PATHWAYS TO CARBON NEUTRALITY IN CALIFORNIA

The Forest Management Opportunity

April 2022

Stanford
Center for Carbon Storage
Carbon Removal Initiative

About

About the Stanford Center for Carbon Storage

Carbon Capture, Utilization, and Storage is a key technology for achieving net-zero greenhouse gas emissions. The Stanford Center for Carbon Storage (SCCS) uses a multidisciplinary approach to address critical questions related to flow physics, monitoring, geochemistry, geomechanics and simulation of the transport and fate of CO_2 stored in partially- to fully-depleted oil & gas fields and saline reservoirs. SCCS is an affiliates program associated with the Stanford University School of Earth, Energy and Environmental Sciences.

About the Stanford Carbon Removal Initiative

The Stanford Carbon Removal Initiative (SCRI) seeks to create science-based opportunities and solutions for gigaton-scale negative emissions and atmospheric carbon removal. The initiative helps to enable removal of atmospheric greenhouse gasses at scale by generating and integrating knowledge, creating scalable solutions, informing policies for technology deployment and governance, and demonstrating approaches and solutions with industry collaborators. All of this is done with a focus on social acceptance and equity, as well as environmental, economic, and social costs. SCRI is an affiliates program associated with the Precourt Institute for Energy and the Woods Institute for the Environment.

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List of Acronyms

BDT	bone dry tons
BioMAT	Bioenergy Market Adjusting Tariff
BioRAM	Biofuel Renewable Auction Mechanism
CCS	carbon capture and storage
CLT	cross-laminated timber
CPUC	California Public Utilities Commission
Glulam	glued laminated timber
IOU	investor owned utility
MW	megawatts
OSB	oriented strand board
PPA	power purchase agreement
PPIC	Public Policy Institute of California
RAM	Renewable Auction Mechanism
USFS	United States Forest Service

Key Findings

- Forests are California's most important working land type for carbon storage and carbon flux; however, intentional management has inherent trade-offs; in particular, carbon storage is often at odds with reduced wildfire emissions and forest management requires investments today to avoid costs in the future.
- The scale-up in forest management to ~1,000,000 acres by 2025 (in-line with state goals), represents a doubling of current United States Forest Service (USFS) work and a 5 fold increase in state funded work on private and other lands; this will generate significant amounts of additional wood products and biomass.
- Biopower is the lowest-value end-use for forest biomass on a dollar per volume basis.
- However, high-value wood products (e.g., lumber, veneer) effectively subsidize forest biomass removal for biopower, suggesting there is opportunity to support forest management with the commercial timber harvest.
- Broadly speaking, engineered wood products are compelling for their ability to lower costs, reduce carbon emissions (by replacing substitute products such as steel and concrete), and create rural jobs (by requiring value-added wood manufacturing).

Introduction

California is blessed with vast working lands including forests, shrublands, grasslands, croplands, wetlands, and deserts. By the nature of these spaces, significant carbon is stored in biomass and soils. Figure 1 highlights the magnitude of this carbon sink – 5,340 million metric tons of carbon are stored in California's working lands, representing over 19 Gt CO_2, or over 45 years of California's current emissions (1).

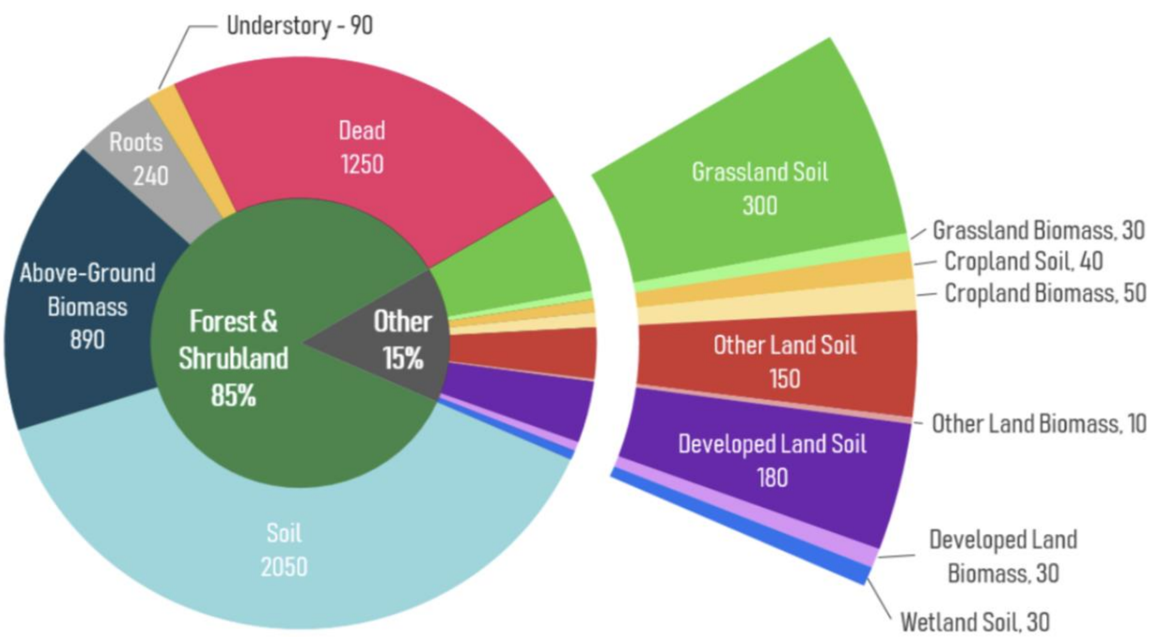

Figure 1: 2014 distribution of biomass and soil carbon stocks on the California landscape in millions of metric tons (Mt) carbon (rounded to the nearest 10 Mt C). There are approximately 5,340 Mt of carbon in the carbon pools for the year 2014 (1).

Carbon stocks in working lands are always in-flux. Vegetation growth provides the primary carbon drawdown (on the order of 7.1-9.9 Mt CO_2e/yr), while wildfire, prescribed fire, forest harvest, forest management practices, agricultural practices, and natural decomposition contribute to emissions (2).

California faces a new paradigm, as working lands have now transitioned to a net emitter vs. a net sink, with both forests and soils losing carbon stock over the past decade. For soils, this was driven primarily by microbial oxidation of organic soil in the Sacramento-San Joaquin Delta, though disturbances caused by tillage and other management practices, land conversion, and land degradation also contributed to the ~1% decline. For forests, this was driven by wildfire, driving ~6% decline (note this figure is prior to the latest years of megafires). Figure 2 highlights the magnitude of this change from 2000-2014 (1).

