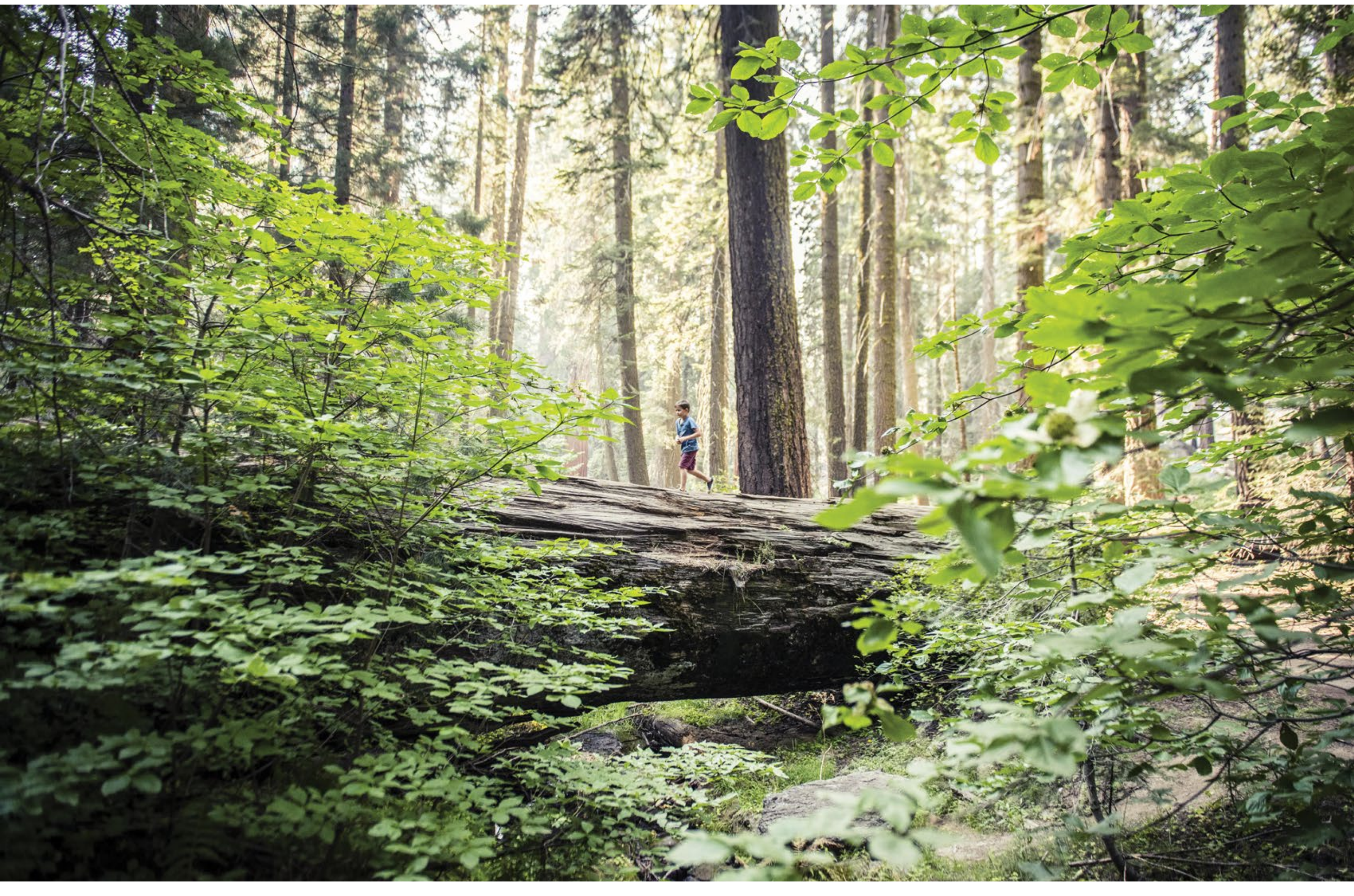
ACCELERATING FOREST RESTORATION

Stimulating a Forest-Restoration Economy and Rebuilding Resilience in California's Fire-Adapted Forests



The Nature Conservancy | BAIN & COMPANY

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December 2020

Hikers looking up at an old-growth redwood tree living in Humboldt County, California. © Mark Godfrey/TNC

Executive Summary

In 2019, The Nature Conservancy, a global conservation leader, and Bain & Company, a top-ranked management consulting firm, partnered to evaluate the role marketable wood products sourced from smaller-diameter trees (such as wood used for bioenergy or lumber) can play in accelerating the restoration of California's fire-prone forests to promote forest health and resilience and reduce the risk of high-severity wildfire.[a] In this briefing paper, we assess the challenges and opportunities associated with making economic use of the by-products of forest restoration. Based on a systematic evaluation of more than 40 end markets (using criteria related to each product's technical feasibility, readiness, environmental impact, and economic viability), Bain concluded that the expanded use of existing technologies (such as bioenergy and sawmills) offers the most promising means of accelerating forest restoration. Bain's investment analysis and interviews with industry experts further suggest that combining these capabilities into an integrated wood-products campus represents the best approach to set the stage for future innovation (e.g., enabling the testing of product manufacturing that is cleaner and/or value-added). However, despite the technological readiness of bioenergy and sawmills, we found that the viability and growth of these two high-priority markets will continue to be challenged without significant changes in public policy and administrative processes. Drawing on extensive interviews, Bain identified multiple systemic barriers related to existing land-management policies and financing, lack of secure wood supply (including contracting hurdles), and limitations on the size of forest-restoration projects. Our comprehensive analysis suggests that creating a restoration economy can play an important role in expanding the pace and scale of ecologically based forest restoration. To that end, we recommend development of appropriate funding, incentives, and preferential policies that bridge the gap between the cost of ecological thinning and the economic viability of wood-processing infrastructure. In addition, we advocate a joining together of federal, state, local, industry, tribal, and non-governmental organization (NGO) interests to define science-based and socially acceptable thinning practices that can in turn provide secure and long-term sources of supply. Finally, we recommend accelerated development of landscape-scale forest-restoration projects with parallel efforts to develop associated wood-processing infrastructure.

a The authors of this briefing paper use "Bain & Company" or "Bain" for findings and recommendations attributable to Bain's analysis and recommendations and "we" (or the equivalent pronoun) for those co-developed with The Nature Conservancy.

