Natural and Working Lands Carbon Inventory: Harvested Wood Products

Proposed 2025 Inventory Update Methods
January 2025

For more information, contact:
nwl@arb.ca.gov
Nature Based Strategies Section
Industrial Strategies Division
California Air Resources Board

Table of Contents

Background

The Intergovernmental Panel on Climate Change (IPCC) has created a defined Harvested Wood Products (HWP) pool for carbon inventory accounting which represents all wood and bark material that leaves harvest sites, regardless of whether it is eventually incorporated into merchandisable products (Pingoud et al. 2006). This category includes harvested boles that are incorporated into durable wood products such as furniture and building materials, forest and perennial crop woody residues used for advanced biofuels like hydrogen, biomethane, and sustainable aviation, woody biomass converted for energy production in processing facilities and power plants, carbon capture and storage technologies such as biochar and bio-oils, as well as decomposable wood in landfills or in California's Natural and Working Lands (NWL) outside of the original harvest sites (i.e., does not include wood left in-place to decompose or burn). Current and emerging technologies provide a wide array of HWP utilization pathways, with unique regional adoption and scalability across California. One aspect of HWPs, which differ depending on the products durability, is their ability to store carbon over long periods. On one hand, wood harvesting is the second-largest global contributor to the reduction of carbon stocks in NWL vegetation and soils (Marques et al. 2019). However, long-lived products, such as timber used in construction and furniture, can also store carbon for decades or even centuries. Conversely, short-lived products such as biofuels, electricity, and even paper, may release their stored carbon more quickly as they experience combustion or decomposition. Given that the NWL Carbon Inventory explicitly tracks carbon stocks, and not GHG emissions, other benefits associated with HWP utilization pathways (e.g. substitution effects for biofuel displacement of fossil fuels) will not be accounted for.

The HWP carbon stock represents a lateral transfer from and, therefore, reduction of the carbon stock from its original harvested land type (i.e. forests and woodlands, croplands, etc.). Whereas the total GHG impact of HWPs depends upon factors such as harvest management, transportation, processing energy, and the type of product manufactured, the carbon stock persistence of HWPs is more directly related to the specific product feedstock (i.e. characteristics of the wood) and the durability of its usefulness (Zeng et al. 2013). California's climate strategies aim to enhance the use of harvested wood products (HWP) as a component of the state's climate mitigation and forest management goals. By promoting sustainable harvesting practices, the strategy seeks to enhance carbon storage in long-lived wood products while reducing reliance on fossil-fuel-intensive materials. Many state initiatives are encouraging the development of durable products like mass timber, engineered wood products, and biochar, which store carbon and therefore may provide climate benefits. Simultaneously, others are looking toward HWPs to assist in the development of California's mixed renewable energy portfolio. These strategies aim to align with forest health and wildfire risk reduction efforts, by incentivizing the removal of excess biomass and its transformation into valuable HWPs, while also supporting the state's circular bioeconomy and contributing to California's broader goals of achieving carbon neutrality.

Climate change presents risks to forest health (e.g., fire, disease, and altered growing conditions), which could impact the availability of raw feedstock for HWP. The 2022 edition of CARB's Scoping Plan for Achieving Carbon Neutrality ("Scoping Plan") projects California's forest biomass carbon stocks to decline over the upcoming decades. Efforts throughout the state of California are expanding implementation acreage of adaptive forest management techniques, as well as focusing on how wood product industries can best utilize harvested materials to build community-scale economic development in tandem with social, environmental, and climate resilience goals. Ongoing research aims to understand the complexities of forest and fuel-load management, product life cycles, and the role of HWPs in a sustainable, low-carbon economy. Implementing carbon stock quantification methodologies, such as within this inventory, aim to contribute towards tracking these efforts.

State of the Science

Harvested Wood Product (HWP) carbon stock accounting has advanced significantly over the recent decade. Current models are primarily guided by Intergovernmental Panel on Climate Change (IPCC) guidelines, which outline three tiered approaches (Tiers 1-3) and emphasize either stock-based or flux-based conceptual frameworks (Pingoud et al. 2006). Models such as the U.S. Forest Service's Harvested Wood Product Carbon (HWP-C) model and Canada's National Forest Carbon Monitoring, Accounting, and Reporting System for Harvested Wood Products (NFCMARS-HWP) model adopt Tier 3 methodologies, integrating regionally-specific empirical data into deterministic modelling frameworks to estimate HWP carbon stocks within defined boundaries (Lucey et al. 2024). These models allow users to track the flow of carbon from forests and other harvested land types into various categories of wood products, accounting for how these products store or release carbon throughout their lifecycle.