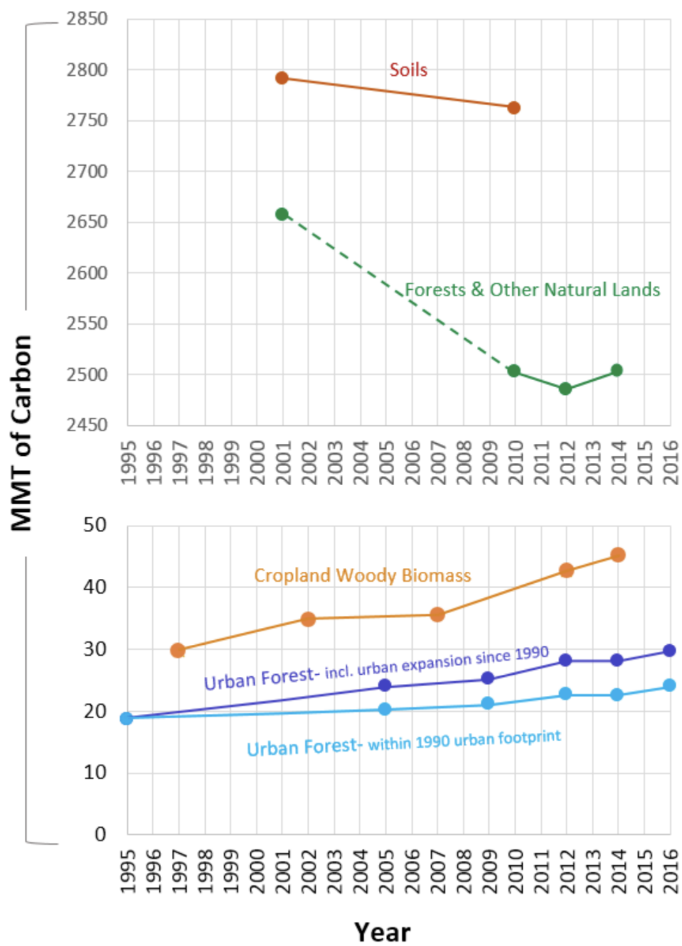

Figure 2: Trends in carbon stocks over time (Mt of carbon). Due to large difference in scale, soils and forests & other natural lands are shown in the top panel, and cropland woody biomass and urban forest are shown in the bottom panel. Each solid circle represents a "snapshot" of inventory estimate based on available empirical data (1).

The decline in carbon stocks -- along with the importance and scale of California's working lands -- has stimulated significant research and interest in opportunities to increase carbon storage in ecosystems through so-called ‘natural climate solutions’. Examples of these initiatives with their potential emissions impacts are summarized in Figure 3 below, suggesting that there is potential to cost-effectively sequester over 500 Mt CO_2e between now and 2050 (3).

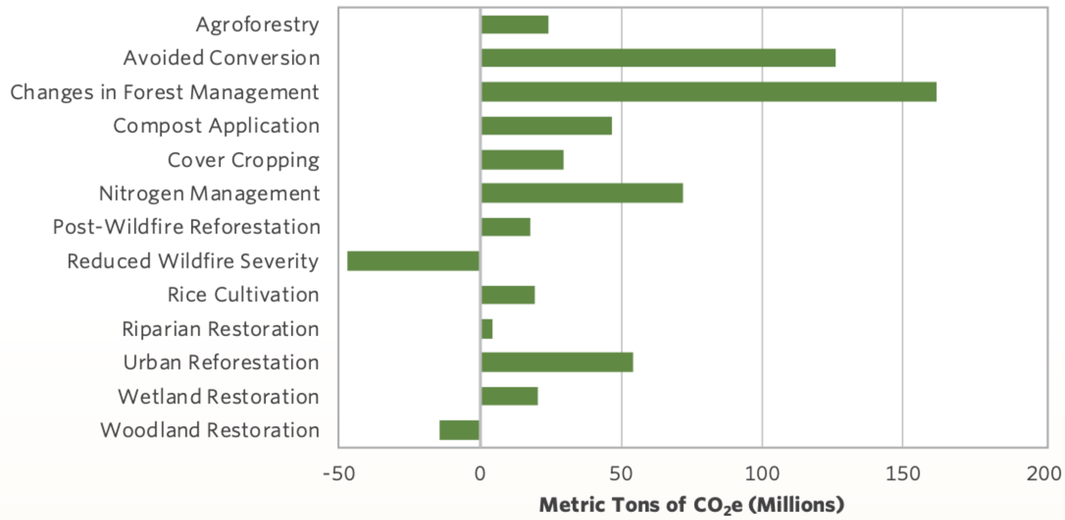

Figure 3: Cumulative emission reduction potential—derived from three separate studies and aggregated by The Nature Conservancy —is shown for 13 nature-based climate solutions out to the year 2050. Negative values represent a net increase in emissions out to the year 2050 (3).

Forests are California’s most important working land type for carbon storage and carbon flux; however, intentional management has inherent trade-offs. Figure 1 shows that forests and shrublands store the majority of carbon (~85%), while Figure 3 illustrates that we face trade-offs in how we manage forests, as there are potentially conflicting incentives in managing forests. Two key trade-offs were identified in the context of forest management:

> **1. Carbon storage vs. reduced wildfire emissions:** Allowing California’s forests to store more carbon involves increasing the biomass density; biomass, in turn, is fuel for fires and greater biomass can increase intensity and mortality of wildfires. In contrast, reducing wildfire severity involves intentional management to remove biomass from the forest, typically with a focus on small diameter trees, dead biomass, and the tops and branches of harvested timber logs (often removed in conjunction with a commercial timber harvest).
>
> To be clear, there are methods designed to optimize between these two objectives, for example, maintaining larger, more fire-resistant trees while removing smaller diameter and dead biomass. However, these optimized paths still face complicated, multi-dimensional trade-offs. Continuing the example, large trees are most valuable for timber, which can effectively subsidize removal of small diameter trees. As California now confronts unprecedented wildfire emissions on-par with industrial emissions at over 100 Mt CO_2e in 2020 (Figure 4), the trade-off is more tangible than ever (2).

