is 40 years, with 10 year time steps.

Carbon pools: As forest growth models for estimating biomass/carbon such as FVS are best at estimating above ground live and dead carbon, evaluation should be restricted to these forest ecosystem pools. Other carbon pools such as the wood products pool are unaffected by this restriction.

Tools: GIS, database/spreadsheet

Boundary data (FRAP, and others), vegetation type classifications, available field survey and inventory data, District and subdistrict boundaries (FRAP), Ownership data including public versus private lands (FRAP), Spatial location of all commercial timberlands (FRAP)

Scenarios

The baseline and alternative scenarios should be clearly identified, with assumptions. For each alternative scenario considered, specific differences in management and their equivalent modeling parameters are identified and are defined, to be used in modeling vegetation, wildfire and emissions. The baseline scenario should be specific to the fireshed being analyzed, but may also be jurisdictional. Jurisdictional baselines can be established that represent a set of firesheds, a forest district, or a region. Alternative scenarios will be developed that represent exclusion or alteration of one or more of the rules chosen for analysis.

Tools: GIS, Database

Data: Forest regulations

Expected climate and weather

Expected climate and weather to be used in forecasting models (vegetation and fire) are established. Daily temperature, humidity, wind speed, and fuel moistures are the critical weather inputs for fire behavior modeling. The baseline climate is defined using weather data recorded by the most appropriate RAWS (remote automated weather station) or combination of RAWS and processed by Fire Family Plus. General Circulation Model (GCM) data can be used in FVS (Climate-FVS extension) to account for climate change in forest vegetation modeling. Downscaled climate predictions from Scripps Institute will be used to modify expected weather parameters to be used in wildfire behavior modeling. Expected frequency of certain types of fire weather events (e.g., moderate, high, and extreme) can be used in conjunction with fire emissions modeling to better estimate potential wildfire emissions.

Tools: Fire Family Plus, Climate analysis tools, databases

Data: Historical weather station and gridded weather data, PRISM, Downscaled climate projections

Expected fire regimes

Current, contemporary, and quarter-century trends reported for fire related and disturbance agent mortality can be established based on the historic fire record, fire severity maps, and mortality surveys (where available). Future rates of loss to wildfire and other disturbance agents can be assumed to be equivalent to historical trends. Alternatively (or in combination) conditional probability of fire impacting a given acre within a fireshed can be established using the MTT algorithm in the FlamMap fire spread model.

Potential frequency of different types of fire weather from weather analysis (above) can be used in combination with fire probability information for different forest types under different weather scenarios to establish a probability of low-moderate, and high severity fire.

This information will be used to estimate expected extent and severity of fire for different forest types, to be applied as probabilities in VDDT transition pathways.

Tools: Vegetation Dynamics Development Tool (VDDT), FlamMap, GIS, Database/spreadsheet

Data: FRAP fire data (FRID, Fire Hazard, Fire Threat), Forest Biomass and Biomass Potentials (FRAP), Woods Hole Research Center datasets, Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) forest vegetation datasets

Expected disease and other disturbance

An analysis can be performed to evaluate the potential for disease and other disturbance impacts on the landscape. Diseases and disturbance specific to the unit of evaluation (e.g., fireshed) should be identified, and their expected effects over time should be enumerated for specific forest types. The National Insect and Disease Risk Mapping (NIDRIM) can be used in this context. Input parameters for specific forest growth and development models (e.g., FVS) should be specified.

This information will be used to estimate expected extent and effects of disease or other disturbances for different forest types within the fireshed, to be applied as probabilities in VDDT transition pathways.

Forest ecosystem carbon sequestration and emissions

The current forest practice rules can be converted into a spatially explicit layer to determine areas available for harvest under current regulations. The baseline assessment can be conducted by developing cell classes and transition pathways using existing vegetation data, expected harvest levels, and expected probabilities of fire, disease, or other disturbances. Each cell class, representing a vegetation cover type/structural stage combination can be associated with a carbon value using existing tools and data such as growth models (e.g. FVS), or lookup tables (e.g. Carbon Online Estimator). Specificity of the classes and carbon values could be scaled, depending on the scope of the analysis, to represent either specific site conditions, or broad regional forest type conditions.

This information can be used in VDDT to project future landscapes and net baseline forest carbon stocking by establishing transition pathways through which cells move over time. The probabilistic and deterministic pathways for the baseline scenario can be set using the "current" (2014) levels of harvest, wildfire, or disturbance, or an average of the past 10 years ("contemporary"), and/or 25 years ("quarter century trend").

Net carbon stocking for alternative scenarios can be established by modifying expected harvest levels and probabilities of fire, disease or disturbance based on alternative rule scenarios being examined. Current, contemporary, or the "quarter century trend" in reported growth, mortality, regeneration, management actions, and wood removals will be derived from existing information data for the periods described. The growth and removal rates would be forecast out for 40 years using this information. The information will be stratified by parcel number. An important note: stratification by parcel requires seamless statewide coverage of harvest locations and volumes; further research would need to be determined if existing databases can be used as a source of this data. At present time, there are two commonly used datasets which provide seamless coverage for the continental US (and California). The first is Woods Hole Research Center (WHRC) National Biomass and Carbon Dataset (Kellndorfer 2000). The WHRC could be downscaled to the parcel level, though the dataset provides an assessment of forest carbon for the year 2000. The second dataset, from the USDA Forest Service, provides a seamless map of forest carbon for the years 2000-2009 (Wilson et al. 2013). Both of these datasets can be used for analysis with the understanding that: a) They may not have data for years of interest or recent years, and b) they may be downscaled to the parcel level, though their accuracy at that scale will rely on the volume and quality of data used to create the data at that parcels particular location.

Expected emissions from wildfire of different severities in different forest types can be derived using expected weather parameters and representative forest stand data in emissions models such as CONSUME, FOFEM, or FVS (Fire and Fuels Extension). These emissions values can be applied post-hoc to cells that burn under probabilistic pathway rules.

Tools: Vegetation Dynamics Development Tool (VDDT), Forest Growth models (FVS), Emissions models (CONSUME, FOFEM, FVS-FFE), ArcGIS, Database/Spreadsheet
Data: FIA (COLE) data, BOE harvest data, third party timber data, CAL FIRE Timber Harvesting Plan GIS and database

Forest Operations Analysis

Understanding the fate of biomass removed from the fireshed and ultimately how much winds up as carbon sources vs. sinks is a critical component of this framework. The following elements are considered:

Harvesting, transporting and processing emissions - Total quantity of wood products derived from Board of Equalization; using sensitivity analysis to estimate processing emission impact based on literature review (i.e., how much would processing emissions need to be to impact results; is this realistic using published numbers)

Bioenergy emissions and product substitution - Analyzing the impact of product substitution using full substitution benefits for bioenergy as well as a range of no substitution as well as full substitution effects for wood products based on literature estimates for full substitution effects (e.g. CORRIM literature or the NREL Life Cycle Inventory Database)

Tools: ARB protocol lookup tables
Data: Board of Equalization Literature (e.g. CORRIM and NREL LCI Database)

Wood Removal Analysis

Wood products (in-use and post-use)

- Using ARB lookup tables for mill efficiencies, wood products by subregion and long-term carbon storage in wood products in landfills.
- Use Appendix C of the ARB protocol to estimate the long-term wood products storage in in-use and landfill storage over 100 years.
- The default percentages for wood products in each class may be found in the appendix F excel file on the ARB website, in the "Supersections_HWPs"
- The ARB compliance offset protocol provides tables to estimate average long-term (100 year) carbon storage in in-use and landfilled wood products. See Table C.2. Worksheet to estimate long-term carbon storage in in-use wood products (p99) and Table C.3. Worksheet to estimate long-term carbon storage in wood products in landfills (p101).

Carbon Accounting

All GHG losses or savings are summarized for the entire evaluation unit (e.g. fireshed) on a per-unit-area basis. For each management scenario (vs. baseline) at each time step, net GHG storage loss from treatment is examined, offset by GHG benefits realized from merchantable and non-merchantable wood removal life cycles. The benefits expected from avoided wildfire emissions are examined, as well as avoided redirection emissions, and modify these benefits by the probability of fire actually occurring on the landscape. These losses and savings are summed up to determine the effect of management scenarios on the carbon balance at each time step.

Tools: Database/Spreadsheet
Data: From analysis

Economic Analysis

Leakage default of 20% taken from CAR Forest Project Protocol Version 3.2. CAR defines a decision tree for project developers to determine the appropriate leakage factor. Leakage is defined as 0% for improved forest management projects on actively managed forestland for projects that increase harvesting. Improved forest management projects that result in reduced harvesting relative to the baseline are assumed to have a leakage rate of 20% of the difference in harvest volume.

Tools: CAR Forest Project Protocol Version 3.2

Data: From analysis

Tradeoffs of Utilizing This Approach

The "Silver Option" would provide a flexible, semi-spatial analysis to assess the California Forest Practice Rules on forest carbon balances at a Forest District Level. Some of the components of the analysis, including the development of a spatially explicit layer of the Current California Forest Practice Rules, are also utilized in the "Bronze Option". In comparison to the Gold Option (Full Modeling Approach), the state and transition tool VDDT will allow a flexible format that can be scaled, depending on the specificity desired for the cover type/age structure groups. Assigning carbon values, fire probabilities, and other attributes to the cover/age groups may still require some stand-level modeling, in addition to using existing data. Although VDDT is not by itself spatially explicit, results can be presented in map form as well as aggregated at the Forest District Level. It is anticipated that this analysis would take up to 6 months to complete, barring unforeseen limits in data availability or usability.

The "Silver Option" analysis would rely in-part on using existing reported values from the datasets described for forecasting, and be subject to any error(s), uncertainty, or bias associated with these datasets. In addition, the forecasting would also utilize a set of basic assumptions for rates of harvest, mortality (wildfire or other disturbance related), and other variables based on an average of the recent past. While this average of the past provides quantitative information supported by existing data, it may not entirely reflect actual potential future pathways under a variety of climate scenarios. Generally speaking, most if not all modeling efforts will be subject to the same set of assumptions and issues. Probably the greatest tradeoff of this approach is that the primary model would be non-spatial, with data aggregated and reported at the Forest District Level. Given the depth and quality of ancillary spatial datasets (ownership, T & E species locations, other census data) that could be integrated into a more detailed analysis, this lack of a spatial component could adversely impact future analysis at a spatial, statewide scale. This option would allow modeling basic scenarios that were spatially explicit (for example, increased harvest levels from a specific type of landowner or species type or an assumed change in loss due to wildfire) at the parcel or larger (i.e., watershed, woodshed, or fireshed) scales.

Table 8. Overview of Analysis Considerations for the Silver LCA Option.