The methodologies involve estimating carbon stocks and annual changes through simple calculations that consider timber and primary product ratios, conversion factors, and life cycle dynamics. They most often utilize national-scale data to allocate carbon among products and estimate stocks and/or emissions, with flexibility to model specific scenarios. These models rely on fixed rates and functions, which rely on national or regional averages for production efficiencies, product utilization ratios, and subsequent decay that most often do not reflect regional socioeconomic or climatic differences (Brandeis et al. 2021; Karanjekar et al. 2015). HWP models also tend to assume specific half-lives for different HWP categories, reflecting the longevity of each product, its lifespan before disposal, and its likelihood of being recycled. Ultimately, these factors determine the periodicity of carbon storage for these products before being released through decay or combustion. A key limitation of these fixed ratios and half-lives is their assumed similarity from year-to-year, based on historical studies that do not fully account for real-life variation in product use, disposal, or recycling practices. These HWP models also tend to assume relatively consistent carbon content across wood species types and do not dynamically adjust for changes in market trends, recycling practices, or technological advancements that could influence carbon storage over time (Singh et al. 2022; Zhao et al. 2022).

Primary Drivers of Change

The challenge of achieving California's wildfire, climate, and landscape resilience goals is intrinsically linked to the production of woody biomass (CARB, 2022). Sustainable sources of HWPs also fill social needs for housing, fuel, electricity, and other critical environmental and social services. Substantial volumes of wood products are generated from timber harvesting each year, with global harvest rates projected to increase 50-60% from 2010 to 2050 (Peng et al., 2023). However, over previous decades, geopolitical, social, environmental, and market-based drivers have decreased California's annual timber harvest, and the estimated carbon stock removal from these activities has declined relative to the previous decades (BBER, 2021). As such, and given the disposal and decay of HWPs across time, the carbon stock associated with California's domestically produced in-use HWP pool has been estimated to be in decline (Stockmann et al., 2014; Christensen et al., 2021). Simultaneously, reductions in timber harvest and a century of fire exclusion activity have contributed toward a buildup of dense vegetation and fuels throughout California's forests, increasing susceptibility to severe wildfires. As such, expanding volumes of less merchantable (i.e. smaller, lower quality, etc.) woody biomass are also being generated resulting from increasing acreage of fuel reduction management and forest resilience treatments across the state.

The primary drivers of change for HWPs include economic, environmental, policy, and technological factors that shape their production, usage, and carbon storage longevity (Zhao et al. 2022). Economic drivers such as timber supply, demand, and price fluctuations directly influence the volume and types of HWPs produced, while industry innovations and advancements in manufacturing create new product categories and impact efficiency of production and recycling processes. Environmental factors including climate change, forest health, and disturbances like wildfires and disease affect the availability of timber, the harvesting methods, and the subsequent quality and characteristics of harvested woody feedstocks. Policy and regulatory influences, such climate change mitigation and adaptation strategies, as well consumer-driven demand may drive the adoption of HWPs as substitutes for carbon-intensive materials and promote sustainable forest management.

A subset of domestically produced California HWPs is exported, and therefore leave CARB's NWL Inventory boundary. California is also estimated to import a large plurality of its currently in-use wood products (Evans et al. 2023). Therefore, national and international trade may drive substantial shifts in California's HWP carbon pool. As will be discussed later, IPCC accounting approaches may differ in their system boundaries, with some inventorying changes in the HWP pool based on where the products are produced and others where the products are consumed (i.e. accounting for imports and exports).

Nature-Based Solutions Targets

While the AB 1757 NBS Targets do not explicitly describe goals for HWP utilization, several targets within Agriculture, Forestry and Other Land Uses (AFOLU) have impacts on HWP carbon stocks. The Wildfire Risk Reduction target calls for ramping up acreage, up to 1 million per year by 2045, of fuel reduction activities such as thinning, mechanical treatments, and uneven-aged timber harvesting in forests, shrublands and chaparral, and grasslands across the state. CARB's 2022 Scoping Plan estimates that this may generate up to 5.6 million BDT of mobilizable forest residues per year, of which 3.1 million BDT is estimated as socially beneficial to mobilize across statewide HWP utilization pathways. Other land-type specific targets may also impact HWP supply and utilization.