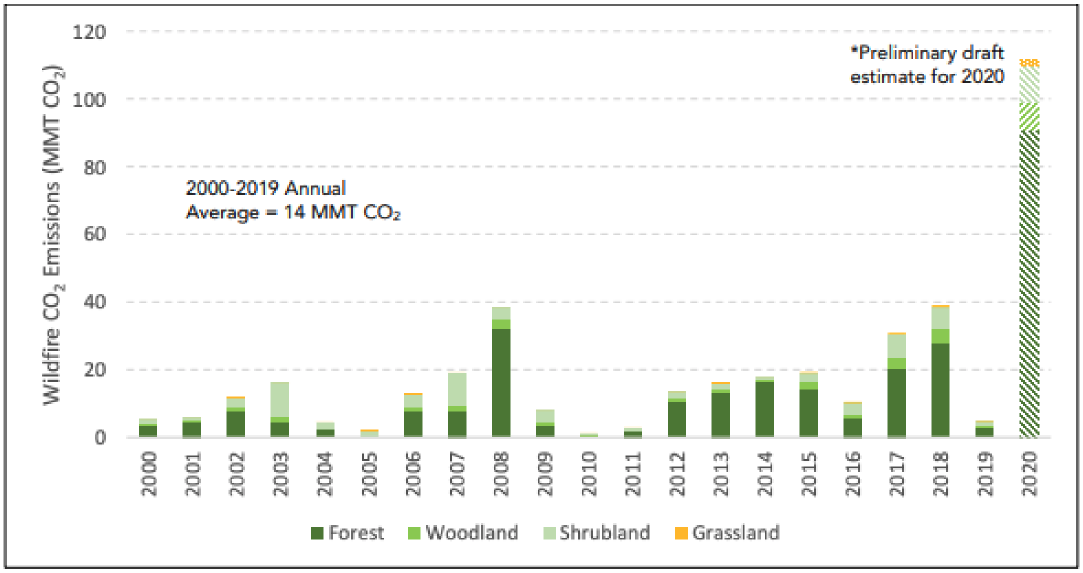

Figure 4: Annual wildfire CO_2 emissions (million metric tons, Mt) by general vegetation category (2).

2. Costs now vs. costs in the future: Investing in forest management presents a budgetary dilemma – spending money now will reduce future costs, most of which are uncertain due to the unpredictable nature of wildfire and the 10X increase in wildfire scope and intensity vs. historical data. Additionally, while some of the future costs have clearly identifiable victims (e.g., capital costs to home or business owners in the path of the fire), others are dispersed (e.g., health costs due to increased particulate matter from wildfire). Perhaps unsurprisingly, this has led to a paradigm in which investments in emergency firefighting dramatically exceed investments in management and prevention (4).

However, the realized costs of California's most recent wildfires have been significant. The estimated direct economic costs to GDP of the 2020 fires have been estimated at $10B (5), a number that would cover CalFire's budget for 4 years and fund the treatment of an estimated 10-20M acres at rough costs of $500-1,000 per acre. This represents the majority of California's forests requiring management, and ~30-60% of total forested area. Other researchers have highlighted that when indirect costs – including such items as health costs and reverse tourism – are included, the values can be significantly higher with 2018 estimates at ~$150B (6).

Whether $10B or $150B, these costs – many of which Californians are feeling more tangibly than ever before – appear to be moving the state towards action. The original driver of increased forest management investment came from the state's decision to fund forest management with cap-and-trade revenues. Then, in 2018, the legislature committed $1B over five years, leading to a 5 fold increase in funding for CalFire in 2019 and 2020 (7). Since 2020, there have been two significant policy breakthroughs. First, in 2020 California and the United States Forest Service agreed to a Shared Stewardship Agreement, which outlined – amongst many objectives – the goal of treating 1 million acres per year (8). Second, California passed the Wildfire Resilience Package, which included a meaningful investment of $1.5B on wildfire prevention and forest resilience investment over three years (to be compared to CalFire's annual budget of ~$2.6B in 2021-22) (4).

The following sections review the opportunities and challenges across technology, economics, and policy to support California's action on forest management. The approach first evaluates the supply of potential forest biomass that could be generated through forest management, then turns to review various sources of demand (from the traditional timber and wood products industry, biopower, and engineered wood products; while there is a brief discussion on the role biofuels could play, the detailed analysis is included within the companion study "*Pathways to Carbon Neutrality in California: The Bioenergy Opportunity*" (9).

Forest Management Opportunities and Challenges

To evaluate opportunities and challenges for forest management in California, this study first evaluates the potential supply of forest biomass, then in-turn reviews potential sources of demand: traditional timber and wood products, biopower, engineered wood products, and advanced biofuels.

A crucial limitation of the methodology discussed here is that, in practice, it is not possible to fully separate supply from demand. Like all markets, the volume, type, and – crucially for forest biomass – location of supply will impact demand. While outside the scope of this research, a future, fully integrated, spatially explicit supply and demand analysis for forest biomass would be valuable.

Supply

Forest is the dominant land cover type in the state of California, stretching across ~32 million acres and around one-third of the state's land area. The USFS is the largest owner with over 15 million acres or ~48% of forested lands (the federal government manages another ~3 million through the Bureau of Land Management, the National Park Service, and other managers). The State of California, through CalFire, is responsible for managing the remaining ~14 million acres or ~42% of private or state-owned forested lands. The majority of the land managed by CalFire is owned by private non-corporate and private corporate landowners (10).

Forests supply a range of products. For the sake of simplifying the discussion, we focus on two broad categories:

- *High-value wood products:* the majority is merchantable logs, including timber logs (sent to sawmills to be converted to lumber and other sawn products) and veneer logs (sent to veneer facilities that convert slightly smaller diameter trees to veneer panels used in products like plywood). However, there are various other possible wood products, including posts and poles, briquettes/pellets, and firewood.
- *Biomass chips:* a general term that refers to forest biomass that cannot be made into a higher value product and most commonly is combusted in a biopower facility to generate electricity. Typically, the biomass comes from one of three sources: the tops, bark, and branches of harvested logs, small diameter trees, and non-salvageable dead biomass.