Aerial view of trees killed by the 2014 King Fire. The wildfire burned more than 97,000 acres, much of it at high intensity. © Placer County Water Agency

Introduction

Forests of the Sierra Nevada and across the western U.S. are under unprecedented threat from catastrophic wildfire, insect outbreaks, and drought. Over the last seven years alone, eight separate wildfires in the Sierra Nevada have burned 100,000 acres or more, with unusually large patches of forest seeing a majority of trees killed and a dramatic transformation of the ecology of the landscape.[1,2] As of this writing, California's 2020 wildfire season is making history with more than 4 million acres burned, more than double the previous record. Over a similar period, the number of dead trees from insect outbreaks, drought, and disease has skyrocketed since 2014.[3] According to the California Legislative Analyst's Office,[4] "the Sierra National Forest has lost nearly 32 million trees, representing an overall mortality rate of between 55% and 60%." Statewide, the USDA Forest Service estimates that more than 162 million trees have died since 2010. As the climate continues to warm, similar or more extreme events are predicted. A recent California-wide study found that since the late 1970s, the average number of days with extreme fire weather in the autumn season has more than doubled.[5] Beyond the direct threat of catastrophic wildfires to the lives and communities of California residents, the dramatic loss of healthy, resilient forestland and forested watersheds degrades the many benefits these ecosystems provide, including clean water, carbon storage, wildlife habitat, and economic and recreational opportunities. Furthermore, climate scientists predict that long-term or permanent forest loss is likely if extreme fire behavior grows unchecked.[6–8]

How did we get here? Before the 20th century, frequent natural lightning wildfires and those intentionally set by Native Americans played important ecological functions: nutrient cycling, reducing tree densities, and initiating the germination of native plant species, among others.[6–9] However, starting in the mid-19th century, Euro-Americans settled the West, causing burning by Native Americans to decline precipitously. This decline continued unabated and was followed by more than 100 years in which the largest, most fire-resistant trees were felled for logs amid an effective policy of fire suppression that remains in place today. Through it all, many young forests in the Sierra Nevada have continued to grow denser. Over time, dead trees and branches, or "surface fuels," have accumulated and, once lit, carry fire to brush, small trees, and the lower branches of larger trees ("ladder fuels"). This produces the kind of high-severity "crown fires," or wildfires, that we have witnessed moving rapidly through the forest canopy in recent years. While overall the frequency of wildfires remains relatively low compared to pre-European settlement, scientists have documented rapid increases in fire size[10,11] and have found evidence of increasing fire severity in recent decades.[12–17]

In California alone about 6–9 million acres of forestland need some form of ecological treatment to restore their health and resilience.[1,18] In 2018, the Forest Service succeeded in treating more than 300,000 acres of forestland, a promising achievement but not enough to address the total acreage sufficiently quickly to mitigate serious ecological and climate risks. Fortunately, recent research provides insights into how to manage forests so they are less prone to large, severe wildfires and more resilient to drought[19–22] while mitigating the risk to sensitive plant and wildlife species. A prior paper published by The Nature Conservancy (TNC) lays out three primary treatments as part of the case for ecological forestry in the Sierra Nevada: targeted ecological thinning, prescribed burning, and careful management of naturally ignited wildfires on federal lands, within predetermined boundaries ("managed wildfire").[2] The current challenge facing California is to greatly accelerate the speed and scale with which these treatments are applied, which is critical to address the widespread and long-term nature of the problem. TNC believes that taking no action, or letting forests burn at high severity under current conditions, is not a desirable option based on the ecological values that forests provide and the threat to lives and communities.

TNC is working with state, federal, and private partners to develop the strategic application of all three aforementioned treatments at large scale (e.g., more than 100,000 hectares) to protect nature and people. This paper focuses primarily on ecological thinning as a critical component of TNC California's overall ecological forestry strategy. Such thinning is often a necessary pre-condition for the reintroduction of prescribed or managed fire and, as a by-product, can produce large quantities of wood fiber that may be converted into a variety of wood-based products.

TNC believes that taking no action, or letting forests burn at high severity under current conditions, is not a desirable option based on the ecological values that forests provide and the threat to lives and communities.

A primary constraint on expanding the pace and scale of forest restoration is the high cost of ecological thinning and the limited wood-processing infrastructure to support it. If more aggressive restoration targets can be met, there will be significant need for additional processing capacity to defray restoration costs and provide valuable end uses for thinned material. This basic "forest-restoration cost and infrastructure" problem is the central focus of our research. This briefing paper explains the current state of California's wood-products industry and the need for additional processing capacity to support forest restoration. It then assesses end-market opportunities for ecologically thinned material and discusses the enabling conditions required to support a forest-restoration economy in California.