2018 NWL Carbon Inventory Methods

Methods Description

The utilization pathways for HWPs intersect AFOLU, Energy, and Waste Sectors, and thus appears in both the NWL Inventory and annual statewide GHG inventory. Boundaries between these inventories must be clear and, to avoid double counting of emissions, the IPCC Inventory Guidelines instruct for reporting some emission categories for informational purposes only. For instance, CO2 emissions associated with combustion of forest residues during power generation in a processing facility may be reported as an informational item in the GHG inventory, but the carbon stock loss is accounted for in the NWL Inventory, whereas the CH4 and N2O emissions from combusting HWP are accounted for in the GHG inventory. Further, the CO2 release associated with decomposition of HWP discarded in solid waste disposal sites (SWDS) are reported as informational items in the GHG inventory, while the carbon stock change is accounted for in the NWL Inventory.

Previous efforts have been made to generate and report estimates of California's HWP carbon stocks and changes. Most notably, as directed by AB 1504, the California Department of Forestry and Fire Protection (CAL FIRE) initiated a collaboration with the U.S. Forest Service (USFS) Pacific Northwest Research Station (PNW) Forest Inventory and Analysis (FIA) program (Christensen et al., 2021). While the 2018 edition of the Natural and Workings Lands Carbon Inventory outlined the need for articulating and estimating HWP utilization across the state, no carbon stock estimates were included as data and tools were not available at the time of CARB's 2018 NWL Carbon Inventory development. However, a description of the stratification of HWP emissions and carbon stocks between CARB's various inventories were provided. Section 2B.2 states that:

> *"The removal of carbon from land associated with HWP is accounted in the NWL Inventory through quantification of carbon stock change, and the annual statewide GHG inventory also includes this carbon as CO2 as an informational item if it enters the atmosphere through human-made equipment, vehicles, structures, and products. Its treatment as an informational item in the annual statewide GHG inventory avoids double-counting of carbon that leaves the land base, which is already accounted for as a carbon loss in the NWL Inventory."*

While no carbon stock estimate was provided in the 2018 NWL Carbon Inventory, the "Future Inventory Improvements" section of this inventory highlighted the need for an improved estimate of HWP carbon stocks using more updated mill survey and industry data, which provided the foundation for new method development in upcoming inventory versions.

Benefits and Limitations

The omission of HWP estimates in the previous NWL inventory results in underreporting of California's total statewide biomass carbon stock. Estimates from CAL FIRE's AB 1504 reporting suggest that HWPs domestically produced within California between 2001-2019, including those both currently in-use and disposed in SWDS, may contribute upwards of 2-3% of the state's total carbon stock (Christensen et al., 2021). The AB 1504 reporting is based on the IPCC Production Approach, which is a "producing entity-based approach" that accounts only for domestically produced HWPs and excludes all imports and exports of HWP across boundaries. The total estimated statewide HWP carbon stock would be expected to increase with the inclusion of import and export accounting, as described within the IPCC Stock-Change Approach.

A notable limitation of the Production Approach, given the difficulty in tracking the fate of exported goods, is that this approach assumes the same behavior for raw timber and other HWP exports as those that remain for domestic consumption, applying the same product ratios, decay rates, and other parameters. While this aligns with the Production Approach's emphasis on tracking carbon stocks and emissions associated with HWPs produced from wood harvested within California, regardless of whether the products are consumed locally or abroad, this introduces an additional source of error given variability in climate, utilization, and disposal pathways across differing climate and socioeconomic contexts. This approach also underestimates the total carbon stock of all HWPs within California's borders, mostly due to the substantial contribution of wood product imports to California's total HWP pool. Additionally, the exclusion of imports limits the use of downstream accounting tools associated with recycling and upcycling of retired HWP (e.g. landfill surveys), where determination of a product's harvest origin is not possible.

2025 NWL Carbon Inventory Update Proposed Methods

Methods Description

For the 2025 NWL Carbon Inventory Update, the carbon stock accounting and reporting approach will follow a Tier 3 Stock-Change Approach (Figure 1), using methods outlined under IPCC Guidelines for National Greenhouse Gas Inventories. This method relies on tracking input and output flows using a mixture of detailed jurisdiction harvest, utilization, and discard data alongside process-based decay assumptions. A brief description of this method from IPCC is described below:

> *"Use detailed country data beginning with a number of decades in the past and estimate each year, up to the present time, including (i) additions to pools of HWP in use, (ii) discards from use, (iii) additions to pools of HWP in SWDS, and (iv) decay from SWDS. Estimates for SWDS may use survey estimates of the amount of HWP placed in SWDS*

each year, rather than the amount of HWP going out of use and the portion going to SWDS. This method is also based on flux data and lifetime analysis just as for Tier 1 and Tier 2 methods, but the rate at which products are discarded from use may differ from the first-order decay assumption used in Tiers 1 and 2."