	Pool				
Analysis Considerations	**Forest Ecosystem**	**Operations**	**Products**	**Fate**	**Leakage**
Temporal Scale	40 yrs	40 yrs	40 yrs	40 yrs	40 yrs
Spatial Scale	Stand to region	Statewide	Statewide	Statewide	Statewide
Empirical Data	Stand inventory, FIA, LANDFIRE	Board of Equalization, CORRIM, NREL LCI database	Board of Equalization, ARB	ARB	CAR default factors
Relevant Models	VDDT, FVS	N/A	ARB protocol lookup tables	ARB protocol lookup tables	N/A
Data Gaps/ Uncertainty	Inherited from source data for class definitions. Growth model uncertainty (site), forest type classification uncertainty (region)	No Ca-specific LCA data	Largely model based assumptions, sensitivity analysis on product substitution benefits	Largely model based assumptions	National default factors
IPCC Tier 3 Compliant	Yes	N/A (IPCC Energy Sector)	Yes	N/A (IPCC Waste Sector)	N/A
Strategy to Improve	Calibrate growth models and validate pathway transitions with empirical data.	CA-specific industry surveys, customized LCA analysis	CA-specific industry surveys, customized LCA analysis	Landfill surveys, CalRecycle data	Improved CA-specific leakage analysis

Bronze Option – Generalized Approach

The general approach for this option is to utilize existing datasets and models for all analysis, and complete the analysis at the Forest District Level as defined by the current California Forest Practice Rules, then aggregate values at each district to a statewide level. Within the High Use Sub-District and other counties that have additional rules (Marin, San Mateo, Santa Clara, Santa Cruz, Lake, and Monterey), this option would quantify the effects of these additional rules into the analysis. This analysis would generally be non-spatial, with ArcGIS primarily used to extract data from existing datasets and convert into an Excel format. Baseline forest carbon stocks would be based on a lookup, using the COLE system (Carbon Online Estimator) or similarly broad scaled option. Assumptions for harvest levels, forest growth, and losses due to wildfire or other disturbance would be based on "current" or 2014 levels, a "contemporary" trend average over the last 10 years, and/or a "quarter century trend" which utilizes available data for up to the past 25 years. The analysis itself could be conducted using a series of Excel based spreadsheet to estimate and summarize current and future carbon stocks over the analysis period under future climate scenarios. The analysis would follow the general steps below (see also Table 9).

System Boundaries

Spatial Boundaries and Reporting Units: The evaluation unit for this option should be of a larger scale than the stand-fireshed approach used in the Gold and Silver options. Forest Districts can be stratified by forest type, site class, ownership, and land use. Unique strata considered homogenous within Districts can be evaluated independently, then summarized for each district. As appropriate, Counties with additional rules (San Mateo, Santa Cruz, Marin, and Lake), and the High-Use Subdistrict will be analyzed at the county or sub-district level.

Temporal Boundaries: Similar to the Gold and Silver options, total analysis period should probably be limited to ~40 years, evaluated in 10 year time steps.

Carbon pools: As forest growth models for estimating biomass/carbon such as FVS are best at estimating above ground live and dead carbon, evaluation should be restricted to these forest ecosystem pools. Other carbon pools such as the wood products pool are unaffected by this restriction.

Tools: ArcGIS

Data: District and subdistrict boundaries (FRAP), Ownership, including public versus private lands (FRAP), Spatial location of all commercial timberlands (FRAP)

Scenarios

The baseline and alternative scenarios should be clearly identified, with assumptions. For each alternative scenario considered, specific differences in management and their equivalent modeling parameters are defined for use in modeling vegetation, wildfire and emissions. The baseline scenario should be specific to the fireshed being analyzed, but may also be jurisdictional. Jurisdictional baselines can be established that represent a set of firesheds, a forest district, or a region. Alternative scenarios will be developed that represent exclusion of one or more of the rules chosen for analysis.

Tools: GIS, Database

Data: Forest regulations

Analyze expected climate and weather

In this option, historical weather parameters can be used to estimate future expected wildfire emissions. Daily temperature, humidity, wind speed, and fuel moistures are the critical weather inputs for fire emissions modeling. Baseline and alternative scenario weather parameters are defined using historical

weather data recorded by the most appropriate RAWS (remote automated weather station) or combination of RAWS and processed by Fire Family Plus.

Tools: Fire Family Plus

Data: Historical weather station and gridded weather data

Analyze expected fire regimes

Current, contemporary, and quarter-century trends reported for fire can be established based on the historic fire record, fire severity maps, and mortality surveys (where available). Future rates of loss to wildfire and other disturbance agents can be assumed to be equivalent to historical trends.

Historical frequency of different types of fire weather from weather analysis (above) can be used in combination with fire emissions information for different forest types to establish expected emissions of low-moderate, and high severity fires.

Tools: Vegetation Dynamics Development Tool (VDDT), FlamMap, GIS, Database/spreadsheet

Data: FRAP fire data (FRID, Fire Hazard, Fire Threat), Forest Biomass and Biomass Potentials (FRAP), Woods Hole Research Center datasets, Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) forest vegetation datasets

Analyze expected disease and other disturbance

An analysis can be performed to evaluate the potential for disease and other disturbance impacts on the landscape. Diseases and disturbance specific to the unit of evaluation (e.g. fireshed) should be identified, and their expected effects over time should be enumerated for specific forest types. Input parameters for specific forest growth and development models (e.g. FVS) should be specified.

This information will be used to estimate expected extent and effects of disease or other disturbances for different forest types within the fireshed, to be applied as probabilities in VDDT transition pathways.

Forest ecosystem carbon sequestration and emissions

The current forest practice rules will be converted into a spatially explicit layer to determine areas available for harvest under current regulations. Baseline carbon stocks will be assessed using the COLE system (Carbon Online Estimator) or similar data. The baseline harvest assessment can be conducted using past harvest and disturbance regimes. The baseline levels could be set using the “current” (2014) levels of harvest, wildfire, or disturbance, or an average of the past 10 years (“contemporary”), and/or 25 years (“quarter century trend”).

Current, contemporary, or the “quarter century trend” in reported growth, mortality, regeneration, management actions, and wood removals will be derived from existing information data for the periods described. The growth and removal rates would be forecast out for 40 years using this information.

Similar to harvest and growth regimes, current, contemporary, and the “quarter century trends” reported for fire related and disturbance agent mortality will be based on the historic fire record, fire severity maps, and mortality surveys (where available). The current level of loss to wildfire and other disturbance agents will be assumed as the previous 10 year average. The loss rates from wildfire and disturbance would be forecast out for 40 years using this information.

Tools: GIS, Database/Spreadsheet

Data: BOE harvest data and FRAP data (specifically for related fire or other salvage), CAL FIRE Timber Harvesting Plan GIS and database (specifically fire or other salvage), USDA Region 5 Fire Severity Database, which covers both public and private lands

Forest operations

Analyzing the impact of product substitution using full substitution benefits for bioenergy as well as a range of no substitution as well as full substitution effects for wood products based on literature estimates for full substitution effects (e.g. CORRIM literature). The following elements are considered:

Harvesting, transporting and processing emissions

- Ignoring processing emissions or using sensitivity analysis (how much would processing emissions need to be to tilt results; is this realistic using published numbers)

Bioenergy emissions and product substitution - Analyzing the impact of product substitution using full substitution benefits for bioenergy as well as a range of no substitution as well as full substitution effects for wood products based on literature estimates for full substitution effects (e.g. CORRIM literature or the NREL Life Cycle Inventory Database)

Forest wood removals

Carbon fluxes and pools for wood products (in-use and post-use) will be based on Smith et al. (2006) lookup tables.

Carbon accounting -All GHG losses or savings are summarized for the entire District or other reporting unit, on a per-unit-area basis. For each management scenario (vs. baseline) at each time step, net GHG storage loss from treatment is examined, offset by GHG benefits realized from merchantable and non-merchantable wood removal life cycles. The benefits expected from avoided wildfire emissions are examined, as well as avoided redirection emissions, and modify these benefits by the probability of fire actually occurring on the landscape. These losses and savings are summed up to determine the effect of management scenarios on the carbon balance at each time step.

Tools: Excel, Access
Data: Outputs from previous steps

Economic analysis

A leakage default of 20% for timber products will be based on CAR Forest Project Protocol Version 3.2.

Tools: CAR Forest Project Protocol Version 3.2.
Data: N/A

Tradeoffs of Utilizing This Approach

The "Bronze Option" would provide a relatively less expensive option to conduct a coarse scale assessment of the California Forest Practice Rules on forest carbon balances at a Forest District Level. Some of the components of the analysis, including the development of a spatially explicit layer of the Current California Forest Practice Rules, could be utilized in the "Silver" and "Gold" analysis options. The need to integrate several disparate modeling tools in this analysis is limited, as the primary analysis tool will be Excel.

The "Bronze Option" analysis would rely heavily on using existing reported values from the datasets described for forecasting, and be subject to any error(s), uncertainty, or bias associated with these datasets. In addition, the forecasting would also utilize a set of basic assumptions for rates of harvest, mortality (wildfire or other disturbance related), and other variables based on an average of the recent past. While this average of the past provides quantitative information supported by existing data, it may not entirely reflect actual potential future pathways under a variety of climate scenarios. Generally speaking, most if not all modeling efforts will be subject to the same set of assumptions and issues.

Probably the greatest tradeoff of this approach is that it would be non-spatial, with data aggregated and reported at the Forest District Level. Given the depth and quality of ancillary spatial datasets (ownership, T & E species locations, other census data) that could be integrated into a more detailed analysis, this lack of a spatial component could adversely impact future analysis at a spatial, statewide scale. This option would have limited value in running scenarios that were spatially explicit (e.g., increased harvest levels from a specific landowner or species type or an assumed change in loss due to wildfire), especially at a scale finer than the Forest District Level. For the post-harvest carbon emissions this version would use simplified lookup tables from Smith et al. (2006). While these tables are debated in their applicability in California, the carbon fluxes affected by post-harvest carbon pool behavior is most likely small compared to landscape carbon fluxes with the exception of leakage and wood product substitution assumptions.

Table 9: Overview of Analysis Considerations for the Bronze LCA Option.

	Pool				
Analysis Considerations	**Forest Ecosystem**	**Operations**	**Products**	**Fate**	**Leakage**
Temporal Scale	40 yrs	40 yrs	40 yrs	40 yrs	40 yrs
Spatial Scale	Forest District	Pool not considered	Statewide	Statewide	Statewide
Empirical Data	FIA, Weather	N/A	Smith et al. 2006 lookup tables, CORRIM, NREL LCI database	Smith et al. 2006 lookup tables	CAR default factors
Relevant Models	COLE	N/A	CORRIM/ NREL LCI Database for full substitution benefits	N/A	N/A
Data Gaps/ Uncertainty	Generalization of FIA data to broad classes within districts	N/A	Lookup table based assumptions, sensitivity analysis on product substitution benefits	Lookup table based assumptions	National default factors
IPCC Tier 3 Compliant	Yes	N/A (IPCC Energy Sector)	No	N/A (IPCC Waste Sector)	N/A
Strategy to Improve	More specificity in forest type/owner classes (e.g. site class)	See Silver option	Apply ARB lookup tables (CA specific)	Apply ARB lookup tables (CA specific)	Improved CA-specific leakage analysis

Alternative Life Cycle Assessment Options

These options provide only a skeleton idea at this point and should serve as a template to brainstorm for additional options differing considerably from the options described above.