Sierra mixed-conifer forest following ecological thinning—French Meadows Project (American River watershed), Tahoe National Forest. © Brie Anne Coleman, Placer County Water Agency

Small-Diameter Wood Processing Is Needed to Accelerate Forest Restoration

California's wood-products industry has undergone a major transformation over the last 30 years.[23–25] Historical overharvesting brought about changes to California's social, political, and legal environment that significantly limited the level of timber harvesting, particularly on public lands. Moreover, historical clear-cutting focused on the largest, most accessible, and highest-value logs, leaving a less profitable (and less attractive) mix of materials available for harvest over time. At the same time, changes in land ownership and land-use preferences reduced California's productive timberland and associated infrastructure. Finally, increasing competition from industry players with predictable low-cost supply sources and more favorable operating environments—particularly in Canada, the Pacific Northwest, and the southeastern U.S.—put further pressure on California's wood-products operators. As a result, California's timber harvest declined from nearly 5 billion board feet (Scribner[b]) in the mid 1980s to 1.5 billion board feet (Scribner) in 2016, while the number of active wood-products facilities in California declined by more than 40% over a similar period (1985–2016)[26] [Exhibit 1]. While milling-efficiency improvements have enabled these facilities to keep pace with declining harvest volumes, a significant gap remains between infrastructure footprint and in-state demand for wood products. Today, despite being the largest wood-products market in the country, California imports up to 80% of wood products used in the state,[27] primarily from the Pacific Northwest and Canada.

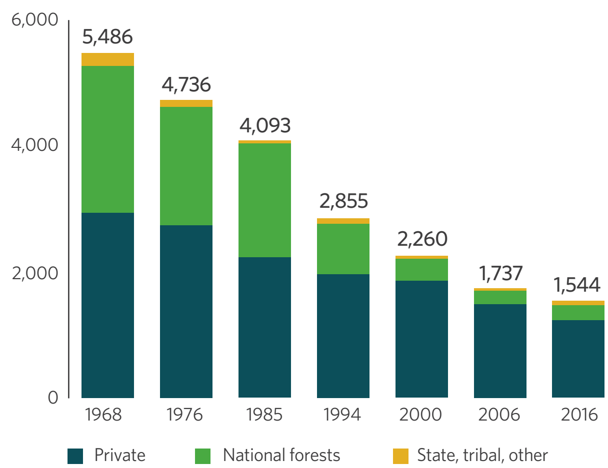
Because there is little infrastructure in California to handle forest-thinned material, expanding the pace and scale of restoration efforts would quickly overwhelm the capacity of existing infrastructure to absorb the supply. A recently

b The Scribner log rule is used to "scale logs"—a process by which their gross and net volume is estimated and expressed in customary units (e.g., board feet, cubic feet, etc.). See the *"National Forest Log Scaling Handbook"* for more information.

Exhibit 1 | The California timber industry has been in long-term decline due to historical overharvesting, leading to limitations on federal land harvesting and infrastructure.

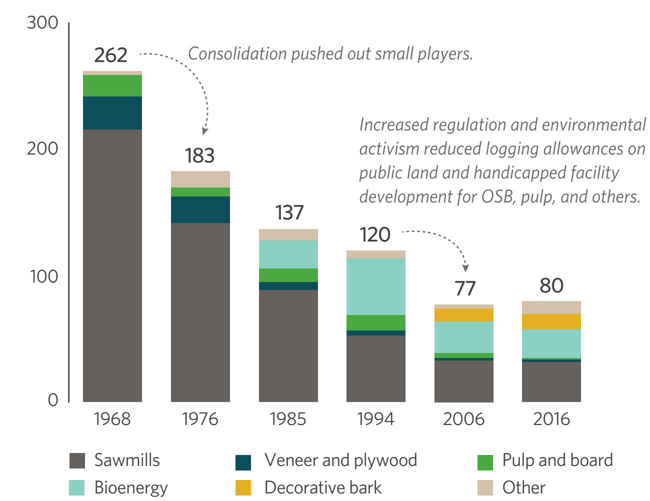
Timber harvest volume, particularly on public land, has declined dramatically from historical highs.

Timber harvest (million board feet, Scribner)



Infrastructure footprint has shrunk accordingly.

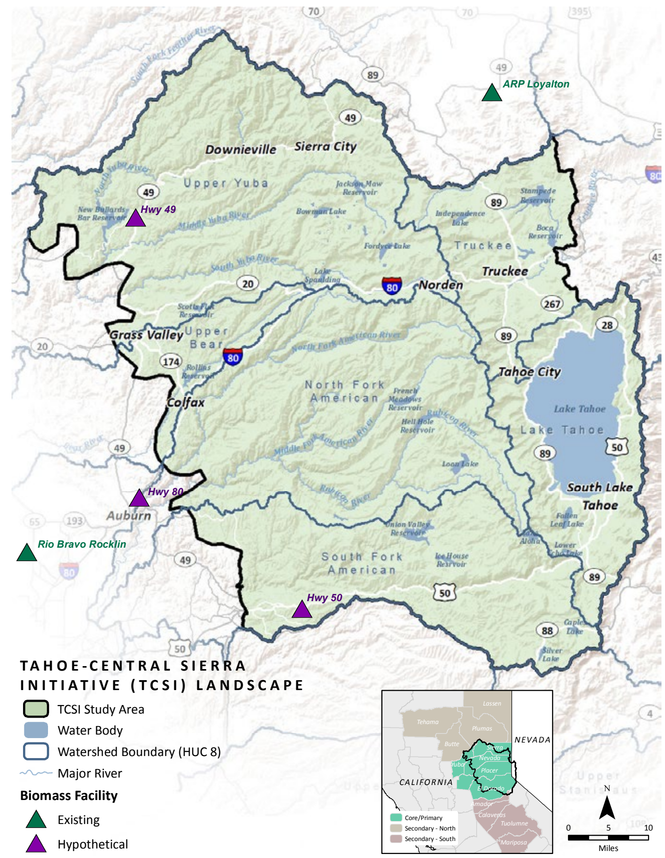
Active California primary wood-products facilities by sector