Across the diverse forested landscapes of California, there are multiple methods for conducting forest management, each of which generates different types of wood products or biomass supply:

- *Timber harvest:* The most common method is to leverage a commercial timber harvest for conducting forest management. Historically, this has been the primary driver of forest management; for example, in a subset of Sierra watersheds, the Public Policy Institute of California (PPIC) estimated that ~66% of the total treated acreage was due to timber harvest, driven disproportionately by private forested land owners (11). As expected, the primary wood output of this type of intervention is commercial timber used to produce lumber and veneer. However, the saw milling process generates low quality biomass which can be used for other purposes; it is possible to harvest non-timber biomass from tree tops and branches (most common), small diameter trees, and non-salvageable dead biomass. It is important to note, however, that best estimates are that 40-80% of this non-timber biomass is left in the forest after a commercial harvest (12).
- *Prescribed burning:* This involves the use of controlled fire to reduce biomass. Again referencing only a subset of watersheds, PPIC estimated ~16% of treated acreage used this method. Proponents of this method highlight the potential for much lower cost and higher scale forest management, particularly for steep, inaccessible slopes. However, barriers include difficulties in receiving permits given the air quality impact and lack of California-specific experience and research on how to safely execute this form of management. As expected, there are no wood products that come as a result of prescribed burning.
- *Mechanical treatment:* This practice refers to mechanical removal of non-timber biomass, with a particular focus on small diameter trees and non-salvageable dead biomass. PPIC identified this practice on ~12% of treated acres, despite mechanical treatment receiving a meaningful amount of the discussion around California's path forward. The primary criticism of mechanical treatment is the cost – estimates range from $500-1,900 per acre (13), and land managers have quoted $500-1,200 per acre (12). The primary wood products from this type of intervention are small diameter trees (which have a range of applications from posts and poles, to chippable-wood for oriented strand board, to firewood, to fuel for biopower facilities).
- *Combined treatment:* This refers to some combination of the above three methods, and as a result can generate a mix of wood products. This is least common at ~5% of acres according to PPIC.

The scale-up in forest management to over 1,000,000 acres by 2025 represents a doubling of current USFS work and a 5 fold increase in state funded work on private and other lands; this will generate significant amounts of additional wood products and biomass. Ultimately, the volume and mix of supply will be driven by the final mechanisms selected for forest management. For high value wood products, the estimate for California's theoretical inventory in 2016 was 95 billion net cubic feet (14). The California Energy Commission sponsored research that leveraged an integrated model that incorporated estimates of profitability and wildfire severity to identify 400,000 acres that could be economically treated generating 9M bone dry tons (BDT) of biomass (compare to ~1M BDT average annual consumption of direct forest biomass by biopower facilities 2015-17) and 11M BDT of merchantable logs (15). Another study modeled an increase to 800,000 acres of mechanical treatment that is estimated to generate 24M BDT of biomass (15).

While the exact amounts vary, the take-home message is the same: an increase in forest management will meaningfully increase the supply of wood products and biomass coming from California's forests.

Demand

In the previous section, the mechanics for high-value wood product and biomass supply were discussed; now, the analysis transitions to reviewing various sources of demand for forest biomass. The timber harvest and wood products industry and biopower are discussed in detail; the potential for advanced biofuels is touched on briefly, but primarily covered in the companion study "*Pathways to Carbon Neutrality in California: The Bioenergy Opportunity*" (9). In each section, the discussion provides a summary of the I) background, II) market dynamics, and III) challenges and opportunities in the sector.

Timber Harvest and Forest Products Industry

I) Background

California has a long history of forestry and wood products. Native Californians used low-intensity fire to stimulate plant growth for food, create habitat desirable for target hunting species, reduce severity of natural forest fires, and make travel easier. Other land practices, while less common, were nevertheless employed: sowing seeds, transplanting shrubs and small trees, pruning, and water diversion for irrigation and erosion control (17)

The arrival of Europeans dramatically increased the wood products harvested from California's forests. Demand for timber for the transcontinental railroad and mining stimulated the wood product industry in the 1800s. By the end of the century, logging of coastal forests involved the now-infamous approach of using streambeds as transportation routes (leading to sediment-laden streams and destroying habitat for salmon). The World Wars further increased demand for timber, leading to increased road networks which we see to this day. From 1940-60 the state timber harvest grew from 2 to 6 billion board feet annually (17).

To meet the new demand, novel approaches to forest management were deployed, leading to increased fire risk and intensity. First, due to the value of timber, fire suppression became the management practice of choice in the early 1900s. This approach has led to a build-up of biomass within forests which, when ignited, burn hotter and with higher mortality rates. Second, clear-cutting was widely used; when this happens, a diverse forest of different sizes and ages is replaced with a single age, high-density stand. This leads to a situation where a forest does not have older, more fire-resistant trees.

Several regulatory and social changes led to the ~80% decline of the California timber harvest after 1960, and particularly after 1980. At the national level, the passage of the Clean Air and Water Act – along with the Endangered Species Act – provided regulatory support for activist challenges to the timber industry. At the state level, the Forest Practice Act of 1973 has resulted in the most comprehensive set of forestry regulations in the US (and, some practitioners argue, the world). Additionally, the tax law changed in 1976 in a way that eliminated the incentive to harvest timber supply in order to reduce property taxes. As a combined result, the commercial timber harvest has dropped significantly, from the ~6 billion board feet in 1960 to under 2 billion today (see Figure 5). Note the extreme drop-off in timber volume on United States Forest Service (USFS) land (18).