Reference-region Option

If LCA alternatives to options heavily reliant on process-modeling are sought after, this option would use empirical datasets for a region to assess the GHG emission impact of a given rule or set of rules. The advantage of this approach would be to limit the uncertainty derived from the inherent simplifications and bound rationalities characterizing each model when projecting trends forward.

There are three potential paths to implement this empirical method. One is a cross-regional comparison of empirical datasets with one region having a given rule implemented and comparing results with outcomes form a region that lacks this specific rule. The challenge here lies in identifying comparable regions that warrant meaningful results.

The other approach would be a retro-active comparison of datasets within the same region. If historic (forest inventory) data is available for a given region, the onset of a given rule could be correlated to changes in inventory over time. The feasibility of this approach hinges on two requirements: historic data is available and sufficient historic data is available for pre- and post-rule implementation periods. In case of forestry in California, FIA data would not be sufficient for this kind of retro-active analysis and the effort would rely on the availability of inventory data of private timberlands.

The third option would be to categorize FIA plots by the rules they are governed under. In a second step, multivariate analysis of variance or other statistical approaches could be employed to parse out rule-induced differences in carbon pools and fluxes. This option would forgo any requirement for trend extrapolation.

FASOM-GHG Option

If leakage should be assigned a more prominent role in a LCA modeling effort, a market-sector modeling option as outlined below provides an alternative. This section describes only the basic framework of such a market sector modeling effort to contrast its approach against the biophysical modeling options described above. Advantage of this option is that the U.S. Forest and Agricultural Sector Model with Greenhouse Gases (FASOM-GHG) can integrate leakage effects into the analysis from the onset. FASOM-GHG is an inter-temporal partial equilibrium model that accounts for CO_2, CH_4, and N_2O across forest, crop, and livestock management activities; CO_2 accounting includes biogenic feedstock (forest carbon) and non-biogenic feedstock (soil) pools. Forest sector representation includes logs from timber harvest and secondary wood products and forest residues and can account for land use competition (leakage effects) through endogenous competition between cropland, forestland, and grazing lands.

FASOM-GHG is widely used to assess the market, land use, and GHG implications of market drivers but can be also applied to rule-driven scenarios. The downside of applying an econometrics-focused model like FASOM-GHG is that it has limited capacities for growth and yield assumptions and non-economic 'shock' events affecting landscape-carbon such as high-severity wildfire or relies on other models for inputs in this field.

A basic outline for the application of FASOM-GHG in this context is described below:

1) Yields (except PNWW) are derived from the old ATLAS model they are empirical yield tables where the plot data (i.e. stand age and cubic foot total volume) is basically "fit" with a yield curve and then the growth curve is used to generate the growth from the current strata volume per acre. That means that non-stand replacing fire damage would be already represented in those yields (because the reduced volume per acre of fire damaged stands would have been used in the yield table generation) and therefore you wouldn't account for non-stand replacing disturbance.

2) Non-stochastic stand replacing fire events would not be part of the yield tables and so one would have to enact some regime into the model whereby some set number of acres over a range of strata would be moved into the 0 age class without the wood entering the forest sector (i.e. it burned). Because this option uses use a stock change approach the volume of carbon in those stands reset to 0 would be emitted. The model would know exactly what the fire damage would be and thus how it affects the industry ahead of time and so would react "perfectly" to a fire regime.

3) Stochastic fire events would be more difficult. First, the model would need to be run iteratively for all time periods, but fixing single period activities in each iteration. That way, the model behaves as if it has perfect information, but as one moves forward in time (an iteration) the modeler changes what happened and what the modeler thinks will happen in the future.

LITERATURE CITED

Abt, R. C., F. W. Cubbage, and G. Pacheco. 2000. Southern Forest Resource Assessment Using the Subregional Timber Supply (SRTS) Model. Forest Products Journal, Vol. 50, No. 4

Andrews, P. L. 2013. Current status and future needs of the BehavePlus Fire Modeling System. International Journal of Wildland Fire 23(1):21-33.

Andrews, P. L., C. D. Bevins, and R. C. Seli. 2003. BehavePlus Fire Modeling System: Version 2.0: User's Guide. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Ascui, F. and H. Lovell 2011. As frames collide: Making sense of carbon accounting. Accounting, Auditing, and Accountability Journal 24(8): 978–999.

Bahro, B., K. H. Barber, J. W. Sherlock, and D. A. Yasuda. 2007. Stewardship and fireshed assessment: a process for designing a landscape fuel treatment strategy. In Proc. of conf. on Restoring fire-adapted ecosystems: 2005 National Silviculture Workshop, Powers, RF (ed.). US For. Serv. Gen. Tech. Rep. PSWGTR-203 (pp. 41-54).

Battles, J. J., P. Gonzalez. T Robards, B. M. Collins and D. S. Saah. 2014. California forest and rangeland greenhouse gas inventory development. Final Report. California Air Resources Board Agreement 10-778. State of California Air Resources Board.

Beach, R.H., D. Adams, R. Alig, J. Baker, Gregory S. Latta, B. A. McCarl, B. C. Murray, S. K. Rose, and E. White. 2000. Model Documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). RTI International, 3040 Cornwallis Road, Research Triangle Park, NC 27709. RTI Project Number 0210826.016

Beukema, S. J., W. A. Kurz, C. B. Pinkham, K. Milosheva, and L. Frid. 1995. "Vegetation dynamics development tool user's guide." Vancouver, BC, Canada: ESSA Technologies Ltd.

Bird, D.N. 2013. Estimating the displacement of energy and materials by woody biomass in Austria. Joanneum Research, Graz, Austria.

Blois, J.L., Williams, J.W., Fitzpatrick, M.C., Jackson, S.T., and Ferrier, S. (2013). Space can substitute for time in predicting climate-change effects on biodiversity. Proc. Natl. Acad. Sci. 110, 9374–9379.

Bonan, G.B. 2008. Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science 320, 1444–1449.

Bradshaw, L., McCormick, E. 2000. Fire Family Plus user's guide, Version 2.0. Gen. Tech. Rep. RMRS-GTR-67WWW. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Carlton, Don. 2004. "Fuels management analyst plus software, version 3.8. 19." Fire Program Solutions, LLC, Estacada, Oregon.

Brander, M.; Tipper, R.; Hutchison, C.; Davis, G. 2008. Technical Paper: Consequential and attributional approaches to LCA: a Guide to policy makers with specific reference to greenhouse gas LCA of biofuels; Econometrica Press.

Breidt, L., Ogle, S.M., Powers, W., Hoover, C., 2014. Chapter 2: Uncertainty Assessment for Quantifying Greenhouse Gas Sources and Sinks. In Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity - Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC. 606 pages. July 2014. Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar, Editors.

Buchholz, T., Friedland, A., Hornig, C.E., Keeton, W., Zanchi, G., Nunery J. 2014. Mineral soil carbon fluxes in forests and implications for carbon balance assessments. Global Change Biology-Bioenergy 6(4): 305–311.

Buchholz, T., Prisley, S., Marland, G., Canham, C., and Sampson, N. 2014. Uncertainty in projecting greenhouse gas emissions from bioenergy. Nat. Clim. Change.

Campbell, J.L., Harmon, M.E., Mitchell, S.R. 2011. Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions? Frontiers in Ecology and the Environment, 10, 83–90.

Cherubini, F., Bright, R.M., and Strømman, A.H. 2013. Global climate impacts of forest bioenergy: what, when and how to measure? Environ. Res. Lett. 8, 014049.

Christensen, G. A.; S.J. Campbell, J. S Fried, tech. eds. 2008. California's forest resources, 2001–2005: five-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-763. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 183 p.

Daugherty, P.J. and J.S. Fried. 2007. Jointly optimizing selection of fuel treatments and siting of biomass facilities for landscape-scale fire hazard reduction. INFOR: Information Systems and Operational Research 45(1):353-372.Dixon, G. E. (2002). Essential FVS: A user's guide to the Forest Vegetation Simulator. Fort Collins, CO: USDA-Forest Service, Forest Management Service Center (2002).

Environmental Protection Agency 2011a. Accounting framework for biogenic CO2 emissions from stationary sources. Office of Atmospheric Programs, Unites States Environmental Protection Agency, Climate Change Division, Washington DC, 140p.

Environmental Protection Agency 2011b. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. USEPA #430-R-11-005. Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/emissions/usgginventory.html.

Environmental Protection Agency 2014. Framework for Assessing Biogenic CO2 Emissions from Stationary Sources. Office of Atmospheric Programs, Unites States Environmental Protection Agency, Climate Change Division, Washington DC, 69p.

ESSA Technologies Ltd. 2007. Vegetation Dynamics Development Tool User Guide, Version 6.0. Prepared by ESSA Technologies Ltd., Vancouver, BC. 196 pp.

ESSA Technologies Ltd. 2008. TELSA - Tool for Exploratory Landscape Scenario Analyses: User's Guide Version 3.6. Prepared by ESSA Technologies Ltd., Vancouver, BC. 235 pp.

European Commission 2009. Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Brussels, Belgium, 32p.

Eve, M., M. Flugge, D. Pape, 2014. Chapter 2: Considerations when Estimating Agriculture and Forestry GHG Emissions and Removals. In Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity - Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC. 606 pages. July 2014. Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar, Editors.

FIA 2014. EVALIDator population estimates based on the current FIADB.

Fight, R. D., B. R. Hartsough, and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. Gen. Tech. Rep. PNW-GTR-668. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p.

Finney, M. A. 2004 (Revised). FARSITE: Fire Area Simulator—model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Finney, M. A. 2006. An overview of FlamMap modeling capabilities. In Proceedings: Fuels Management — How to Measure Success, 28–30 March 2006, Portland, Oregon. Edited by P.L. Andrews and B.W. Butler. RMRS-P41. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Co. pp. 213–220.

FRAP 2010. California's Forests and Rangelands: 2010 Assessment. Fire and Resource Assessment Program, California Department of Forestry and Fire Protection. Sacramento, CA

Fried, J. S.; Barbinour, R.; Fight, R. 2003. FIA Biosum: Applying a multiscale evaluation tool in southwest Oregon. Journal of Forestry. 101(2):p. 8(1).

Fried, J.; Christensen, G. 2004. FIA BioSum: a tool to evaluate financial costs, opportunities and effectiveness of fuel treatments. Western Forester. 49(5): 12-13.

Fried, J.S., G. Christensen, D. Weyermann, R. J. Barbour, R. Fight, B. Hiserote, and G. Pinjuv 2005. Modeling opportunities and feasibility of siting wood-fired electrical generating facilities to facilitate landscape-scale fuel treatment with FIA BioSum. In: Bevers, M.; Barrett, T.M., comps. Systems analysis in forest resources: proceedings of the 2003 Symposium. Gen. Tech. Rep. PNW-GTR-656. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 195-204.

Gonzalez, P., Battles, J.J., Collins, B.M., Robards, T., Saah, D.S. (2015) Aboveground live carbon stock changes of California wildland ecosystems, 2001–2010. Forest Ecology and Management, 348, 68–77.