Notes: Residue-utilizing sector includes pulp, paper, board mfg., animal producers, fuel pellet mfg., and decorative bark; Veneer and other includes log-home accents, peeler cores, posts, poles, pilings, and log furniture; Bioenergy and decorative-bark figures unavailable before 1985; Other includes log homes, firewood, log furniture, fuel pellets, exporter, and utility-pole mfg.; Other sale value for CA includes pulp/paper.

Sources: USDA; University of Montana; CAWBIOM; *LA Times*; National Renewable Energy Laboratory

Exhibit 2 | Tahoe–Central Sierra Initiative (TCSI) Landscape.



Map: Tanushree Biswas, The Nature Conservancy

completed wood-supply analysis of the 2.4 million-acre Tahoe–Central Sierra Initiative region [Exhibit 2, map of TCSI] indicates a supply overage of 30–100 million board feet (MMBF) per year of saw logs and 240,000–340,000 bone dry tons (BDT) per year of biomass (from live and dead trees), depending on the land-management scenario.[28] This implies a need for at least one additional small-log sawmill and up to four additional biomass energy facilities in this region alone. Best-available statewide research indicates currently operating sawmills and biomass facilities are running at greater than 85% capacity utilization,[26,29] underscoring the need for additional processing capacity across the state. For sawmills, the gap in specialized small-log (e.g., less than 20 inches in diameter) processing capacity appears to be particularly acute.

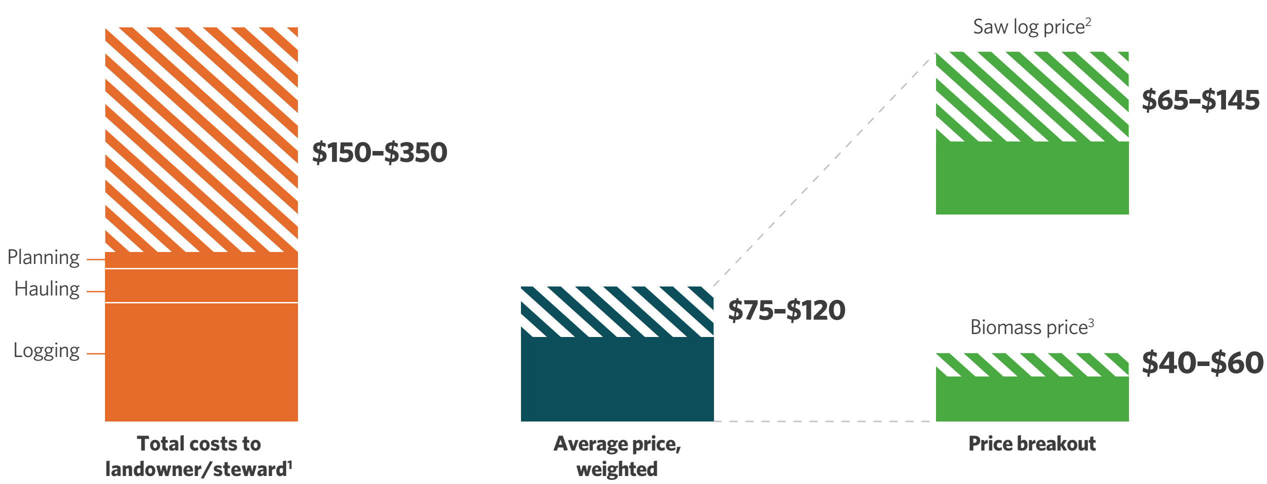
The Importance of End Markets

Why are robust wood-products markets important for increasing the pace and scale of forest restoration? First, without offtakers for low-value forest material, land managers will continue current practices for disposing of forest waste—primarily open pile burning, broadcast burning, or masticating/chipping and spreading on site. These practices are undesirable from a climate and air-quality standpoint and have poorly understood effects on forest ecology. Open pile burning releases substantial amounts of air pollutants and carbon, which pose significant human health and climate risks.[30] Masticating or chipping and then spreading woody material on site is a reasonable alternative among a limited set of options but releases large amounts of carbon, alters the ecology of the forest floor, and, in some cases, can temporarily extend the period of elevated wildfire risk.[31] It is important to find better alternative uses for this material.

Second, viable end markets for woody biomass can help defray the high cost of ecological thinning. The cost of ecological thinning can range significantly depending on the operability of the land and other variables, but estimates suggest it typically falls between about $1,000–$3,000 per acre[32–34] (about $150–$350 per BDT, depending on the productivity of the land). Without nearby markets in which to sell forest-thinned material, this can be prohibitively expensive for landowners who typically bear the cost of planning, logging, and hauling the material. On the other hand, investments in nearby processing infrastructure can significantly reduce hauling costs for landowners and offer delivered prices for biomass and sawtimber in the range of $40–$60 per BDT and $60–$145 per BDT, respectively, depending on the offtaker and feedstock mix [Exhibit 3]. While this may not be enough to fully offset the cost of ecological thinning, it can make a significant impact on a landowner's or land steward's calculation of the viability of forest-restoration projects, especially if coupled with additional support in the form of financial resources or planning and implementation expertise. Because approximately 58% of the forestland in California is federally owned, the citizens of the U.S. will bear a significant proportion of these costs or, if no action is taken, pay more in wildfire response, recovery, and rehabilitation costs.