Carbon stock accounting for the HWP pool in the NWL Carbon Inventory includes lumber, paper and pulp, durable timber products such furniture and building materials, as well as decomposable wood in landfills and throughout California's NWLs outside of the original harvest site. It does not include compost, woody mulches, and other woody biomass converted for energy production in processing facilities and power plants. It also does not include forest and perennial crop woody residues used for advanced biofuels like hydrogen, biomethane, and sustainable aviation fuel. While some of these utilization pathways may be included in forthcoming inventory efforts, in conjunction with SB 905, these use pathways are considered to render 100% emissive in terms of the HWP carbon accounting for this inventory. However, carbon stocks within compost, mulch, and biochar applications are expected to be accounted for within the NWL ecosystem carbon stocks portion of this inventory, accounted for as a management practice as they are applied to the landscape.

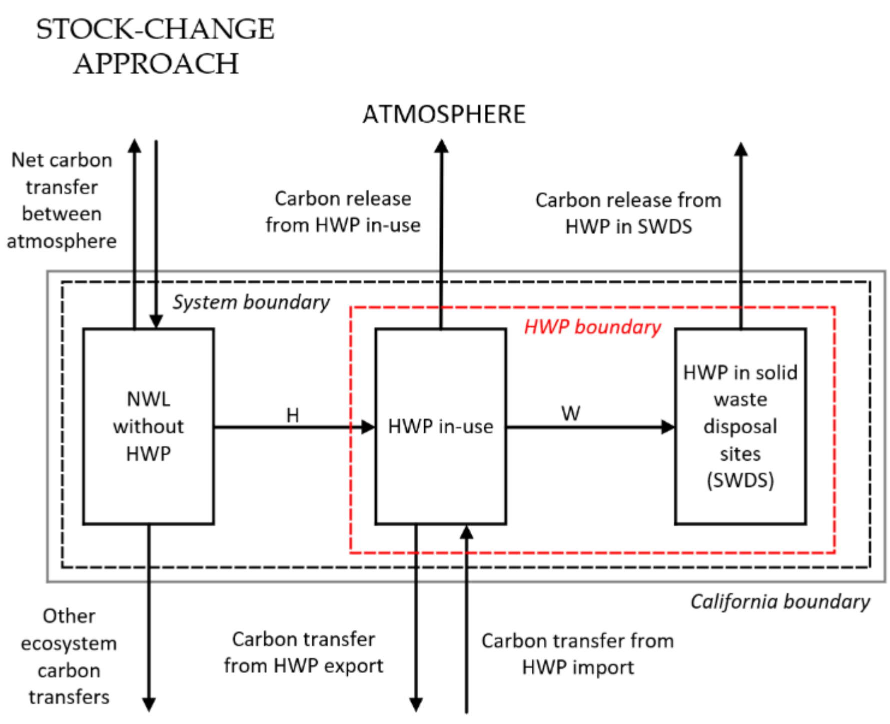

Figure 1: System boundary of the Stock-Change approach (adapted from IPCC Guidelines for National GHG Inventories, 2006)

The goal of this inventory is to track annual changes in carbon stock of HWP within California, including HWP stocks from both domestic harvest and imports, but excluding exports. Exports will be reported as an informational item for tracking purposes. This Tier 3 approach will rely on both empirical datasets (harvest data, mill surveys, trade data, etc.) and modelling-based approaches (input-output (I/O), computable general equilibrium (CGE), etc.) to directly estimate HWP carbon stocks flux between in-use and SWDS pools, as well as stock flows imported and exported across California's borders. Input datasets for this model are wide ranging and varied from economic data and harvest volumes to discard quantities and decay functions (Table 1). The cumulative stock accounting period for HWPs will begin in 1952, which represents to oldest available datasets for California. The IPCC Stock-Change approach calculates annual HWP carbon stocks using the formula shown below (Equation 1).