Gustavsson, L., Karjalainen, T., Marland, G., Savolainen, I., Schlamadinger, B., and Apps, M. 2000. Project-based greenhouse-gas accounting: guiding principles with a focus on baselines and additionality. Energy Policy 28, 935–946.

Heath, L. S., M. C. Nichols, J. E. Smith, and J. R. Mills 2010. FORCARB2: An updated version of the U.S. Forest Carbon Budget Model. Gen. Tech. Rep. NRS-67. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 52 p. [CD-ROM]

Hurteau MD, Robards TA, Stevens D, Saah D, North M, Koch GW. 2014a. Modeling climate and fuel reduction impacts on mixed-conifer forest carbon stocks in the Sierra Nevada, California. Forest Ecology and Management, 315, 30–42.

Hurteau MD, Westerling AL, Wiedinmyer C, Bryant BP 2014b. Projected Effects of Climate and Development on California Wildfire Emissions through 2100. Environmental Science & Technology, 48, 2298–2304.

Ince, P. J., A. D. Kramp, K. E. Skog, H. N. Spelter, and D. N. Wear. 2011. U.S. forest products module: A technical document supporting the Forest Service 2010 RPA assessment. Research Paper FPL-RP-662. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 61 p.Main, W. A., D. M. Paananen, and R. E. Burgan (1990). "Fire family plus." USDA Forest Service General Technical Report, NC 138.

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Chapter 1: Introduction, International Panel on Climate Change, Geneva, Switzerland, 21 p.

IPCC 2013a. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Ch.8, p. 714, Table 8.7. 2013. Retrieved 2014-02-13.

IPCC 2013b. Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol Task Force on National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Geneva, 268p.

ISO 2006a. International Standard ISO 14040. Environmental management — Life cycle assessment — Principles and framework. International Standard Organization, Geneva, Switzerland, 28p.

ISO 2006b. International Standard ISO 14044. Environmental management – Life cycle assessment – Requirements and guidelines. International Standard Organization, Geneva, Switzerland, 54p.

ISO 2008. Buildings and constructed assets – Service life planning – Part 8: Reference service life and service life estimation. ISO 15686-8:2008(E).

ISO 2011. Buildings and constructed assets – Service life planning – Part 1: General Principles. ISO 15686-1:2011(E).

Johnson, D.R., Willis, H.H., Curtright, A.E., Samaras, C., and Skone, T. 2011. Incorporating uncertainty analysis into life cycle estimates of greenhouse gas emissions from biomass production. Biomass Bioenergy 35, 2619–2626.

Kellndorfer, J., Walker, W., LaPoint, E., Bishop, J., Cormier, T., Fiske, G., Hoppus, M., Kirsch, K., and Westfall, J. 2012. NACP Aboveground Biomass and Carbon Baseline Data (NBCD 2000), U.S.A., 2000. Data set. Available on-line at http://daac.ornl.gov from ORNL DAAC, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/1081. - See more at: http://www.whrc.org/mapping/nbcd/#sthash.fjpJHbt6.dpuf

Kendall, A., Chang, B., and Sharpe, B. 2009. Accounting for Time-Dependent Effects in Biofuel Life Cycle Greenhouse Gas Emissions Calculations. Environ. Sci. Technol. 43, 7142–7147.

Levasseur, A., Lesage, P., Margni, M., Brandão, M., Samson, R. 2012. Assessing temporary carbon sequestration and storage projects through land use, land-use change and forestry: comparison of dynamic life cycle assessment with ton-year approaches. Climatic Change, 115, 759–776.

Litman, L., Nakamura, G. 2007. Forest stewardship series 3. Forest Ecology. Publication 8233, University of California, 17p. http://ucanr.edu/sites/forestry/files/78650.pdf

Marland, G., Buchholz, T., and Kowalczyk, T. 2013. Accounting for Carbon Dioxide Emissions. J. Ind. Ecol. 17, 340–342.

Morgan, T.A., Brandt, J.P., Songster III, K.E., Keegan, C.E., Christensen, G.A. 2012. California's forest products industry and timber harvest, 2006. Gen. Tech. Rep. PNW-GTR-866. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Moritz M.A., Parisien M.-A., Batllori E., Krawchuk M.A., Van Dorn J., Ganz D.J, Hayhoe K. 2012 Climate change and disruptions to global fire activity. Ecosphere, 3, art49.

O'Hare, M., Plevin, R.J., Martin, J.I., Jones, A.D., Kendall, A., and Hopson, E. 2009. Proper accounting for time increases crop-based biofuels' greenhouse gas deficit versus petroleum. Environ. Res. Lett. 4, 024001.

Ottmar, R. D., D. V. Sandberg, C. L. Riccardi, and S. J. Prichard 2007. An overview of the Fuel Characteristic Classification System-Quantifying, classifying, and creating fuelbeds for resource planning This article is one of a selection of papers published in the Special Forum on the Fuel Characteristic Classification System. Canadian Journal of Forest Research, 37(12), 2383-2393.

Ottmar, R. D., M. F. Burns, J. N. Hall, and Aaron D. Hanson 1993. "CONSUME: users guide."

Parisien, M.-A., Moritz, M.A. 2009. Environmental controls on the distribution of wildfire at multiple spatial scales. Ecological Monographs 79(1):127-154.

Reinhardt, E. and N. L. Crookston (Technical Editors). 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.

Reinhardt, E. D., R. E. Keane, and J. K. Brown 1997. First order fire effects model: FOFEM 4.0, user's guide.

Ritchie, M. W. and J. D. Hamann 2013. CONIFERS package in R: rconifers. 12p. http://www.fs.fed.us/psw/topics/forest_mgmt/conifers/

Rollins, Matthew G. 2009. "LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment." International Journal of Wildland Fire 18.3: 235-249.

Rural Urban Connections Strategy (RUCS). 2011. Sacramento Region Rural Urban Connections Strategy. 24p. Downloaded from http://www.sacog.org/rucs/

Pickett, S.T.A. 1989. Space-for-time substitution as an alternative to long-term studies", in G. E. Likens (ed.). Long-Term Studies in Ecology: Approaches and Alternatives, 110-135.

Saah, D., Robards, T., Moody, T., O'Neil-Dunne, J., Moritz, M., Hurteau, M., Moghaddas, J. 2012 Developing an Analytical Framework for Quantifying Greenhouse Gas Emission Reductions from

Forest Fuel Treatment Projects in Placer County, California. Spatial Informatics Group, LLC, Pleasanton CA, 130 p.
Schlamadinger, B. and G. Marland 1996. The role of forest and bioenergy strategies in the global carbon cycle. Biomass and Bioenergy 10(5/6), 275–300.
Sedjo, R., Sohngen, B. 2012. Carbon Sequestration in Forests and Soils Annual Review of Resource Economics 4: 127-144.
Silva LCR, Anand M. 2013. Probing for the influence of atmospheric CO2 and climate change on forest ecosystems across biomes. Global Ecology and Biogeography, 22, 83–92.
Silver, W.L., R. Ryals, and V. Eviner. 2010. Soil carbon pools in California's annual grassland ecosystems. Rangeland Ecology & Management", 63(1), 128-136
Skog, K.E. 2008. Sequestration of carbon in harvested wood products for the United States Forest products journal. 58(6): Pages 56-72
Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.
Smith, J. E., Heath, L. S., and Nichols, M. C. 2007. US forest carbon calculation tool: forest-land carbon stocks and net annual stock change. Revised. Gen. Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p. [DVD-ROM].
Stockmann, K. D., N. M. Anderson, K. E. Skog, S. P. Healey, D. R. Loeffler, G. Jones, J. F. Morrison 2012. Estimates of carbon stored in harvested wood products from the United States Forest Service Northern Region, 1906-2010. Carbon Balance and Management. 7: 1-16.
Stratton, R. D. 2006. Guidance on spatial wildland fire analysis: models, tools, and techniques. General Technical Report RMRS-GTR-183. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 15 p.
USDA Forest Service. 2015. Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units; Pacific Southwest Region. 45 pp. Whitepaper. O:\OfficeOfTheChief\ClimateChange\Program\Carbon\CarbonAssessmentsNFS
Vaillant, N.M., A.A. Ager, J. Anderson, and L. Miller 2012. ArcFuels User Guide: for use with ArcGIS 9. X. Internal Report. Prineville, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center
Wensel, L. C., B. E. Krumland, and W. J. Meerschaert 1987. CRYPTOS User's Guide: Cooperative Redwood Yield Project Timber Output Simulator. Division of Agriculture and Natural Resources. University of California
Wensel, L. C., P. J. Daugherty, and W. J. Meerschaert 1986. CACTOS user's guide: The California conifer timber output simulator. Northern California Forest Yield Cooperative.
Westerling AL, Turner MG, Smithwick EAH, Romme WH, Ryan MG 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. Proceedings of the National Academy of Sciences, 201110199.
Wilson, Barry Tyler; Woodall, Christopher W.; Griffith, Douglas M. 2013. Forest carbon stocks of the contiguous United States (2000-2009). Newtown Square, PA: USDA Forest Service, Northern Research Station. http://dx.doi.org/10.2737/RDS-2013-0004
Woudenberg, S.W., B. L. Conkling, B. M. O'Connell, E. B. LaPoint, J. A. Turner, K. L. Waddell, D. Boyer, G. Christensen, and T. Ridley. 2011. The Forest Inventory and Analysis Database: Database Description and Users Manual Version 5.1 for Phase 2.
Zheng, D.L.S. Heath, M.J. Ducey and J.E. Smith. 2011. Carbon changes in conterminous US forests associated with growth and major disturbances: 1992–2001. Environmental Resource Letters 6: 014012.

York, R. 2012. Do alternative energy sources displace fossil fuels? Nature Climate Change, 2, 441–443.

APPENDIX A: APPLICABLE MODELS FOR USE IN FOREST CARBON LIFE CYCLE ASSESSMENT

Identification of Existing Models Used for Climate, Wildfire, Vegetation Growth, Emissions, and Life Cycle Analysis

There are dozens of models, equations, lookup tables and tools that can be used to help assess the impact of California forest management rules on carbon sequestration and GHG emissions. These models are valuable for estimating the role or impact of climate, wildfire and vegetation growth, and emissions, with some providing a framework for developing complete life cycle assessment under a variety of user-defined scenarios. These models can range from those developed as part of a single research project to fully integrated platforms. For this assessment, the emphasis was on identifying models and/or tools which share some or all the following characteristics:

- The model has been utilized in previously published scientific research,
- The specific model is required for use according to policy or is accepted as a model which meets policy guidelines for procedures and accuracy,
- The model is regularly updated by a professional team, has clear documentation, and end user support, either on-line or via phone,
- The model has been in both research and professional use and is an accepted "industry standard" for its specific field of application.

Through this review several models have been identified and are summarized by their general area of use in Table 10 below. Table 11 provides additional detailed information for each model, including its scale of use, data sources, and other information.

Summary of Models Identified for Potential Use in Forest Carbon Life Cycle Assessment

Table 10: Summary of models by use, scale and source.