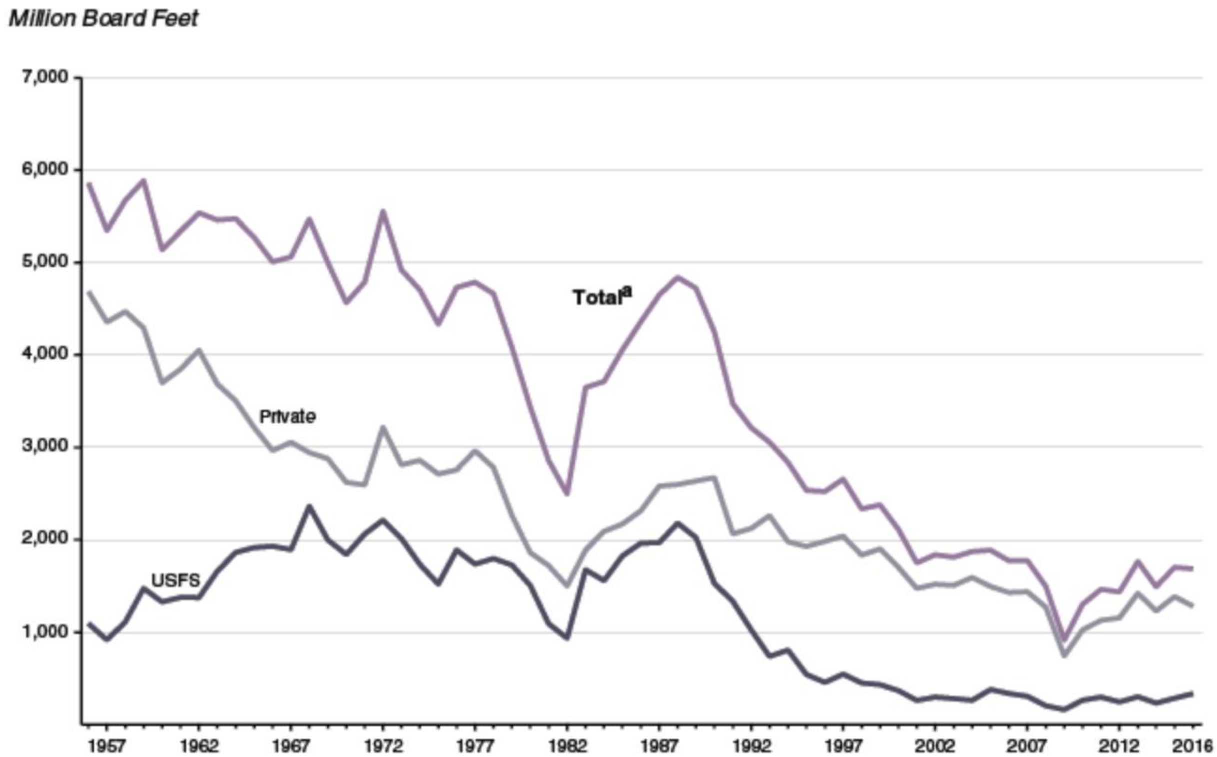

Figure 5: California's timber harvest over time by ownership type, 1952-2016 (18).

Unsurprisingly, the decline in the commercial timber harvest has led to a contraction in the wood product industry as a whole. Since 1968, the number of sawmills has declined 85%, while the number of veneer and plywood facilities has dropped by 90% (18).

While controversial, it is important to recognize that the timber harvest provides forest management services and reduces combustible materials in the forest. Given the 2-4 billion board feet reduction since the mid-twentieth century, this represents a meaningful reduction in fuels management (an estimated 150,000-300,000 acres per year assuming ~13,000 board feet per acre).

II) Market

California's wood product harvest came in at ~1,500 million board feet and a total value of $1.5B in 2016; it is dominated by saw logs. Saw logs drive over 82% of the harvest volume followed by 11% veneer logs, and 5% biomass for biopower (17).

However, biopower is the largest end-use, representing ~40% of the volume. This shift in prominence is the result of meaningful volumes of sawmill residues being directed into the biopower supply chain. In terms of outcomes, this ~40% of the end-use volume contributes only 18% of the value; conversely, lumber and veneer contribute 46% of end-use volume and ~75% of the value. On a per unit basis, this underscores the fact that biomass is the lowest value end use. Figure 6 illustrates the flow of wood products across California's industry from harvest to end-use (18).

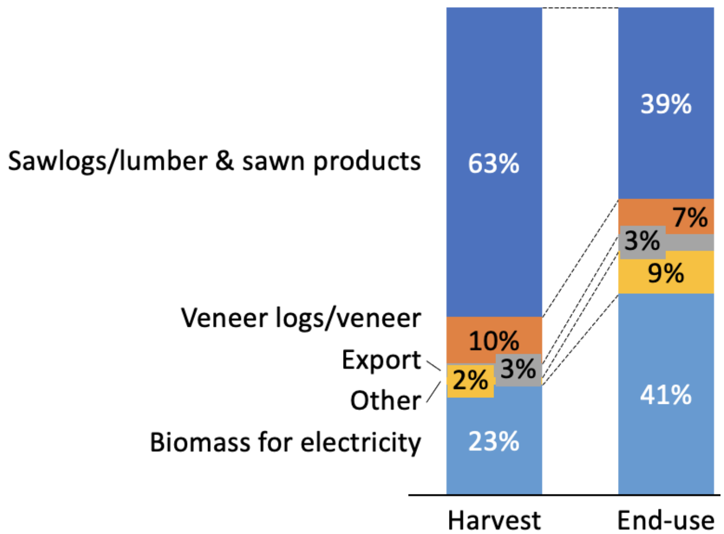

Figure 6: Harvest volume vs. end-use volume of California's Timber harvest, 2016 by product category; excludes bark. Note the figure illustrates relative uses; end-use volume is lower than harvest due to various supply chain losses and uses (17).

The above market dynamics underscore two key points:

1. Biopower is the lowest-value end-use for forest biomass on a dollar per volume basis. While the above analysis focuses on the simplified comparison between saw logs and biomass for biopower, this conclusion holds true for all wood products (e.g., post and poles, firewood, pellets, etc. all provide greater returns than biomass for biopower).

2. High value wood products (e.g., lumber, veneer) effectively subsidize forest biomass removal for biopower. The higher rate of return of saw and veneer logs incentivizes projects for a particular parcel, and biomass removal can be conducted at lower cost in parallel than through a dedicated biomass removal project. Note, this conclusion is evident in the PPIC analysis cited earlier, where timber harvest has driven ~66% of total forest management.

III. Challenges and Opportunities in California's Timber Harvest and Forest Product Industry

There are meaningful challenges impeding the timber harvest and forest product industry. Three are highlighted below.

1) *Workforce development*

Despite the political will and – potentially – the economic support to rapidly scale up forest management, California faces a shortage of skilled forest product and timber workers. Since 2000, the number of skilled forestry and logging workers has declined from ~7,000 to

~5,000 (~30% drop). In the same period, wood products manufacturing employment has declined more steeply from ~48,000 to ~29,000 (~40% drop) (18). Additionally, in order to capitalize on new technologies novel skillsets are required. A dedicated effort will be required in order to support development of the workforce.

2) *Supply chain development (both in-forest and in manufacturing)*

There are not enough in-forest contractors able to execute timber harvest and forest management projects. Thus, even if the USFS were to ramp up the acreage offered for a timber harvest each year, it is not a given that there will be a crew willing and able to execute the project. This challenge is complicated by the fact that contractors need certainty to invest in capital equipment, and yet a challenge regularly cited by the industry is that there is a lack of supply and project certainty, particularly from public lands (19).