Equation 1: Formula for calculating annual HWP carbon stocks using IPCC Stock-Change Approach

$$A)\ C(i+1) = C(i) + C_{DH} + P_{IM} - P_{EX} - \uparrow C_{HWP\ DC} \qquad with\ C(0) = 1952$$

$$B)\ \Delta C(i) = C(i+1) - C(i)$$

Where:

i = year

$C(i)$ = the carbon stock of the HWP pool in the beginning of year i, MMT C

$\Delta C(i)$ = carbon stock change of the HWP pool during year i, MMT C yr^{-1}

C_{DH} = *Harvest of wood to be used for HWP*

P_{IM} = *carbon transfer in the form of imported wood-based biomass*

P_{EX} = *carbon transfer in the form of exported wood-based biomass*

$\uparrow C_{HWP\ DC} = E_{IU} + E_{SWDS}$

E_{IU} = *carbon release to the atmosphere from HWP in-use*

E_{SWDS} = *carbon release to the atmosphere from HWP in SWDS. (Note that here the carbon release is not considered as a sum of C-stock changes as in the Stock-Change and Production approaches. HWP in-use include all harvested wood products consumed in the reporting country and HWP in SWDS include all wood-based waste disposed into the solid waste disposal sites (including both open dumps and landfill sites) of the reporting country).*

The HWP carbon stock atmospheric release (i.e., efflux; $\uparrow C_{HWP\ DC}$) from the in-use and SWDS pools will be calculated using the Harvested Wood Products Carbon (HWP-C) model (Stockmann et al, 2014). The HWP-C model is a long-term accounting tool for estimating cumulative carbon emissions and storage from harvested wood products. The model relies on user-supplied domestic harvest, import, and export information and can use optional stock-change factors or additional user-supplied data for HWP utilization parameters, disposal rates and pathways, and decay processes. Given changes in disposal methods and lifetime use of wood products, users can examine what proportion of harvested wood products remain in use, in disposal sites, or as carbon emitted to the atmosphere. A web-based tool, HWP-C v.R 1.1.0 was previously adapted specifically for California's carbon accounting context, through a partnership between CAL FIRE, U.S. Forest Service, Oregon Department of Forestry (ODF), University of Montana, and Groom Analytics.

The HWP-C model relies on numerous fixed assumptions and underlying processes. As previously implemented, the sole input variable is the annual raw timber harvest. Otherwise, the model assumes specific ratios for the formation of timber products (such as sawlogs and pulpwood) and their conversions into primary products (such as lumber, plywood, and wood panels) and final end-uses such as furniture, building materials, and paper products. Additionally, the model relies on fixed decay rates for products in landfills and uses national or regional averages for production efficiencies and wood utilization rates, which may not reflect local differences. The model also assumes specific half-lives for different HWP categories, reflecting the longevity of each product, its lifespan before disposal, and its likelihood of being recycled. Ultimately, this determines the time carbon remains stored in these products before being released through landfill decay or combustion.

The accuracy of allocating HWPs into these various category distinctions and across different stages of wood product processing and use is critically important for tracking carbon stocks. CARB aims to enhance the accuracy of the HWP-C model by integrating empirical data to replace some of these existing assumptions. By incorporating detailed production data for primary and end-use products, the model can better reflect actual market outputs, improving the precision of carbon storage estimates. Additionally, more accurate data on product recovery, including recycling rates, will enable the model to account for the extended lifecycle of wood products and reduce carbon emissions associated with disposal. Incorporating refined disposal rate information, such as the proportions of products sent to landfills or allocated to energy generation and composting facilities, will allow the model to more precisely estimate carbon fluxes from these processes. These updates will displace generic assumptions about product ratios, half-lives, and waste management practices, making the model more representative of real-world conditions and bolstering the utility of the NWL inventory for policy and climate mitigation analyses.

To further improve the accuracy of the HWP-C model, CARB will be reviewing and updating the remaining fixed variable assumptions. Conversion factors, which translate timber volumes into carbon content, need to be re-evaluated to reflect current wood densities and species-specific variations (especially differences between hard and soft woods). Similarly, pulpwood and wood product loss ratios, which estimate material lost during processing and manufacturing, should be updated using recent data from mills and production facilities to capture technological advancements and efficiency improvements. The bulk of this work relates to improving decay half-lives, which, again, dictate the rate at which carbon is released from products after disposal. These must be reassessed with empirical studies that account for evolving changes in product durability, landfill practices, and regionally-specific climate conditions. Further, the HWP-C model currently assumes all landfill carbon loss occurs through first-order decay functions, whereas the reality is that decay occurs during multiple distinct phases (such as aerobic, anaerobic, and methanogenic stages) – each with differing and specific decay rates.