Type of Modeling or Assessment	Model Name	Scale of Use	Source Website (Citation)
Weather	Fire Family Plus (FF+)	Local to landscape	http://www.firelab.org/project/firefamilyplus (Main et al. 1990, Bradshaw et al. 2000)
Vegetation Growth	Forest Vegetation Simulator (FVS)	Stand	http://www.fs.fed.us/fmsc/fvs/ (Dixon 2002)
	CACTOS (CAlifornia Conifer Timber Output Simulator)	Stand	http://www.CNR.berkeley.edu/~wensel/cactos/cactoss.htm *(website not functional as of 09/26/2014) (Wensel et al. 1986)* See also: *http://www.fire.ca.gov/resource_mgt/resource_mgt_statefores ts_forestry_growth.php#cactos*
	CRYPTOS (Cooperative Redwood Yield Output Simulator)	Stand	http://www.CNR.Berkeley.EDU/~wensel/cryptos/cryptoss.htm *(website not functional as of 09/26/2014) (Wensel et al. 1987).* See also: http://www.fire.ca.gov/resource_mgt/resource_mgt_statefores ts_forestry_growth.php#cactos
	CONIFERS	Stand	http://www.fs.fed.us/psw/topics/forest_mgmt/conifers/ (Ritchie and Hamann 2013)
	Vegetation Dynamics Development Tool (VDDT)	Landscape	http://essa.com/tools/vddt/ (Beukema et al. 1995), User Guide (ESSA Technologies Ltd. 2007).
	Telsa	Landscape	http://essa.com/tools/telsa/ (ESSA Technologies Ltd. 2008).
Wildfire, Prescribed Fire, and Fire Effects	BehavePlus	Stand	http://fire.org/index.php?option=content&task=category&sectionid=2&id=7&Itemid=26, See also https://www.frames.gov/partner-sites/behaveplus/home/ (Andrews et al. 2003, Andrew 2013)
	The Fire and Fuels Extension (FFE) for the Forest Vegetation Simulator (FVS)	Stand	http://www.fs.fed.us/fmsc/fvs/ (Reinhardt et al. 2003)
	Fuels Management Analyst (FMA)	Stand	http://www.fireps.com/fmanalyst3/ (Carlton 2004)
	FARSITE	Landscape	http://www.firelab.org/project/farsite (Finney 2004)
	FlamMap (includes RANDIG for Conditional Burn Probability Calculations)	Landscape	http://www.firelab.org/project/flammap (Finney 2006)
	Rare Event Risk Assessment Process (RERAP)	Landscape	http://depts.washington.edu/nwfire/project.php?projectID=362 (Stratton 2006)

Type of Modeling or Assessment	Model Name	Scale of Use	Source Website (Citation)
	First Order Fire Effects Model (FOFEM)	Stand	http://www.firelab.org/document/fofem-software (Reinhardt et al. 1997)
	Fuel Characteristic Classification System (FCCS)	Stand	http://www.fs.fed.us/pnw/fera/fccs/ (Ottmar et al. 2007)
	Arc-Fuels	Landscape	http://www.fs.fed.us/wwetac/arcfuels/ (Vaillant et al. 2012)
Wildfire and Prescribed Fire Emissions	Fuel Characteristic Classification System (FCCS)	Stand	http://www.fs.fed.us/pnw/fera/fccs/ (Ottmar et al. 2007)
	CONSUME	Stand	http://www.fs.fed.us/pnw/fera/research/smoke/consume/index.shtml (Ottmar et al. 1993)
Economic Modeling and Analysis	FASOMGHG Forestry and Agricultural Sector Optimization Model with GHG (USDA)	Sub-state	http://agecon2.tamu.edu/people/faculty/mccarl-bruce/FASOM.html (Beach et al. 2010)
	Subregional Timber Supply Model SRTS	Stand	http://www.treesearch.fs.fed.us/pubs/2289 (Abt et al. 2000)
	BIOSUM 3	Stand	http://www.fs.fed.us/pnw/fia/biosum/ (Fried et al. 2005)
	Econometric Model	Regional	http://www.sacog.org/rucs/ (RUCS 2011)
Wood Products, Carbon, and Life Cycle Analysis (LCA) Estimates	Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)	Stand	http://www.nrcan.gc.ca/forests/climate-change/13107
	Carbon On-Line Estimator (COLE)	Sub-state	http://www.ncasi2.org/COLE/
	FORCARB2: An updated version of the U.S. Forest Carbon Budget Model	Stand	http://www.nrs.fs.fed.us/pubs/35613 (Heath et al. 2010)
	U.S. Forest Carbon Calculation Tool (CCT)	Stand	http://www.nrs.fs.fed.us/pubs/2394 (Smith et al. 2007)
	USFS Harvested Wood Products Modeling Application	Stand	http://maps.gis.usu.edu/HWP/Home/About (Stockmann et al. 2012)
	U.S. Forest Products Module (USFPM)	Stand	http://www.treesearch.fs.fed.us/pubs/39750 (Ince et al. 2011)
	WOODCARB2	Stand	http://www.nrcan.gc.ca/forests/climate-change/13107
	FORSEE (FORest and Stand Evaluation Environment)	Stand	http://www.cagym.com/
	FPS (Forest Projection and Planning System)	Stand	https://forestbiometrics.com/software/fps/

Type of Modeling or Assessment	Model Name	Scale of Use	Source Website (Citation)
	CAL FIRE THP Greenhouse Gas Emissions Calculator	Stand	http://calfire.ca.gov/resource_mgt/downloads/THP_GreenhouseGasEmissions_Calculator_061110.xls and http://www.fire.ca.gov/resource_mgt/downloads/THP_GreenhouseGasEmissions_Calculator_UserGuide_061110.pdf (Anonymous 2010)
	UC Carbon Sequestration Tool for THPs	Stand	http://ucanr.edu/sites/forestry/Carbon_Sequestration_Tool_for_THPs/
	GORCAM (Graz/Oak Ridge Carbon Accounting Model)	Landscape	http://www.sciencedirect.com/science/article/pii/0961953495001131 (Schlamadinger and Marland 1996)
Life Cycle Assessment/ Analysis Software Tools	SimaPro	Variable	http://www.pre-sustainability.com/simapro
	GaBi	Variable	http://www.gabi-software.com/america/index/

Detailed Descriptions of Models

Table 11: Detailed description of models by use and scale.

Type of Modeling or Assessment	Model or Assessment Name	Model Description
Weather	Fire Family Plus (FF+)	Fire Family Plus is software for analysis of a wide range of daily Remote Automated Weather Stations (RAWS) weather data and fire indices. Users can calculate fire weather conditions from all or a specified portion of the historical record from one or more stations. Fire Family Plus also allows users to analyze historical fire data in conjunction with fire climate data.
Vegetation Growth	Forest Vegetation Simulator (FVS)	The Forest Vegetation Simulator (FVS) is a family of forest growth simulation models. It is a system of highly integrated analytical tools that is based upon a body of scientific knowledge developed from decades of natural resources research and experience. FVS answers questions about how forest vegetation will change in response to natural succession, disturbances, and proposed management actions. Extensions to the base model are available to assess the effects of insects, disease, and fire. The Fire & Fuels Extension (FFE) includes live tree, dead tree, down dead wood and forest floor biomass information, which can be used to estimate changes in carbon stocks over time. A climate-sensitive version known as Climate-FVS is currently available for western states, and an eastern version is in development. Climate-FVS changes core growth, mortality, and regeneration estimates to respond to climate change, according a user-selected general circulation model (GCM), thereby allowing users to model the effects of management under changing climate conditions.
	CACTOS (CAlifornia Conifer Timber Output Simulator)	Models stand level conditions for conifer forests, including scheduled harvests, growth, and yield
	Cryptos (Cooperative Redwood Yield Output Simulator)	Models stand level conditions for redwood forests, including scheduled harvests, growth, and yield
	CONIFERS	Conifers is an individual-plant growth and yield simulator with two variants developed by the PSW Research Station. The SWO variant is for young mixed-conifer stands in southern Oregon and northern California and the SMC variant is for northwestern Oregon and western Washington. Conifers provides forecasts for young plantations of single species or mixed-species growing with or without competition from shrubs.
	Vegetation Dynamics Development Tool (VDDT)	The Vegetation Dynamics Development Tool (VDDT) is a user-friendly, Windows-based computer tool which provides a state and transition landscape modelling framework for examining the role of various disturbance agents and management actions in vegetation change. It allows users to create and test descriptions of vegetation dynamics, simulating them at the landscape level.
	Telsa	Telsa is a spatially explicit, GIS-based landscape-level model for simulating terrestrial ecosystem dynamics.
Wildfire, Prescribed Fire,	BehavePlus	BehavePlus is a tool to predict surface and crown fire behavior for the specified weather, fuel model, and topography.

Type of Modeling or Assessment	Model or Assessment Name	Model Description
and Fire Effects	The Fire and Fuels Extension (FFE) for the Forest Vegetation Simulator	FFE assesses standard fire modeling metrics on any tree list generated in FVS. Metrics include predicted flame length, fire type (surface, active, or passive crown fire), probability of torching ("P-Torch"), torching index, crowning index, and probability of mortality
	Fuels Management Analyst (FMA)	Similar to FFE, Fuels Management Analyst can assess standard fire modeling metrics at the stand level, based on FVS tree list or custom tree list files, formatted correctly for input into FMA
	FARSITE	FARSITE is a landscape fire model that simulates fire growth in the landscape using GIS layers. It integrates place-specific vegetation, fuel and topographic attributes with streaming weather data to predict attributes of fire behavior including flame length, spotting distance and rate of spread (Finney and Andrews 1999). FARSITE requires five GIS layers: elevation, slope, aspect, fuel model and canopy cover. Additional layers that may be important depending on the question asked include tree height, crown base height, crown bulk density, duff loading and woody surface fuel.
	FlamMap (includes RANDIG for Conditional Burn Probability Calculations)	FlamMap generates maps of fire behavior (such as rate of spread, crowning, flame length, etc.) by integrating GIS layers of fuel and vegetation with topography and fixed weather conditions. Unlike FARSITE, FlamMap does not calculate fire spread or differential behavior that results from header or flanking fires. Neither does it use streaming weather data. Instead, it models fire behavior that is likely to occur at different locations, given topography, fuels and specified weather station parameters.
	Rare Event Risk Assessment Process (RERAP)	The Rare Event Risk Assessment Process (RERAP) helps calculate the information needed to manage prescribed fires, wildland fire use fires, and wildland fires. RERAP allows a user to dynamically calculate the risk of undesired fire movement, including how to: 1) identify high and low risk opportunities for wildland fire use and general prescription control strategies; and 2) estimate fire movement and spread events based on historical weather information and professional knowledge. The RERAP program consists of three modules: 1) the Term Module, which allows a user to calculate the Weibull waiting-time probability distribution for fire-stopping events; 2) the Spread Module, which allows a user to estimate the rate of fire spread toward a designated location; and 3) the Risk Module, which combines information from term event information and fire spread events and allows a user to specify and combine fire-stopping and fire movement waiting-time probability distributions to estimate the likelihood of a fire impacting a designated location before a fire-stopping weather event.
	First Order Fire Effects Model (FOFEM)	FOFEM predicts tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire.