Similarly, investment will be required in the downstream supply chain to support any form of timber harvest scale-up. At a minimum, this is true for traditional sawmills, which operated at 73% utilization in 2016 (18). However, this is particularly true for any form of new, engineered wood product which will require novel facilities and, as discussed above, a unique workforce.

3) *Climate change*

Climate change is impacting the nature of California's forests; two key shifts include forest-type changes and increased scale and severity of wildfires. These changes make it difficult to predict the state of California's forests in one or two decades time; for example, if the ~4 million acres of wildfire realized in 2020 are repeated, it will only take 8 years before every acre of California's forests have been impacted. Yet, in the face of this uncertainty, multi-decade investments are required in order to invest in the timber harvest and wood products industry; for example, an oriented strand board (OSB) plant requires multiple hundreds of millions of capital investment with an estimated 9 years to payback (20).

Fortunately, in the face of these challenges, the timber harvest and forest product industry present unique pathways for driving sustainable forest management in support of reducing state-wide emissions. The below highlights opportunities in 1) expanded sustainable harvest and 2) engineered wood products.

1) *Expanded sustainable timber harvest*

Given the ability of saw and veneer logs to subsidize biomass removal, there is potential to improve forest health by increasing the annual timber harvest acreage. The current harvest is below historical rates and below estimates of California's sustainable rate, particularly on Federal Lands (as identified as part of the 2021 Forest Resilience Plan which calls for a 25% increase in USFS harvest). If executed responsibly, an expanded harvest presents the opportunity to extend the acreage of annual forest management (4).

However, it is important to employ low-impact or reduced-impact logging techniques. These approaches aim to harvest timber to meet current needs without compromising the ability of future generations to do the same. Typically this means smaller, periodic harvests with a focus on harvesting the lowest value trees. Notably, this does not include the practice of clear-cutting, which historically was integral to the timber harvest in California. While clear-cutting is no longer conducted on USFS lands in California, it still occurs on private forest land.

Fortunately, the state of California has begun investing in expanding the timber harvest and wood products industry. The Wildfire and Forest Resilience Package calls for $76 million in forest sector economic stimulus, including workforce development, a loan fund to support private and public projects, and general market development including a broad framework for aligning wood utilization policies, funding to develop pilot projects, and executing a wood product x-prize. Similarly, priorities to support the broad timber harvest are included, such as expanding USFS Harvest from 400 to 500 million board feet, increasing incentives for timber harvests that support forest resilience (potentially to include improved permitting and payments for multi-age stands, increased carbon storage, and biodiversity) (4).

Crucially, an expansion in the timber harvest would generate well-paying, rural jobs with equity in mind. Ultimately, this is an explicit driver behind some of California's policies designed to support an expanded timber harvest.

2) *Engineered wood products:*

Broadly speaking, engineered wood products are compelling for their ability to lower costs, reduce carbon emissions (by replacing substitute products such as steel and concrete), and create rural jobs (by requiring value-added wood manufacturing). Engineered wood products include all forms of advanced wood products that are designed and manufactured to maximize the natural strength and stiffness of wood (above and beyond lumber, veneer, posts, poles, and other traditional wood products). Three product types in particular are interesting in the context of California: i) oriented strand board (OSB), ii) cross laminated timber (CLT), and iii) glued laminated timber (glulam).

i) Oriented strand board

Oriented strand board is formed by adding adhesives and then compressing layers of wood strands, or flakes, placed in specific orientations. Typically, it is used in construction such as sheathing in walls, flooring, and roof decking. Additionally, it is often used internally within furniture. See Figure 8 for a picture of this iconic building material.

Figure 8: an OSB panel (from iStockphoto).

OSB presents a theoretical potential for California forest management for two reasons. First, it is a high value wood product that can make use of small diameter trees. It is estimated that a single facility in northern California could support the equivalent of over 30,000 acres of forest management per year (though note in reality the feedstock supply would likely be a mix of tree tops, small diameter trees, and sawmill residues). Crucially, it is estimated that a California-based OSB facility could afford to pay up to $100 per BDT of forest biomass, meaningfully higher than current market rates for forest biomass. Second, there is a large and growing market in and around California. And third, there is a lack of nearby OSB manufacturing despite the fact that transport ends up being a meaningful share of the cost of OSB – the nearest facilities are in east Texas and British Columbia (19).

Additionally, OSB contributes to reducing California's emissions. Through a full life cycle, OSB is estimated to have 1.18 ton carbon benefit for every 1 ton carbon of feedstock, largely driven by substituting for other, emissions-heavy materials (21)**.**

ii) Cross-laminated timber
Cross-laminated timber is a heavy timber panel produced from laminated layers of lumber, typically with grains oriented perpendicularly. Usually, CLT is used in structural applications including walls, floors, and roofs in multi-story buildings.

CLT is the core product enabling 'mass timber,' a term used to describe the ability to make tall buildings out of wood. Recent advancements have demonstrated the potential; the record is held by a Norwegian building at 85 meters tall and 18 stories (22). Much of CLT's promise lies in the potential for wooden skyscrapers to displace emissions-heavy building materials like steel and concrete.

Unfortunately, CLT does not currently lead to increased utilization of small diameter trees; instead, it is included due to i) potential for massive market growth and ii) the emissions reduction potential (vs. steel and concrete). CLT has the potential to support an expansion of the broader timber harvest and forest products industry. As discussed previously, a timber harvest ramp-up is a huge opportunity for supporting and subsidizing forest management. Additionally, as California addresses the housing crisis with mandates for high density housing throughout the state, there is a meaningful opportunity to incentivize use of carbon-storing California wood products over carbon-emitting steel and concrete.

iii) Glued laminated timber
Glued laminated timber consists of layers of dimensional lumber bonded together with adhesives (grains parallel in contrast to CLT). Similar to CLT, glulam is able to outperform traditional building materials (steel and concrete) on strength per pound and emissions intensity. Typically, it is used in beams, arches, domed roofs, and more.

Glulam is a key product used in mass timber buildings. So, similar to CLT, the product is supported by a potential for a meaningful increase in the market size.

Glulam is unique amongst the products used in mass timber in its ability to use small diameter trees. Thus, there is an added advantage in pursuing glulam as a product designed and manufactured within California.