Benefits and Limitations

The USFS HWP-C model uses the IPCC production approach and the HWP-C v.R 1.1.0 web tool developed for use in the annual state-level inventory applies both the IPCC production approach and the simple-decay approach. Under both approaches, HWPs exported from the area of analysis are included but imported HWPs are excluded and, therefore, it measures only the domestic production (DP) of HWPs. The NWL Carbon Inventory, on the other hand, implements the IPCC Stock-Change Approach and quantifies carbon stocks from both DP and domestic consumption (DC). There are several notable benefits from taking this approach. First, at a state level, carbon stocks in and emissions from HWP consumed within the state boundaries are expected to be substantially greater than that from only timber harvested within the state. Additionally, carbon accounting that relies on DP data alone (i.e. does not allow inclusion of imports) does not allow integration of disposal and recycling survey data, since the HWP origin in those datasets are not specified. Lastly, inclusion of DC data allows for additional verification between datasets (e.g. mill surveys, economic census and trade data, etc.). While the Stock-Change approach omits exports from the official reported inventory values, this methodology nevertheless requires estimating carbon stocks from exports and, therefore, still facilitates the inclusion of this value as an informational item within the NWL Carbon Inventory.

DP estimates for California date back to the early 1950's, with the initial reporting date for the spatially-explicit and descriptive DP survey datasets, the Timber Product Output (TPO) reports, beginning in 1952. While this supports the NWL Carbon Inventory reporting period, which begins in 2001, it practically limits the capacity of the inventory to accurately quantify the cumulative pool of HWP carbon remaining from harvesting and processing predating this 1952-2024 period. While some industry and government databases may assist in estimating HWP production and the subsequent cumulative carbon pools existing before the reporting period, these databases are limited. Further, no currently identified datasets support accurate estimates for HWP import and export before 2001, which is likely to result in an underestimation of HWP carbon stocks prior to this reporting period. Another data limitation is the reporting frequency for much of the survey data (Table 1). A computable general equilibrium (CGE) framework (Babatunde et al., 2017) integrated with input-out (I/O) modelling will be conducted using REMI, to be utilized as validation and imputation data.

Input and Validation Datasets

Table 1: Empirical and modeling datasets with reporting frequency.

Input Dataset(s)	Category	Reporting Frequency*
United States Forest Service (USFS) Timber Product Output (TPO) reports	Domestic Production	1-5 years
California Department of Trade and Fee Administration (CDTFA) Timber Yield Tax reports	Domestic Production	To Be Determined
United States Census Bureau (USCB) Commodity Flow Survey (CFS) reports	National Trade (Import/Export)	5 years
United States International Trade Commission (US-ITC) Trade Data reports	International Trade (Import/Export)	Annual
Regional Economic Models, Inc (REMI)	International Trade (Import/Export) National Trade (Import/Export) Domestic Consumption	Annual (Input-Output Modelling)
California Department of Resources Recycling and Recovery (CalRecycle) SWIS database	Solid Waste Disposal	Annual
California Department of Resources Recycling and Recovery (CalRecycle) SB 1383 reports	Recycling	Under Development
Western Wood Products Association (WWPA) Western Lumber Statistics reports	Domestic Production National Trade (Import/Export)	<1 year
Annual Survey of Manufacturers (ASM)	Domestic Production	Annual
American Panel Association (APA) reports	Domestic Production	<1 year

* Reporting frequency may differ depending on variable of interest

Alternative Method for 2025 Update

If necessary, an alternative method will implement the IPCC Tier 1 Approach using globally or nationally averaged data parameters for product categories, decay rates, and carbon content. This method will estimate carbon stocks using predefined half-lives for HWP categories, which assume consistent values for wood utilization and decay processes over time. This avoids the need for both regionally specific data and detailed modeling while still facilitating transparency, reproducibility, and alignment with international standards, as previously noted within this document.

Criteria Assessment

All decisions regarding proposed updates to the NWL Carbon Inventory were made in relation to standardized criteria set forth by CARB (Table 2). These criteria help to ensure that the methods and data CARB uses are appropriate to meet the goals of the NWL Carbon Inventory, are as rigorous and comprehensive as possible, and are reproducible for others.

Table 2: Criteria used to assess methodological updates for the 2025 NWL Carbon Inventory.