Type of Modeling or Assessment	Model or Assessment Name	Model Description
	ArcFuels	ArcFuels is used to design and test fuel treatments at the stand and landscape scale via linkages to models such as FVS-FFE (Forest Vegetation Simulator with the Fire and Fuels Extension), SVS (Stand Visualization System), FARSITE (Fire Area Simulator), FlamMap, Nexus, and FVS (Forest Vegetation Simulator) within a spatial interface. The system was specifically designed to accelerate Fireshed/SPOTS analyses for fuel treatment planning. The ArcMap framework helps specialists leverage local data to address project-specific issues that typify many fuel treatment projects. Specific functionality of ArcFuels includes: (1) An interactive linkage between digital imager, vegetation, data, FVS-FFE, and SVS, providing a map-based tool for designing, simulating, and visualizing stand fuel treatments, (2) Rapid scale-up of stand-specific treatments to simulate landscape packages of treatment alternatives, (3) Data linkages between FVS outputs and FlamMap to allow for simulation of landscape-scale fire behavior and evaluation of fuel treatment scenarios, and (4) full GIS functionality provided with ArcMap for data manipulation, ancillary analyses, mapping, and other GIS functionality (Vaillant et al. 2012).
Wildfire and Prescribed Fire Emissions	Fuel Characteristics Classification System (FCCS)	FCCS's primary use is to predict potential fire behavior and summarize fuel conditions without needing to rely on a standard fuel models. An important secondary function is to summarize carbon storage from stand inventory data.
	CONSUME	Consume predicts the consumption and emissions from dead fuels based on weather and fuel moisture. CONSUME was designed to support fuel treatments after logging.
Economic Modeling and Analysis	FASOMGHG Forestry and Agricultural Sector Optimization Model with GHG (USDA)	Simulates the allocation of land over time to competing activities in both the forest and agricultural sectors. In doing this, it simulates the resultant consequences for the commodity markets supplied by these lands and, importantly for policy purposes, the net greenhouse gas (GHG) emissions. The model was developed to evaluate the welfare and market impacts of public policies and environmental changes affecting agriculture and forestry. To date, FASOMGHG and its predecessor models FASOM and ASM have been used to examine the effects of GHG mitigation policy, climate change impacts, public timber harvest policy, federal farm program policy, biofuel prospects, and pulpwood production by agriculture among other policies and environmental changes.
	Subregional Timber Supply Model (SRTS)	SRTS is a modeling system that uses a standard empirical framework applied to subregional inventory data in the South. Model results indicate significant within-region variation in supply responses across owners and regions. Projections of southern timber markets indicate that results are sensitive to: 1) estimates of current harvest; 2) conversion of natural stands to plantations; and 3) growth rates associated with plantations. Given projected increases in demand, intensive pine management could ameliorate real price increases. For hardwoods, uncertainty about the viability of intensive management or imports makes supply response projections less conclusive.

Type of Modeling or Assessment	Model or Assessment Name	Model Description
	BIOSUM 3	The BioSum analysis framework was developed to combine forest inventory data representing an analysis region, a treatment cost model, a fuel treatment effectiveness model, and a raw material hauling cost model to explore alternative landscape-scale treatment scenarios that achieve a variety of management objectives (Fried et al. 2005). Raw material volumes generated by mechanical treatments designed to reduce canopy fuels are estimated by simulating such treatments using data derived from forest inventory plots; treatment costs are estimated via the Fuel Reduction Cost Simulator (Fight et al. 2006); gross product values are calculated as the product of modeled harvest quantities and local product prices; and a variety of treatments, developed in consultations with local foresters and fuels management experts, are simulated to assess treatment effectiveness and net and gross treatment costs (Fried et al. 2003, Fried and Christensen 2004). Candidate sites for building processing facilities can be simulated and evaluated with respect to economic feasibility (Fried et al. 2005), or the framework can be extended via mixed-integer optimization to jointly select the best treatment for each acre and the best places to site bioenergy capacity (Daugherty and Fried 2007).
	Econometric Model	Building on the crop map and the return-on-investment calculator, SACOG worked with an agricultural economist to build an econometric model—software that combines economic theories with data to test how growing decisions and cropping patterns would change under different conditions. The model can then predict how much land would become fallow (unused) in a variety of land use scenarios. The econometric model is linked back into the I-PLACE3S software to depict scenarios on a map." (RUCS 2011). This model was added in response to stakeholder input.
Wood Products, Carbon, and Life Cycle Analysis (LCA) Estimates	Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)	The operational-scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) is a non-spatial, stand- and landscape-level modeling framework that simulates the dynamics of all forest carbon stocks required under the Kyoto Protocol (aboveground biomass, below ground biomass, litter, dead wood and soil organic carbon). It complies with the carbon estimation methods outlined in the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance For Land Use, Land-Use Change and Forestry (2003) report.
	Carbon On-Line Estimator (COLE)	COLE is an online tool used to generate carbon estimates based on forest inventory data for any area of the continental United States chosen by the user. COLE currently produces results for areas of a county or larger, with the uncertainty of the estimates decreasing for larger areas. Reports can be produced which calculate carbon "growth and yield" curves for 1605b reporting, based on averages across the selected area. Estimates may also be produced corresponding to the format for the inventory of US greenhouse gas emissions and sinks, and can be useful for the carbon criterion in the Montreal Process criteria and indicators for sustainability.

Type of Modeling or Assessment	Model or Assessment Name	Model Description
	FORCARB2: An updated version of the U.S. Forest Carbon Budget Model	Dynamic Recursive model solution technique; Partial market equilibrium model. FORCARB2, an updated version of the U.S. FORest CARBon Budget Model (FORCARB), produces estimates of carbon stocks and stock changes for forest ecosystems and forest products at 5-year intervals. FORCARB2 includes a new methodology for carbon in harvested wood products, updated initial inventory data, a revised algorithm for dead wood, and now includes public forest land, reserved forest land, and forest land of low productivity. The program is written in FORTRAN and is text based, though virtually every parameter is defined by input text-based files that can be modified or built by the user. We expect users who are fairly advanced in terms of knowledge about computers will be most capable in using this model.
	U.S. Forest Carbon Calculation Tool (CCT)	The Carbon Calculation Tool 4.0, CCTv40.exe, is a computer application that reads publicly available forest inventory data collected by the U.S. Forest Service's Forest Inventory and Analysis Program (FIA) and generates state-level annualized estimates of carbon stocks on forest land based on FORCARB2 estimators. Estimates can be recalculated as new inventory data become available. The input set of FIA data files available on the Internet (as well as some older inventory files used to fill in gaps) are summarized by the application, converted to carbon stocks, and saved as part of a state or substate level "survey summary" file. This is used to produce state-level and national tables with annualized carbon stocks and flux (or net stock change) beginning with the year 1990. This user's guide includes instructions for use, example data sets, and a discussion of methods and assumptions.
	USFS Harvested Wood Products Modeling Application	This web-based carbon accounting tool calculates carbon stocks and emissions through time for harvested wood products (HWP) that were cut in the past according to the carbon accounting guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). For most users, estimates are based on the three key datasets: harvest data, timber products ratios and primary products ratios. These datasets are used as inputs to estimate the carbon stored in harvested wood products (HWP) originating from any specific, clearly delineated geographic region. Advanced users have the option of including two additional datasets that further refine the variables that influence carbon storage in HWP. With the help of this tool, any user can easily estimate the amount of carbon stored in HWP from any forest or other geographic region by completing the following steps.
	U.S. Forest Products Module (USFPM)	The U.S. Forest Products Module (USFPM) is a partial market equilibrium model of the U.S. forest sector that operates within the Global Forest Products Model (GFPM) to provide long-range timber market projections in relation to global economic scenarios. USFPM was designed specifically for the 2010 RPA forest assessment, but it is being used also in other applications.
	WOODCARB2	Microsoft Excel based model using extensions of methods suggested by the IPCC

Type of Modeling or Assessment	Model or Assessment Name	Model Description
	FORSEE	FORest and Stand Evaluation Environment. FORSEE is an umbrella model that includes the two models CRYPTOS and CACTOS that are described in this table elsewhere.
	FPS	FPS Version 7.06 provides the full range of tools for managing a working forest using a forest stand-based relational database actively linked to a forest-wide GIS mapping system. These tools include cruise compilation, valuation, growth projections and long-term planning under optional silvicultural influences from planting, ingrowth, site preparation, thinning, pruning, fertilization and genetics.
	CAL FIRE THP Greenhouse Gas Emissions Calculator	Excel spreadsheet based model allowing for Timber Harvest Product C tracing. The GHG Calculator spreadsheet is a tool intended for use in assessing the short-term and long-term greenhouse gas sequestration and emissions resulting from timber harvest activities.
	UC Carbon Sequestration Tool for THPs	The estimated quantity of carbon sequestration is determined from the estimated growth of trees onsite and from carbon stored in wood products and landfills. The calculation of carbon dioxide emissions include harvested wood that does not end up in wood products or landfills, plus non-biological emissions associated with site preparation, timber falling, yarding, loading, trucking and milling.
	GORCAM (Graz/Oak Ridge Carbon Accounting Model)	Excel spreadsheet; Detailed input variation possible across forest growth assumptions, harvest logistics processing and product fate
Life Cycle Assessment/ Analysis Software Tools	SimaPro	An off-the-shelf software tool/LCA model used to collect, analyze and monitor the sustainability performance of products and services. The software allows you to model and analyze life cycles systematically, measure the environmental impact of products and services across all life cycle stages and identify the hotspots in all aspects of the supply chain, from extraction of raw materials to manufacturing, distribution, use, and disposal.
	GaBi	GaBi is an off-the-shelf software tool that allows you to model every element of a product or system from a life cycle perspective. It also provides an up-to-date content database that details the costs, energy and environmental impact of sourcing and refining every raw material or processed component of a manufactured item. In addition, it looks at the impact on the environment presenting alternative options for manufacturing, distribution, recyclability, pollution and sustainability.

APPENDIX B: DATASET INVENTORY FOR FOREST CARBON LIFE CYCLE ASSESSEMENT

Existing Datasets

Appendix A describes models and to some extend datasets available which may be utilized in a LCA of the California Forest Practice Law and Regulations. There is an abundance of data available, much of it at no cost, but its utility of any data used for this specific assessment may be limited by the data's scale, age, quality and extent.

This appendix identifies the best existing data, which may be utilized to develop an approach to Life Cycle Analysis of the California Forest Practice Law and Regulations.

A life cycle assessment (LCA) on the fate of forest associated carbon will require a variety of data covering different phases of the LCA system. There are four phases in an LCA study (ISO 14040 and 14044, 2006):

a) **The goal and scope definition phase**. The scope, including system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.
b) **The inventory analysis phase**. The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.
c) **The impact assessment phase**. The purpose of LCA impact assessment phase (LCIA) is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.
d) **The interpretation phase**. In this phase, significant issues based on the results of the LCI and LCIA phases of LCA are identified. In this phase a practitioner draws conclusions and evaluates whether the evaluation is complete, rules have been consistently applied, data are of sufficient quality to support conclusions and documents recommendation and limitations of the evaluation.