Exhibit 3 | Example of ecological-thinning-project economics illustrates the value of end markets in helping defray the high cost of forest restoration.

Cost and price of thinned materials, in dollars per BDT



1 "High Hazard Fuels Availability Study," Mason Bruce & Girard and The Beck Group, June 2019. Industry participant interviews.

2 California Department of Tax and Fee Administration Harvest Values Schedule, July 2019. State of Oregon Department of Forestry Timber Sales Results. Fritch Sawmill Current Log Price Sheet. Industry participant interviews.

3 "California Assessment of Wood Business Innovation Opportunities and Markets (CAWBIOM)," The Beck Group, Dec. 2015. Industry participant interviews.

Note: Assumes a minimum of roughly a 50-mile haul distance to a processing facility; assumes between 6–12 BDT are thinned from every acre and $1,000–$3,000/acre thinning costs; weighted average based on a sensitivity analysis around French Meadows volume distribution of different diameter trees (43% medium logs, 23% small logs, 33% biomass) and variable saw-log pricing. Lower and upper ranges of cost and price values are shown as solid and striped portions, respectively.

Truck unloading wood chips. © imantsu/iStock

The Best Options to Accelerate Forest Restoration in the Next 5–10 Years Are Existing Technologies such as Sawmills, Biomass Energy, and Integrated Wood-Processing Campuses

From TNC's perspective, public funding or policy that incentivizes wood-processing infrastructure should only be for the removal of small-diameter trees, surface fuels, and ladder fuels (defined further below). Moreover, any tree removal, particularly on federally owned forestlands, should be conducted in a manner consistent with the principles of ecological forestry (e.g., "*Wildfires and Forest Resilience: the case for ecological forestry in the Sierra Nevada*," "*An Ecosystem Management Strategy for Sierran Mixed-Conifer Forests*,"[35] "*Managing Sierra Nevada Forests*,"[36] or an equivalent science-based guidance document). New infrastructure for the removal of hazardous fuels will require significant up-front capital investment, and any public financing must be tied to ecological goals and outcomes.

An understanding of existing end-market infrastructure is critical to determine the state's point of departure for expanding wood-processing capacity. California's current infrastructure footprint consists primarily of sawmills and biomass energy facilities, the majority of which are located in the Northern Sierra and North Coast regions [Exhibit 4]. While sawmills account for the majority of timber volume in the primary processing step (more than 60%), biomass energy ends up accounting for the largest share of the timber volume by final end use (more than 40%)[7] due to the significant amount of mill by-product that lumber conversion generates [Exhibit 5]. Aside from biomass energy, California notably lacks any significant infrastructure that makes use of mill residue, such as pulp and paper, particleboard, or fiberboard products.[26]

With this in mind, Bain evaluated more than 40 potential end markets for forest material derived from ecological thinning based on three criteria: technical feasibility, environmental impact, and economic viability [Exhibit 6]. "Technical feasibility" refers to whether the technology and supporting infrastructure are sufficiently mature to use small-diameter timber and woody biomass to produce the end product. "Environmental impact" refers to the end market's ability to address immediate forest-health goals and provide carbon sequestration benefits, with minimal unintended consequences. "Economic viability" refers to the end market's commercial maturity and ability to achieve a risk-return trade-off that industry players and investors will find attractive. These three criteria were equally weighted when evaluating potential candidates for additional wood-processing infrastructure. The evaluation is based on extensive review of secondary literature as well as more than 50 interviews with experts in industry, academia, government, NGOs, and other institutions.

While there are many promising wood-based technologies at varying stages of technical and commercial development, Bain concludes that the most viable end markets for addressing the forest health crisis on a 10-year timeline* are those that build on California's established infrastructure: sawmills (for both small and medium to medium-large logs**), biomass energy, and integrated wood-utilization campuses. Economic viability, in particular, benefits from synergies achieved by locating by-product markets alongside their primary raw material source (mill residue). Furthermore, integrated campuses offer a platform for incubating more nascent technologies that require further technical or commercial development but may hold potential over a longer period (e.g., cross-laminated timber, biochar, biofuel). Thus, Bain believes integrated campuses represent the most compelling opportunity to address the problem at scale today. However, given the limited footprint of integrated campuses and their reliance on mill residue, there will likely remain a substantial amount of low-value forest material for which the best near-term use is biomass energy and its by-products. Exhibit 7 summarizes the advantages and remaining challenges of the high-priority markets Bain identified.

> *In fact, on a standalone basis, the viability of even these high-priority markets [bioenergy and small-log sawmills] will remain challenged without a common set of enablers in place that are a necessary precondition to a sustainable forest-restoration economy.*