Category	**Criteria Assessment**
Spatial scale • Have accuracy optimized to statewide scales while also providing sufficient accuracy at the county scale • Ensure wall-to-wall coverage with no double counting	These methods will be done at the statewide scale and is appropriate for county scale aggregation and will include estimates of all HWP within California. Datasets will be cross-walked, especially to minimize potential double counting from two or more distinct sources.
Temporal scale • Go back as far in time as possible, at least to 2001 • Be as up to date as possible	These methods will go back to at least 2001 and will provide estimates through as close to present as possible, likely 2023 or one of the surrounding years. Given that HWP carbon stocks are cumulative estimates, attempts will be made to attain production and trade data from before 2001.
Spatial resolution • Be as spatially explicit as possible, at least to the resolution of ecosystem boundaries • Permit analysis at different stratifications, such as by ownership, management action type, land type, or ecoregion	These methods will not provide a spatially-explicit identification of where HWPs exist, within California's boundary. However, they will allow for various spatially-explicit categorical analyses related to locations of domestically-produced HWP.
Temporal resolution • Produce annualized values that can be reported very 3-5 years	These methods will produce annual values that can be updated and reported every 3-5 years.
Thematic resolution • Include as many carbon pools and fluxes as possible • Capture at minimum aboveground biomass carbon • Be generally consistent with IPCC GHG inventory guidelines	These methods capture the pools of carbon within distinct HWP categories (e.g. lumber, paper, etc.). They are consistent with IPCC GHG inventory guidance.
Sensitivity • Be sufficiently sensitive to quantify changes as a result of management and other major drivers of change, including climate change • Prioritize assessing directionality and general magnitude of change through time	These methods are able to quantify changes in carbon through time that result from domestic harvest, manufacturing, trade, or other major drivers of change.
Practical criteria • Generate transparent, repeatable methods that use free or low-cost tools • Prioritize base data that has reasonable expectation of sustainment and openness for use by state staff • Use models that are publicly available and open source • Use base data that require as little pre-processing for state staff as possible • Use base data that have a proven basis in reality and, where applicable, are validated with error or accuracy	In most cases, these methods use open-source, free datasets and tools that have reasonable expectation of sustainment and openness for use by state staff and others. However, some economic datasets may have privacy considerations that will be honored to the extent permitted by the law. Additionally, I/O analyses are conducted using a proprietary model from REMI. If in the future publicly accessible data that provides the same information becomes available, it will be considered

A comprehensive synthesis of harvested wood product carbon models was conducted by Lucey et al, 2024. Table 3 outlines characteristics for HWP models scalable for statewide GHG and carbon stock inventorying, which were used during the model selection process.

CARB staff have identified multiple dataset (Table 1) and HWP model options in-case of contingency. Many of the prevailing models for HWP carbon analysis are not open source, which restricted options for the NWL Carbon Inventory.

Table 3: Synthesis of harvested wood product carbon models.

Model Name	**HWP-C vR 1.1.0**	**ANSE v1.0**	**US EPA State Inventory and Protection Tool**
Must fit context of specific landscape type	**Yes**	**Yes**	**Yes**
Is the model scalable?	**Yes**	**Yes**	**Yes**
Can this model do future projections needed for scoping plan?	**Yes**	**Yes**	**Yes**
Does the model include the major drivers of change in this system and key ecosystem processes?	**Yes**	**Yes**	**No**
Is this model sensitive to climate change	**No**	**No**	**No**
Can this model estimate the impacts of management/NBS actions?	**Yes**	**Yes**	**Yes**
Does the model output carbon stocks and/or GHGs?	**Yes**	**Yes**	**Yes**
Is the model validated and has a basis in reality?	**Yes**	**Yes**	**Yes**
Can this model be run on a regular basis to develop updates and incorporate improvements?	**Yes**	**Yes**	**No**
Has this model been adapted to use IPCC stock-change approach?	**No**	**Yes**	**No**
Is this an open-source model that we can modify and share without restriction?	**Yes**	**No**	**No**
Is this a mature model with a scientific track record?	**Yes**	**Yes**	**Yes**
Are people currently using this model and is there a current user base?	**Yes**	**Yes**	**Yes**
Will this model require a lot of work to make usable for CARB's purposes?	**No**	**Yes**	**No**
Do we have sufficient off the shelf data to parameterize, calibrate, validate (w/ uncertainty statistics) and run this model through time?	**Yes**	**Yes**	**No**
Can CARB staff run this model within our current timeframe for deliverables	**Yes**	**Yes**	**Yes**

References

Babatunde, K. A., Begum, R. A., & Said, F. F. (2017). Application of computable general equilibrium (CGE) to climate change mitigation policy: A systematic review. *Renewable and Sustainable Energy Reviews*, *78*, 61–71. https://doi.org/10.1016/j.rser.2017.04.064

Brandeis, C., Taylor, M., Abt, K. L., Alderman, D., & Buehlmann, U. (2021). *Status and Trends for the U.S. Forest Products Sector: A Technical Document Supporting the Forest Service 2020 RPA Assessment* (No. Gen. Tech. Report SRS–258). https://doi.org/10.2737/SRS-GTR-258

Bureau of Business and Economic Research (BBER). (2021). California's Forest Products Industry and Timber Harvest. Timber Products Output Report. University of Montana.