The datasets required depend on the goal and scope of the LCA as well as the depth of the inventory and impact phase. While some datasets provide more certainty then others, their application might require trade-offs in terms of overall effort or be limited to a few required LCA components. Table 12 provides an overview of potentially applicable datasets and the system components. Table 13 provides more in-depth description for each dataset.

Table 12: Dataset overview and system components covered by each dataset. Covered system components are shaded in grey.

Dataset Name	Forest Carbon Life Cycle Assessment Components										
	Climate	Vegetation	Soil			Fire	Forest Operations	Product Processing	Product fate	Product Substitution	Leakage
		Above Ground & Roots	0 - 20cm	20 - 40cm	Mineral Soil						
Weather station data											
Historical Gridded Weather Data											
Historical data processed and interpolated from PRISM											
Downscaled climate projections from Scripps Institute											
Climate-FVS datasets											
California Forest Project Protocol											
FIA (incl. FIDO, COLE , FORCARB2)											
FRAP											
Landfire											
ARB carbon inventory data											
Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) Datasets											
Woods Hole Research Center Datasets											
Forest Service spatial and attribute data for National Forests											
Lookup tables Smith et al 2006; 1605(b)											
SSURGO											

Dataset Name	Forest Carbon Life Cycle Assessment Components										
	Climate	Vegetation	Soil			Fire	Forest Operations	Product Processing	Product fate	Product Substitution	Leakage
		Above Ground & Roots	0 - 20cm	20 - 40cm	Mineral Soil						
STATSGO2											
BOE harvest data											
Third party timber data on production and exports											
TPO (Timber Products Output Database)											
Christensen et al. 2008 USFS PNW-GTR-763											
CAL FIRE Timber Harvesting Plan GIS and Database											
USFS Harvested Wood Products Modeling Application											
Consortium for Research on Renewable Industrial Materials (CORRIM)											
CAL FIRE THP Greenhouse Gas Emissions Calculator											
UC Carbon Sequestration Tool for THPs											
NREL Life Cycle Inventory Database											
Morgan et al 2012 USFS PNW-GTR-866											
Local datasets formatted to FVS tree list format											
Natural Resource Conservation Service - Soil Maps											
US Forest Service Activity Tracking System (FACTS)											
Allometric equations from Jenkins et al. 2003)											
Existing Timber Harvest Plans (THP's), Sustained Yield Plans (SYP), Habitat Conservation Plans HCP), and Non-Industrial Timber Management Plans (NTMP)											
EIO-LCA dataset (Carnegie Mellon University)											
York et al. 2012											

Dataset Name	Forest Carbon Life Cycle Assessment Components										
	Climate	Vegetation	Soil			Fire	Forest Operations	Product Processing	Product fate	Product Substitution	Leakage
		Above Ground & Roots	0 - 20cm	20 - 40cm	Mineral Soil						
Bird 2013											
EcoInvent 3 (also included in SimaPro and GaBi LCA software)											
Sedjo and Sohngen 2012											

Table 13: Summary description, spatial scale and source of existing datasets that should be considered for use in a life cycle analysis on the fate of forest-related carbon.

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Weather Station Data	Landscape	Climate Data Online (CDO) provides free access to National Climate Data Center's (NCDC) archive of global historical weather and climate data in addition to station history information. These data include quality controlled daily, monthly, seasonal, and yearly measurements of temperature, precipitation, wind, and degree days as well as radar data and 30-year climate. Historical Remote Access Weather Station (RAWS) can be downloaded from http://www.wrcc.dri.edu/ and http://www.wrcc.dri.edu/fpa/.	http://www.ncdc.noaa.gov/cdo-web/
Historical Gridded Weather Data	Landscape	This product fills in gaps in RAWS coverage and is useful for weather analysis with FireFamily Plus at locations where there are no acceptable RAWS.	http://www.wrcc.dri.edu/fpa/
Historical data processed and interpolated from PRISM	Landscape	The PRISM Climate Group works on a range of projects, some of which support the development of spatial climate datasets. The resulting array of datasets reflects the range of project goals, requiring differing station networks, modeling techniques, and spatial and temporal resolutions. Whenever possible, PRISM offers these datasets to the public, either free of charge, or for a fee, depending on the size and difficulty of delivering the dataset and funding for the activity. In order for users to make informed decisions about which dataset is most appropriate for their needs, this document provides information on the PRISM spatial climate datasets currently available.	http://www.prism.oregonstate.edu/
Downscaled climate projections from Scripps Institute	Landscape	This data archive contains fine spatial resolution translations of climate projections over the contiguous United States (U.S.) developed using two downscaling techniques (monthly BCSD and daily BCCA), CMIP3 hydrologic projections over the western U.S. (roughly the western U.S.), and CMIP5 hydrology projections over the contiguous U.S. corresponding to monthly BCSD climate projections.	http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/
Climate-FVS datasets	Stand	Site and species specific climate change parameters adjusted by coordinates for direct input into CLIMATE-FVS	http://forest.moscowfsl.wsu.edu/climate/customData/fvs_data.php
California Forest Project Protocol	Stand	The Assessment Area Data File contains common practice carbon stock estimates for the Forest Inventory and Analysis (FIA) Assessment Areas areas across the United States, mill efficiency data (from 2010) for harvested wood products and FIA supersection maps of the U.S. forest regions.	http://www.climateactionreserve.org/how/protocols/forest/assessment-area-data/

Dataset Name	Spatial Scale	Description of Dataset	Source Website
FIA (incl. FIDO, COLE , FORCARB2)	Sub-state	Build on FIA data, COLE is an online tool used to generate carbon estimates based on forest inventory data for any area of the continental United States chosen by the user. COLE currently produces results for areas of a county or larger, with the uncertainty of the estimates decreasing for larger areas. Reports can be produced which calculate carbon "growth and yield" curves for 1605b reporting, based on averages across the selected area. Estimates may also be produced corresponding to the format for the inventory of US greenhouse gas emissions and sinks, and can be useful for the carbon criterion in the Montreal Process criteria and indicators for sustainability.	http://www.fia.fs.fed.us/

Dataset Name	Spatial Scale	Description of Dataset	Source Website
FRAP		**Extensive GIS dataset on CAL FIRE Administrative Boundaries** (Statewide GIS layer of CDF Unit and Region boundaries (1:100,000 scale) (v13_1)); **CAL FIRE State Responsibility Area (SRA)** (Statewide GIS layer of fire protection responsibility, includes State, Federal and Local Responsibility Areas. Latest release represents our initial determination of 7/1/2014 SRA status); **California's Forests and Rangelands: 2010 Assessment Data** (A complete repository of all the data used in the 2010 Assessment analyses); **Direct Protection Areas for Wildland Fire Protection (DPA)** (Statewide GIS layer showing wildland fire protection areas by state, federal, and local agencies, established by mutual consent); **Facilities** (CALFIRE and Schedule A Contract facilities for fire suppression. Includes fire stations, air attack and helitak bases, conservation camps and support facilities. Version 11_3); **Fire Hazard Severity Zones in SRA** (ADOPTED in 2007) (Statewide GIS layer and maps of ADOPTED Fire Hazard Severity Zones); **Fire Hazard Severity Zones** RECOMMENDED, 5-2008, (county GIS layers of Very High Fire Hazard Severity Zones in Local Responsibility Areas (LRA)) ; **Fire Threat** (Statewide GIS layer (GRID format) of fire threat, which combines expected fire frequency with potential fire behavior to create 4 threat classes (v05_1)); **Fire Perimeters** Statewide geodatabase with wildfire history, prescribed burns, and other fuel modification projects current through 2013); **California Fire Hazard Reduction Projects** (This File Geodatabase contains Project and Treatment polygon feature classes and an Activities table describing a subset of fire hazard reduction treatments conducted by CAL FIRE); **Incorporated California Cities** (A full accounting of incorporated California cities, including the boundary and name of each individual city. Latest version represents city boundaries as of 6/18/2014); **FVEG** (Raster representation of statewide vegetation with WHR types, Anderson classification, and WUI densities); **CalVeg** (GIS layer of vegetation (CALVEG and WHR) from 1997 to the present. Tiled by region); CalWater 2.2.1 (This dataset contains hydrologic regions, huc 8 watershed boundaries, and planning unit watershed boundaries for the state of California); **California Tree Seed Zones** (This dataset contains hydrologic regions, huc 8 watershed boundaries, and planning unit watershed boundaries for the state of California)	http://frap.fire.ca.gov/

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Landfire	Landscape	Products include more than twenty 30-meter raster spatial layers of vegetation structure and composition, fire behavior, fire effects, fire regimes and dynamic vegetation models for all major ecosystems in the United States.	http://www.landfire.gov/datatool.php
ARB Carbon Inventory Data	Landscape	The California greenhouse gas (GHG) emissions inventory compiles statewide anthropogenic GHG emissions and sinks. It includes estimates for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), nitrogen trifluoride (NF_3), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). The current inventory covers years 2000 to 2012.	http://www.arb.ca.gov/cc/inventory/data/data.htm
Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) Datasets	Landscape to State	Datasets from LEMMA include on-going efforts to map forest carbon and vegetation structure in the Pacific Northwest and California. These datasets are available for public download as they are completed.	http://lemma.forestry.oregonstate.edu/projects
Woods Hole Research Center Datasets	Landscape to State	The Woods Hole Research Center have produced a high-resolution "National Biomass and Carbon Dataset for the year 2000". The data includes a high-resolution (30 m), year-2000 baseline estimate of basal area-weighted canopy height, aboveground live dry biomass, and standing carbon stock for the conterminous United States.	http://www.whrc.org/mapping/nbcd/
Forest Service spatial and attribute data for National Forests	Forest to Landscape	Variable by National Forest. Includes data on 1) forest planning and monitoring for northwest California, Sierra Nevada, and southern California land and resource management plans and the Quincy Library Group GIS data sets, 2) Forest datasets such as transportation and land suitability class data,3) Regional level datasets such as Forest Activities (FACTS), vegetation burn severity, allotments and other Regional extent data, and 4) existing vegetation, fire history, fire return interval departure, direct protection areas, and other California extent data sets.	http://www.fs.usda.gov/main/r5/landmanagement/gis