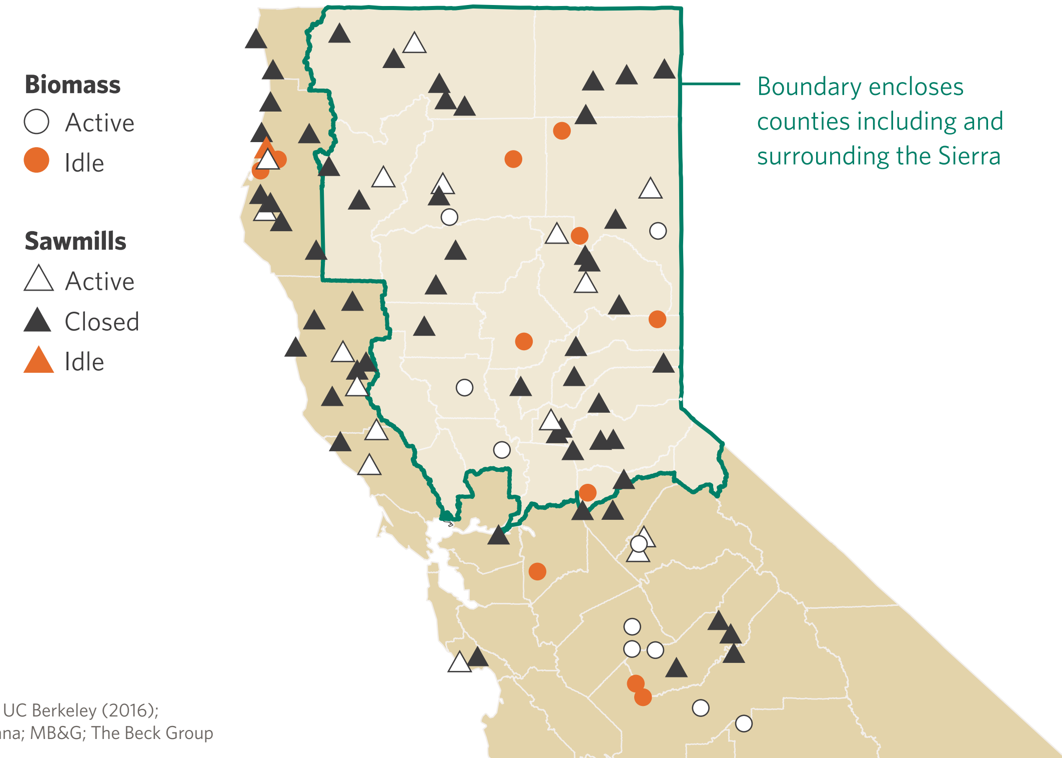
Several other markets, including oriented strand board (OSB), wood pellets, cross-laminated timber (CLT), glulam, green veneer, and medium-density fiberboard (MDF), were flagged as high potential after initial screening, but subsequent analysis and conversations with industry experts revealed one or more significant barriers to their technical or economic feasibility [Exhibit 8]. It is important to note that changes in operating conditions could rapidly enhance or degrade the viability of any market. As a result, our intention is not to categorically exclude other potential markets from consideration in discussions with partners and policy makers, but rather to prioritize top candidates for further investigation and investment.

In fact, on a standalone basis, the viability of even these high-priority markets will remain challenged without a common set of enablers in place that are a necessary precondition to a sustainable forest-restoration economy (see next section). Exhibit 9 approximates the unit economics for an illustrative sawmill, bioenergy facility, and integrated campus operating in California. Though each market can achieve positive operating margins under reasonable assumptions, they require significant capital investments, long payback periods, suitable end-market buyers, and—perhaps most importantly—a secure source of fiber supply. These factors underscore the need for a set of enabling conditions to enhance the viability of wood-processing infrastructure in California.

*Note: The Nature Conservancy recommends adopting this timeline, recognizing the significant backlog of forest treatments, the wildfire risk to communities, and the continuing and rapid growth of second-growth forests.

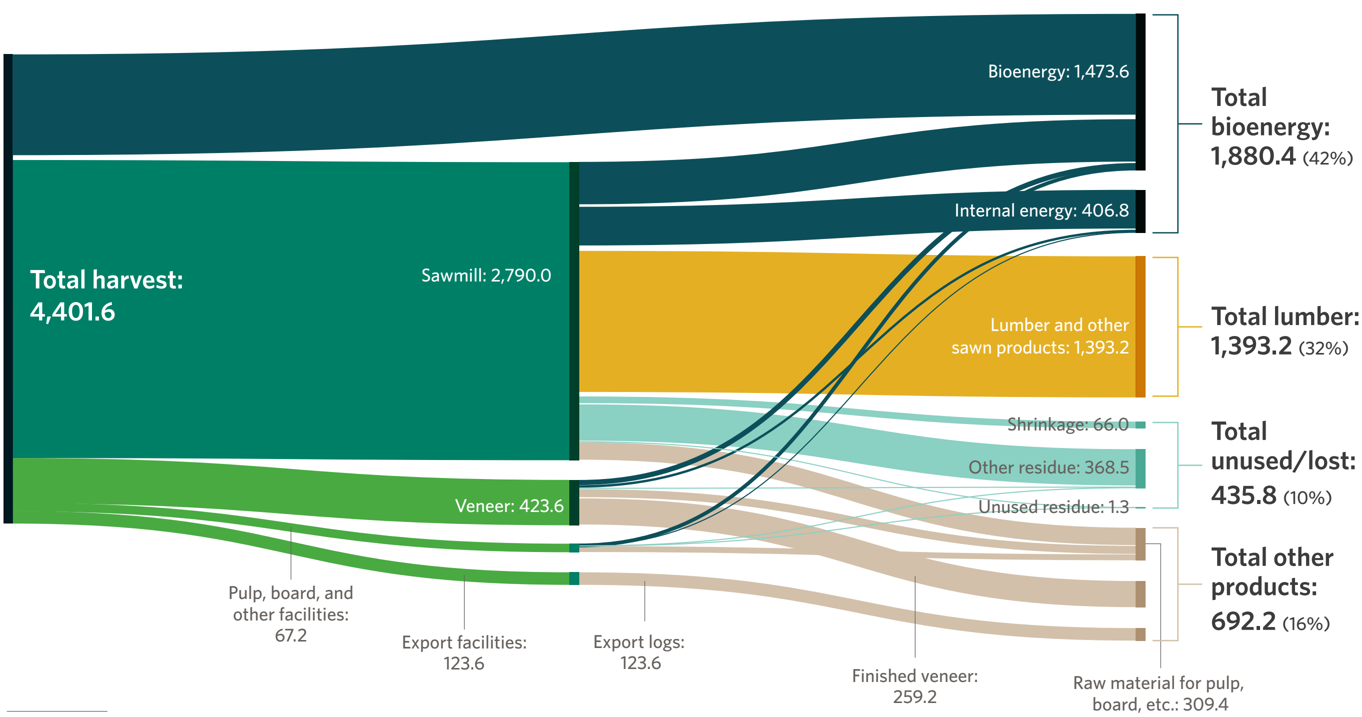
**Note: Medium logs are defined as 12–20″ diameter at breast height (DBH); medium-large logs as more than 20″ and less than or equal to 30″ DBH (and are removed strictly depending on what's required for ecologically based forest restoration). Small logs are defined as merchantable logs less than 12″ DBH. Forest-sourced biomass includes non-merchantable logging and milling by-products, generally less than 10″ DBH. In general, the intended reduction in surface and ladder fuels can be achieved while removing a minor proportion of the medium-large trees.