California Air Resources Board (CARB). (2022). Scoping Plan for Achieving Carbon Neutrality.

Christensen, G.A.; Gray, A.N.; Kuegler, O.; Tase, N.A.; Rosenberg. M; Loeffler, D.; Anderson, N.; Stockmann, K.; Morgan, T.A. (2021). AB 1504 California Forest Ecosystem and Harvested Wood Product Carbon Inventory: 2019 Reporting Period. Final Report. U.S. Forest Service and California Department of Forestry and Fire Protection

Evans, S., Steinmeier, C., Xie, S. H., Komada, V., Potts, M., & Gordon, J. (2023). *Tracking Carbon Emissions across the Wood Product Supply Chain: Carbon Associated with Wood Product Imports into California and China*. California-China Climate Institute.

Karanjekar, R. V., Bhatt, A., Altouqui, S., Jangikhatoonabad, N., Durai, V., Sattler, M. L., Hossain, M. D. S., & Chen, V. (2015). Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: The CLEEN model. *Waste Management*, *46*, 389–398. https://doi.org/10.1016/j.wasman.2015.07.030

Lucey, T. K., Tase, N., Nepal, P., Bergman, R. D., Nicholls, D. L., Khatri, P., Sahoo, K., & Gray, A. N. (2024). *A synthesis of harvested wood product carbon models*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. https://doi.org/10.2737/pnw-gtr-1020

Marques, A., Martins, I. S., Kastner, T., Plutzar, C., Theurl, M. C., Eisenmenger, N., Huijbregts, M. A. J., Wood, R., Stadler, K., Bruckner, M., Canelas, J., Hilbers, J. P., Tukker, A., Erb, K., & Pereira, H. M. (2019). Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature Ecology & Evolution*, *3*(4), 628–637. https://doi.org/10.1038/s41559-019-0824-3

Peng, L., Searchinger, T. D., Zionts, J., & Waite, R. (2023). The carbon costs of global wood harvests. *Nature*, *620*(7972), 110–115. https://doi.org/10.1038/s41586-023-06187-1

Pingoud, K., Skog, K. E., Martino, D. L., Tonosaki, M., Xiaoquan, Z., & Ford-Robertson, J. (2006). Chapter 12: Harvested Wood Products. In *IPCC Guidelines for National Greenhouse Gas Inventories: Vol. Volume 4: Agriculture, Forestry and Other Land Use*.

Robati, M., & Oldfield, P. (2022). The embodied carbon of mass timber and concrete buildings in Australia: An uncertainty analysis. *Building and Environment*, *214*, 108944. https://doi.org/10.1016/j.buildenv.2022.108944

Singh, T., Arpanaei, A., Elustondo, D., Wang, Y., Stocchero, A., West, T. A. P., & Fu, Q. (2022). Emerging technologies for the development of wood products towards extended carbon storage and CO2 capture. *Carbon Capture Science & Technology*, *4*, 100057. https://doi.org/10.1016/j.ccst.2022.100057

Stockmann, Keith; Anderson, Nathaniel; Young, Jesse; Skog, Ken; Healey, Sean; Loeffler, Dan; Butler, Edward; Jones, J. Greg; Morrison, James. (2014). Estimates of carbon stored in harvested wood products from United States Forest Service Intermountain Region, 1911-2012. Unpublished report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory. 28 p.

Zeng, N., King, A. W., Zaitchik, B., Wullschleger, S. D., Gregg, J., Wang, S., & Kirk-Davidoff, D. (2013). Carbon sequestration via wood harvest and storage: An assessment of its harvest potential. *Climatic Change*, *118*(2), 245–257. https://doi.org/10.1007/s10584-012-0624-0

Zhao, J., Wei, X., & Li, L. (2022). The potential for storing carbon by harvested wood products. *Frontiers in Forests and Global Change*, *5*. https://www.frontiersin.org/journals/forests-and-global-change/articles/10.3389/ffgc.2022.1055410