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Lookup tables Smith et al. 2006; 1605(b)	Stand	Forest ecosystem carbon yield tables, representing stand level merchantable volume and carbon pools as a function of stand age, were developed for 51 forest types within 10 regions of the United States. Separate tables were developed for afforestation and reforestation. Because carbon continues to be sequestered in harvested wood, approaches to calculate carbon sequestered in harvested wood products are included. The estimates and methods in this report are consistent with guidelines being updated for the U.S. Voluntary Reporting of Greenhouse Gases Program and with guidelines developed by the Intergovernmental Panel on Climate Change. Lookup tables may need to be revised to better reflect wood utilization characteristics in California.	http://www.treesearch.fs.fed.us/pubs/22954
SSURGO	Stand	SSURGO database contains information about soil as collected by the National Cooperative Soil Survey over the course of a century. The information can be displayed in tables or as maps and is available for most areas in the United States and the Territories, Commonwealths, and Island Nations served by the USDA-NRCS. The information was gathered by reconnaissance soil surveys. Many soil samples were subject to laboratory analysis. The maps outline areas called map units. The map units describe soils and other components that have unique properties, interpretations, and productivity. The information was collected at scales ranging from 1:12,000 to 1:63,360. More details were gathered at a scale of 1:12,000 than at a scale of 1:63,360.	http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627
STATSGO2	Stand	Digital General Soil Map of the United States or STATSGO2 is a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped of 1:250,000 in the continental U.S., Hawaii, Puerto Rico, and the Virgin Islands and 1:1,000,000 in Alaska. The level of mapping is designed for broad planning and management uses covering state, regional, and multi-state areas. The U.S. General Soil Map is comprised of general soil association units and is maintained and distributed as a spatial and tabular dataset.	http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053629
BOE harvest data	Landscape	The Timber Yield Tax program sets the harvest value of timber and collects an in lieu tax when it is harvested. The revenue from this program is allocated to the counties where the timber was harvested.	http://www.boe.ca.gov/proptaxes/timbertax.htm

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Third party timber data on production and exports	Global	Campell Global LLC timber short- and long-term trends and forecasts. Wood Resources International LLC timber short- and long-term trends and forecasts	https://www.campbellglobal.com/; http://www.wri-ltd.com/
Timber Products Output Database (TPO)		FIA conducts Timber Products Output (TPO) studies to estimate industrial and non-industrial uses of roundwood in a state. To estimate industrial uses of roundwood, all primary wood-using mills in a state are canvassed. The questionnaires are designed to determine: location, size and types of mills in a state, and the volume of roundwood received by product species and geographic origin. Also determined is the volume, type and disposition of wood residues generated during primary processing. TPO studies report size and composition of primary wood products using industry-reported numbers. Information includes use of roundwood by product, by species and by geographic location. FIA conducts logging utilization studies to relate TPO to inventory volume. This is done by visiting a cross-section of logging operations in a state to characterize the sites logged, trees cut, products taken, and residues left behind.	http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php
Christensen et al. 2008, USFS PNW-GTR-763	Sub-state	This report highlights key findings from the most recent (2001–2005) data collected by the Forest Inventory and Analysis Program across all forest land in California. The report summarizes and interprets basic resource information such as forest area, ownership, volume, biomass, and carbon stocks; structure and function topics such as biodiversity, forest age, dead wood, and hardwood forests; disturbance topics such as insects and diseases, fire, invasive plants, and air pollution; and information about the forest products industry in California, including data on tree growth and mortality, removals for timber products, and non-timber forest products. The appendixes describe inventory methods in detail and provide summary tables of data, with statistical error, about the suite of forest characteristics inventoried.	http://www.fs.fed.us/pnw/publications/gtr763/

Dataset Name	Spatial Scale	Description of Dataset	Source Website
CAL FIRE Timber Harvesting Plan GIS and database		CAL FIRE's Forest Practice Geographical Information System (GIS) captures current and historic timber harvesting activities for over 4 million acres of California timberland. Silviculture, yarding, new road construction, watercourse classifications, and timberland conversions are tracked through the GIS. Once in the GIS, this information can be graphically represented on maps, can be brought into Google Earth, or used in your own GIS system. The GIS data is available for land-use planning, the analyses of cumulative impacts, and to meet the requirements of California's Forest Practice Rules.	http://www.calfire.ca.gov/resource_mgt/resource_mgt_forestpractice_gis.php
USFS Harvested Wood Products Modeling Application	Stand	This web-based carbon accounting tool calculates carbon stocks and emissions through time for harvested wood products (HWP) that were cut in the past according to the carbon accounting guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). For most users, estimates are based on the three key datasets: harvest data, timber products ratios and primary products ratios. These datasets are used as inputs to estimate the carbon stored in harvested wood products (HWP) originating from any specific, clearly delineated geographic region. Advanced users have the option of including two additional datasets that further refine the variables that influence carbon storage in HWP. With the help of this tool, any user can estimate the amount of carbon stored in HWP from any forest or other geographic region.	http://maps.gis.usu.edu/HWP/Home/About
Consortium for Research on Renewable Industrial Materials (CORRIM)	Stand	Information on renewable industrial materials focused on the environmental impact of the production, use, and disposal of wood and other bio-based materials. CORRIM provides a database to evaluate the environmental performance of wood and alternative materials from resource regeneration or extraction to end use and disposal.	http://www.corrim.org/index.asp
CAL FIRE THP Greenhouse Gas Emissions Calculator	Stand	Excel spreadsheet based model allowing for Timber Harvest Product C tracing. The GHG Calculator spreadsheet is a tool intended for use in assessing the short-term and long-term greenhouse gas sequestration and emissions resulting from timber harvest activities. The estimated quantity of carbon sequestration is determined from the estimated growth of trees onsite and from carbon stored in wood products and landfills. The calculation of carbon dioxide emissions include harvested wood that does not end up in wood products or landfills, plus non-biological emissions associated with site preparation, timber falling, yarding, loading, trucking and milling.	http://calfire.ca.gov/resource_mgt/downloads/THP_GreenhouseGasEmissions_Calculator_061110.xls

Dataset Name	Spatial Scale	Description of Dataset	Source Website
UC Carbon Sequestration Tool for THPs	Stand	Excel spreadsheet; detailed input variation possible across forest growth assumptions, harvest logistics processing and product fate.	http://ucanr.edu/sites/forestry/Carbon_Sequestration_Tool_for_THPs/
National Renewable Energy Laboratory (NREL) Life Cycle Inventory Database	Stand	NREL and its partners created the U.S. Life Cycle Inventory (LCI) Database to help life cycle assessment (LCA) practitioners answer questions about environmental impact. This database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S.	https://www.lcacommons.gov/nrel/search
Morgan et al. 2012, USFS PNW-GTR-866	Sub-state	Technical report 'California's Forest Products Industry and Timber Harvest, 2006' by Morgan et al. (2012), This report traces the flow of California's 2006 timber harvest through the primary wood products industry (i.e., firms that process timber into manufactured products such as lumber, as well as facilities such as pulp mills and particleboard plants, which use the wood fiber or mill residue directly from timber processors) and provides a description of the structure, condition, and economic impacts of California's forest products industry. Historical wood products industry changes are discussed, as well as trends in harvest, production, mill residue, and sales. Also examined are employment and worker earnings in the state's primary and secondary forest products industry.	http://www.fs.fed.us/pnw/pubs/pnw_gtr866.pdf
Local forest inventory datasets formatted to FVS tree list format	Stand	Several private companies maintain detailed stand level data for their ownerships. Utilization of this data where made available and appropriate may give better estimates of forest structure, including carbon balances, than broader scale data derived from FIA plots or other sources. N/A	N/A
Natural Resource Conservation Service Soil Maps	Stand	Basic information on soil carbon can be found in NRCS soils guides and potentially spatial datasets	http://casoilresource.lawr.ucdavis.edu/gmap/; http://sdmdataaccess.nrcs.usda.gov/
US Forest Service Activity Tracking System (FACTS)	State	Has all forest timber activities, including location data for past 20 years; data can likely be obtained further back from individual National Forests.	http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833; http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=stelprd3811519

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Allometric equations from Jenkins et al. (2003)	Tree	A database consisting of 2,640 equations compiled from the literature for predicting the biomass of trees and tree components from diameter measurements of species found in North America. Bibliographic information, geographic locations, diameter limits, diameter and biomass units, equation forms, statistical errors, and coefficients are provided for each equation.	http://www.nrs.fs.fed.us/pubs/6725
Existing Timber Harvest Plans (THP's), Sustained Yield Plans (SYP), Habitat Conservation Plans HCP), and Non-Industrial Timber Management Plans (NTMP)	Project or Portions of Ownership	Existing THP's, SYP's, HCP's, and NTMP's contain project and landowner level information regarding vegetation cover, structure, wildlife, and other key information used for short and long term planning. This information could potentially be incorporated into analysis at the local and regional level.	Various landowner and CALFIRE archives of past and current plans.
EIO-LCA dataset (Carnegie Mellon University)	State	The Economic Input-Output Life Cycle Assessment (EIO-LCA) method estimates the materials and energy resources required for, and the environmental emissions resulting from, activities in our economy. The website takes the EIO-LCA method and transforms it into a user-friendly on-line tool to quickly and easily evaluate a commodity or service, as well as its supply chain. The EIO-LCA models available on the site apply the EIO-LCA method to various national and state economies. Each model is comprised of national economic input-output models and publicly available resource use and emissions data.	http://www.eiolca.net/
York et al 2012	Stand	Paper describing the average pattern across most nations of the world over the past fifty years which is one where each unit of total national energy use from non-fossil-fuel sources displaced less than one-quarter of a unit of fossil-fuel energy use and, focusing specifically on electricity, each unit of electricity generated by non-fossil-fuel sources displaced less than one-tenth of a unit of fossil-fuel-generated electricity.	http://www.nature.com/nclimate/journal/v2/n6/abs/nclimate1451.html

Dataset Name	Spatial Scale	Description of Dataset	Source Website
Bird 2013	Stand	Paper describing that increasing bioenergy production may simply result in more energy being consumed. In this study, a method is developed for estimating the displacement fossil and other energy source by wood - based energy from historical consumption. This method is used to evaluate the effectiveness of bioenergy in displacing other sources of energy in Austria during the period 2000 to 2010. The same methodology is used to estimate the displacement of non - wood materials by wood - materials during the same period.	http://www.smartforests.at/linked/d.06_estimating_substitution_of_biomass_for_energy_and_materials.pdf
EcoInvent	Stand	Ecoinvent - an association founded by ETHZ, EPFL, PSI, Empa and Agroscope - is the world's leading supplier of consistent and transparent life cycle inventory (LCI) data of renown quality. Ecoinvent offers science-based, industrial, international life cycle assessment (LCA) and life cycle management (LCM) data and services. The Ecoinvent database is included in SimaPro and GaBI LCA software.	http://www.ecoinvent.ch/
Sedjo and Sohngen 2012	Stand	Paper describing how forest management and public policy can strongly influence the sequestration process. Economic policies can provide incentives for both forest expansion and contraction. Issues involve carbon additionality, permanence, and leakage. Various economic models are used to estimate the effects of various economic policies on forest carbon stocks. Estimates from the literature of some actual and potential levels of forest carbon are presented.	http://www.annualreviews.org/doi/abs/10.1146/annurev-resource-083110-115941
(NIDRIM)	Watershed	A nationwide strategic assessment and database of the potential hazard for tree mortality due to major forest insects and diseases. The goal of NIDRM is to summarize landscape-level patterns of potential insect and disease activity, consistent with the philosophy that science-based, transparent methods should be used to allocate pest-management resources across geographic regions and individual pest distributions. In other words: prioritize investment for areas where both hazard is significant and effective treatment can be efficiently implemented.	http://foresthealth.fs.usda.gov/nidrm/