Exhibit 4 | California wood-processing infrastructure consists primarily of sawmills and biomass facilities located in Northern Sierra and North Coast regions.



Sources: USDA and UC Berkeley (2016); University of Montana; MB&G; The Beck Group

Exhibit 5 | Flow of timber volume from harvest to end use (MMBF).



Sources: University of Montana; USDA

Exhibit 6 | Commercial opportunities to increase demand for forest-thinned material can be prioritized based on feasibility, environmental impact, and economic viability.

FEASIBILITY

Does the technology and infrastructure exist to use forest-thinned material for this market?

- Forest-thinned material's diameter and species **meet technical requirements**.
- **Scaled proof of concepts exist** in other places.
- There is **existing infrastructure in place** that can be leveraged.
- Further **ecosystem development** needed can be achieved by TNC/partners.
- There is favorable **regulatory and policy** movement in the end market.

ENVIRONMENTAL IMPACT

Will this solution make a significant impact on the problem, with minimal unintended consequences?

- Project addresses **immediate forest-health goals**.
- Limited **unintended consequences** likely (e.g., land abuse, pollution).
- Project **sequesters carbon** in long-lived wood product.
- Serving this market proves **future scale-up models** in other locations.

ECONOMIC VIABILITY

Is there a path to a risk-return tradeoff that partners will find attractive?

- There is sufficiently large **raw material supply** to meet project needs.
- Market is sufficiently **large and growing**.
- Project can achieve **positive operating margin** under reasonable assumptions.
- Project **payback period** is reasonable for given level of capex investment.
- Market is **eligible for financial support** (e.g., subsidies, carbon offsets).

Exhibit 7 | Pros/cons of high-priority markets.

<table>
<tr><th colspan="2">SAWMILL</th></tr>
<tr><td>Advantages
Technically feasible for a large portion of wood supply using a range of log diameters, particularly if improved technology for small-log processing is used (e.g., HewSaw).
Sequesters carbon in a long-lived wood product.
Achieves relatively attractive economics under reasonable assumptions (e.g., a payback period of about 10 years).</td><td>Remaining challenges
Execution risk due to thin margins and limited operators with expertise in small-log technologies.
Lumber price and demand volatility.
Allowable mix of small- vs. medium-diameter trees must be driven by appropriate ecological guidelines, which may degrade sawmill economics (if supplemental supply sources cannot be secured).
Competition from large, established players (if new entrant).</td></tr>
<tr><th colspan="2">BIOMASS ENERGY</th></tr>
<tr><td>Advantages
Utilizes widest range of forest material, including residue, treetops, chips, and dead trees.
Large number of recently decommissioned facilities could be rapidly put back into operation at low cost relative to greenfield capital expenditure requirements, assuming doing so poses no safety concerns.
Reliable, baseload energy source that provides local grid resilience to rural communities.</td><td>Remaining challenges
Price for delivered energy not cost competitive with other renewable-generation methods or natural gas, making long-term utility contracts difficult to secure without regulatory intervention.
Less favorable carbon profile vs. other end uses for woody biomass (e.g., biofuels, biochar).
Poor public perception of air-quality impact due to historical pollution by a few bad actors.
Challenging greenfield economics limit number and location of potential facilities.
Execution risk due to thin margins and uncertain supply prices.</td></tr>
<tr><th colspan="2">INTEGRATED SAWMILL + BIOMASS ENERGY CAMPUS</th></tr>
<tr><td>Advantages
Diverts feedstock mix to its best use, using low-value material for bioenergy and higher-value logs for dimensional lumber and possibly mass timber.
Anchored by large, commercially proven markets today (e.g., sawmills, bioenergy) that do not rely on technological advancements for viability.
Generates significant incremental synergies by locating bioenergy production alongside its primary raw material source (mill by-product), enhancing the overall economic viability of the venture.
Can serve as a platform to incubate more nascent technologies that make use of the residual by-products and low-value material.</td><td>Remaining challenges
(incremental to standalone sawmill and bioenergy challenges)
Requires higher up-front capital expenditures.
Increased complexity in finding an operating partner, suitable development site, and financiers depending on the diversity of businesses involved.</td></tr>
</table>

Exhibit 8 | Further analysis surfaced one or more significant barriers to the technical or economic viability of other high-potential markets.