Biopower

I) Background

California was an early leader in the US in deploying biopower. As part of California's Renewable Energy portfolio, biopower generation capacity reached close to 1,000MW in the 1990s.

However, as these original power purchase agreements with investor owned utilities (IOUs) expired, they were not renewed as there were more affordable options in wind and solar. This led to many facilities going idle.

In partial response to increasing severity of wildfires, there was a policy shift to use biopower to fund forest management. In 2015, Governor Brown required the California Public Utilities Commission (CPUC) to extend purchase contracts to existing biopower facilities provided that they procure feedstock from High Hazard Zones (as identified by CalFire). In turn, the CPUC mandated the IOUs procure 50MW of forest biomass biopower from Renewable Auction Mechanism (RAM) facilities, often called BioRAM facilities. This requirement was later increased to 125MW.

However, concerns were raised by environmentalists about the large, old BioRAM facilities. Given their size, activists were concerned about long transport of biomass required and localized air emissions impacting marginalized communities.

In response, small-scale facilities were proposed as a solution – a program called Bioenergy Market Adjusting Tariff (BioMAT). IOUs were mandated to procure 250MW from facilities no more than 3MW in size (later increased to 5MW); of this, 50MW must be procured from bioenergy using byproducts of sustainable forest management, including material sourced from High Hazard Zones (23).

II) Market

Biopower contributes ~3% of California's energy via 87 operating facilities. These include facilities that burn biomass, digester gas (anaerobic digestion), landfill gas, and municipal solid waste (24).

In terms of biomass facilities, the data from 2017 highlights 24 facilities consuming 3.4 million BDT of biomass. A subset, seven of these facilities are BioRAM facilities consuming 1.1 million BDT and with a capacity of ~200MW. In 2017, ~45% of the biomass came from forestry or mill residues. Tables 1 and 2 outline the biomass market in more detail (12).

Feedstock	Units	2015	2016	2017	Avg. 2015-17
Ag	Estimated BDT	813,421	744,673	581,056	713,050
In-forestry	Reported BDT	552,323	298,577	503,939	451,613
Mill Residue	Reported BDT	1,305,490	816,666	1,116,881	1,079,679
Urban & Other	Estimated BDT	1,446,082	1,080,585	955,127	1,160,598

Total		4,117,316	2,940,500	3,157,003	3,404,940
# of Facilities	#	29	22	24	25

Table 1: Biomass utilization in BDT by all biomass power plants in California, 2015- 2017. USFS data from UM BBER 2012 (McIver, et al., 2014) and indicated harvested volume (The Beck Group, 2019).

Feedstock	Units	2015	2016	2017	Avg. 2015-17
Ag	Estimated BDT	337,385	352,877	330,859	340,374
In-forestry	Reported BDT	224,431	150,366	339,810	238,202
Mill Residue	Reported BDT	156,668	193,735	175,909	175,437
Urban & Other	Estimated BDT	421,821	251,984	268,360	314,055
Total		1,140,305	948,962	1,114,938	1,068,068
# of Facilities	#	7	7	7	7

Table 2: Biomass utilization in BDT by BioRAM power plants in California, 2015- 2017. USFS data from UM BBER 2012 (McIver, et al., 2014) and indicated harvested volume (The Beck Group, 2019).

Both BioRAM and BioMAT facilities receive favorable PPA rates; but the economics remain difficult. BioRAM facilities have reported the ability to remain profitable as long as the price of purchasing biomass is under $65-75 per BDT. BioMAT facilities, despite the extremely favorable PPA rates of $0.19/kwh, report breakeven at $45 per BDT (note the lower ability to pay is a function of higher fixed costs associated with the small BioMAT facilities). For reference, market prices, driven by bidding wars between BioRAM facilities for High Hazard Zone fuels, have previously reached up to $60-70 per BDT while general biomass markets have remained below $40 per BDT (12).

To date, no BioMAT facility has made it on-line (though there are multiple that are in final stages).

III) Challenges and opportunities in Biopower

Biopower faces a number of challenges in scaling up in support of forest management and emissions reductions. Five are highlighted below.

1) *Cost of harvesting forest biomass often exceeds ability to pay*

Fundamentally, forest biomass for biopower faces a basic, economic challenge – the ability to pay is often lower than the cost of bringing biomass out of the forest. The costs to execute a project are driven by various factors, with transport costs being the variable that often impacts the viability of removing the biomass from the forest. Experts often cite a rule of thumb that if the biopower off-taker is more than 50 miles away, the cost of removing the biomass likely exceeds the payment received.

As discussed previously, incorporating forest biomass removal with a commercial harvest does reduce the total cost. An analysis of three actual USFS projects highlighted a cost per BDT of forest biomass of $55-66 (before contractor profit) when paired with commercial harvest (25); this approaches the breakeven rate for BioRAM facilities and exceeds the broader market rate for biomass. It is estimated that, due to these dynamics, 40-80% of the forest biomass that is available during commercial harvest is left in the forest (12). This economic reality is further underscored by the USFS, which has claimed that at times they

have offered a timber sale with the requirement to remove forest biomass, and no entities placed a bid. When the biomass requirement was removed, they did receive bids.
The costs associated with a fuels-reduction project only are higher, ranging from $67-118 per BDT (25). This underscores the fact that conducting fuels-reduction only as means of forest management is not economical with only Biopower as the off-taker.

2) *Supply uncertainty*

In order to run a biopower facility, a consistent and guaranteed supply of biomass is required. However, inconsistent supply has been highlighted as one of the big challenges for BioRAM facilities; for example, the Loyalton biopower facility has highlighted their ability to only secure 1-3 year contracts, with over 30 in-place at a given time, leading to significant operational challenges (at one point, the facility procured pallets from the Tesla Gigafactory). For BioMAT facilities, the inability to secure long-lasting biomass contracts inhibits financing opportunities (19).

Timber market volatility can also impact supply. As discussed, saw logs drive the value of a commercial harvest and often subsidize the forest biomass removal. If there is a downward swing in the prices of saw logs, entire projects will be canceled or put on hold until the economics work out. This impacts biopower facilities that can no longer count on the supply of biomass.

Similarly, the rise in wildfires impacts supply by redirecting focus from standard timber sales to salvage logging. Given there is only a certain scale of supply chain, crews are regularly redirected to focus on salvage logging, which produces much less in terms of biomass.

3) Contradictions between biopower facility goals and forest management goals

Biopower facilities are incentivized to source the lowest-cost biomass, which typically means tree tops and branches from commercial harvest sourced from nearby locations. However, this may not be aligned with the biomass type (e.g., small diameter trees) and areas (far from town) that are most important in terms of forest management and reducing wildfire risk. The implication is, yet again, that biopower alone cannot be the economic mechanism to drive fuels reduction at landscape scale.

Ultimately, policy deployed to-date does not incorporate the type of biomass or the location in providing incentives.

4) Forest roads were built for logging, not removing forest biomass

Many forest roads cannot accommodate the chip vans needed for removing forest biomass. Experts have estimated that 30-50% of California's forests are inaccessible to chip vans due to the tight roads originally designed only for logging trucks (12).

5) Carbon lifecycle analysis of standard combustion biopower facilities is questionable

Given the relatively low carbon intensity of California's grid, most lifecycle analyses of biopower demonstrate modest carbon benefits (e.g., 0.11 ton carbon benefit per 1 ton carbon input feedstock). In fact, one analysis has suggested that simply allowing the biomass to decay could provide greater climate benefit at 0.14 ton carbon per 1 ton carbon feedstock (21).

However, it is important to note that the above analyses do not fully capture the carbon value of baseload power.

Fortunately, biopower does have a number of potential opportunities.

1) *Integrated wood product campuses*

There is an opportunity in integrated wood product campuses to capture more value and subsidize biomass removal. In practice, this would mean a single site that is able to process a stream of biomass into various end-uses. For example, the Tule Creek Forest Products business model was based on generating commercial firewood when possible, then using the remainder for their biopower facility. Analyses have shown market potential in posts and poles, animal bedding, firewood, and other wood products.

2) *New technologies*

There is potential to pursue Biopower with carbon capture and storage (CCS). This has the benefit of potentially improving the overall economics through incentives and potential carbon market revenue. Lifecycle analysis of biopower with CCS suggests 0.82 t carbon of benefit per 1 t carbon of feedstock; given each BDT of forest biomass is ~50% carbon, this translates to 0.4 t carbon benefit or ~1.5 tons of CO_2 benefit per BDT. At current 45Q tax credit values of $50/ton of CO_2, this adds an incremental income of $75.

3) *Clear forecast of supply*

If the USFS is able to provide greater certainty in projects (and therefore biomass supply), the biopower market can better plan; from contracting to financing. Fortunately, the USFS and CalFire have signed a joint Memorandum of Understanding which includes a joint plan and map of projects for the coming years.

4) *Incentives or subsidies*

Providing a logical incentive or subsidy that incorporates the type of biomass (tree tops/branches vs. small diameter trees vs. dead, non-salvageable trees) and the distance to a biomass buyer is crucial to overcome the economic realities of biopower.

Biofuels

The use of forest biomass to generate biofuels holds much promise, including pyrolysis fuels, ethanol, and Fischer-Tropsch fuels. The full discussion of these fuels, their utility, and application is included in the companion study " *Pathways to Carbon Neutrality in California: The Bioenergy Opportunity*" (9).

However, forest biomass will typically remain the most expensive type of biomass due to the cost of transport as compared to agricultural residues or municipal solid waste. As biofuel markets are established, it will be crucial to recognize this fact and – if desired – provide incremental incentives to forest biomass-based biofuels if supporting forest management is an objective.

Forest Management Scenario options

California has declared an ambitious set of objectives in scaling up forest management. By deploying a mix of the strategies discussed above, California can make progress against the state-wide goal of delivering 1,000,000 acres of forest management per year, representing a near doubling of area covered versus today.

Generating a spatially explicit estimate of the cost of expanding forest management was beyond the scope of this deep-dive, and ultimately will be largely driven by the choice of policy incentives employed. In particular, the cost is expected to vary depending on the degree to which opportunities like expanded timber harvest, biopower, and engineered wood products are invested in with the co-benefit of supporting forest management. Quantifying the cost in a spatially explicit manner under various policy scenarios is an area of further research.

However, a simple estimate of the quantitative costs suggest the effort could cost an incremental ~$110 million to ~$450 million annually. While these are meaningful amounts, they pale in comparison to the $10B-$150B annual wildfire cost estimates discussed earlier. These simple forest management incremental costs are calculated using high and low threshold. The lower estimate, ~$110 million, is based on the optimistic assumption that investments in core timber harvest and biopower can subsidize the cost of forest management down to $250 per acre for the 450,000 acre expansion, which is an even higher cost than estimates discussed previously (15) (23). The higher estimate, $450 million, is based on the costs cited for investments in forest management exclusively at $1,000 per acre (4) (23). If there is conviction that investment in forest management can reduce the costs of wildfire by at least ~5% ($500 million as a share of the lower cost estimate of $10 billion), then under all scenarios California breaks even on the investment.

Admittedly, there are potential downsides to the 1 million acre scenario. In particular, a question the authors heard multiple times is on the feasibility of the scale up and the potential need to scale down. If the supply chain is scaled up to reach 1 million acres, how will the workforce and industry be supported once the backlog of forest management is completed? Is there a way to sustainably build the industry?

Regardless, the key message on the rough scenario analysis is clear – the costs of investing in forest management are expected to be significantly lower than the costs of maintaining the business as usual.

Conclusions

California's working lands – and forests in particular – have a major role to play in the path to net zero. Crucially, the 100 Mt+ annual CO_2 emissions from recent wildfire seasons must be controlled through intentional forest management on the order of 1 million acres per year, a doubling of current rates.

The supply of biomass coming from forests will increase dramatically with more dedicated forest restoration, with estimates ranging from 10-24M BDTs (versus 1.5M currently consumed).

In order to fund the scale-up in forest management, opportunities have been identified in the timber harvest and forest products industry, including an expanded commercial harvest and development of engineered wood products (including oriented strand board, cross-laminated timber, and glued laminated timber).

Using forest biomass for electricity generation through biopower, conversely, is the lowest value end-use for biomass. However, it still can play a critical role in helping subsidize the cost of forest restoration. Thus, it will be crucial to support the biopower industry by pursuing integrated wood product campuses, investing in new carbon capture and storage technologies, providing clear forecasts of supply, and investing in incentives or subsidies that directly fund biomass removal (specific to the type of biomass and distance to off-taker).

Biofuels also represent significant opportunities for supporting forest management. However, additional subsidies will be needed to incentivize use of forest biomass over municipal solid waste or agricultural residues given the high costs of transport.

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