SUBJECT	DESCRIPTION	FEASIBILITY	
Oriented strand board (OSB)	**A structural panel product consisting of wood strands that are layered and oriented for maximum strength and stability**	✓ (Moderate)	• Input rigidity and strength requirements restrict use of certain species in Sierra conifer-mix forests.
Wood pellets	**Biomass fuel that is burned to heat buildings or co-fired with coal to generate electricity**	✓ (High)	• Feasible with forest-thinned material.
Cross-laminated timber (CLT)	**A pre-fabricated solid-engineered wood panel made of at least three orthogonally bonded layers of solid sawn lumber that are laminated by gluing longitudinal and transverse layers**	✓ (Moderate)	• Quality requirements restrict use of some species and sizes of wood. • Approximate 10% conversion rate from thinned material to CLT production.
Glulam	**Engineered machine-stress-rated product created by adhesively bonding individual pieces of structural composite lumber**	✓ (Moderate)	• Can use forest-thinned material but needs to be machine-stress graded.
Green veneer	**Thin sheets of wood fiber that are peeled from logs and used in a variety of composite wood products**	✓ (Moderate)	• Can use forest-thinned material but requires at least some share of large diameter, especially for laminated veneer lumber (LVL) that has higher-quality requirements.
Medium-density fiberboard (MDF)	**Panel composed of wood that has been reduced in size to individual fibers or fiber bundles that are combined with a synthetic resin and bonded together**	✓ (High)	• Feasible with forest-thinned material.

✗ Limited feasibility/impact/viability ? Unclear ✓ Moderate feasibility/impact/viability ✓ High feasibility/impact/viability

	ENVIRONMENTAL IMPACT		ECONOMIC VIABILITY
✓	• Sequesters carbon but some concerns about air quality.	✗	• High cost of input material compared to Southeastern United States (SE U.S.) that utilizes low-cost yellow pine from easily operable private land. • High-cost operating environment relative to SE U.S. due to additional processing for CA-specific wood species and labor and air-quality regulations.
✓	• Releases carbon but is a substitute for coal.	✗	• Large international market (esp. Japan and S. Korea) but unpredictable demand dependent on favorable policies. • High cost of using forest-thinned materials compared to scale competitors (e.g., Pinnacle, Enviva) using mill residue. • Large up-front capex to build port infrastructure.
✓	• Sequesters carbon in a long-lived wood product.	✗	• High level of low-value residue produced. • Uncertain demand, requiring experienced developers/architects willing to use CLT, adoption of CLT-friendly building codes at local levels, etc. • Several competing sources of supply in nearby states (e.g., Katerra, Vaagen, SmartLam).
✓	• Sequesters carbon in a long-lived wood product.	✗	• Market has excess low-cost supply, including from large-scale international players. • Demand has remained stagnant.
✓	• Sequesters carbon in a long-lived wood product.	✗	• Demand for plywood declining. • LVL growth would require a higher ratio of larger-diameter, higher-quality timber vs. typical ecological thinnings.
✓	• Sequesters carbon in a long-lived wood product.	✗	• Commoditized product with significant price competition. • Limited supply-demand gap with large U.S. suppliers such as Weyerhaeuser, West Fraser, etc. • Economics rely on low-cost mill residue vs. forest thinnings.

Exhibit 9 | Illustrative unit economics for priority end markets.

	BIOENERGY (BioRAM facility)	**SAWMILL** (small and medium-large log lines†)	**INTEGRATED CAMPUS** (bioenergy + sawmill)
Modeled output	20MW	~200MMBF lumber	20MW + 200MMBF
Modeled intake	~340MMBF	~960MMBF	~960MMBF
Total revenue	$17M	$72M	$81M
Lumber revenue	N/A	$70M ($350/MMBF[4] * 200 MMBF)	$72M[9]
Energy revenue	$17M ($120/MWh[1] * 142K MWh[2])	N/A	$9M ($75/MWh[10] * 121K MWh[11])
Other revenue	$0M	$2M (Residues: $10/BDT[5] * 200K BDT[6])	$0M
Total costs	$14M	$59M	$59M
Raw material cost	$9M ($65/BDT[3] * 142K BDT)	$36M ($90/BDT[7] * 400K BDT)	$37M (Sawmill $36M; Bioenergy: $1M[12])
Other costs	$5M	$23M[8]	$22M[13]
Operating margin	$3M ~16%	$13M ~19%	$22M ~27%
Capital expense	~$20M brownfield ~$100M greenfield	~$150M greenfield	~$170M–$250M
Payback period	~7 yrs. brownfield ~37 yrs. greenfield	~12 yrs. greenfield	~8 yrs. (greenfield sawmill, brownfield bioenergy) ~11 yrs. (greenfield sawmill, greenfield bioenergy)

†Medium to large logs typically defined as 12–20" DBH and above (strictly depending on what's required for ecologically based forest restoration); small logs defined as merchantable logs less than 12" DBH; forest-sourced biomass includes non-merchantable logs (typically those less than 5–6" DBH), dead trees, and logging and milling by-products.

Notes: 1. Assumes bioenergy plant has a $120/MWh PPA similar to BioRAM plants; 2. Assumes plant operates at industry-standard capacity of ~80%; 3. Costs higher than typical biomass prices due to BioRAM market distortions; 4. Last five-year median lumber price; 5. Revenue from residues sold at low value to various offtakers (e.g., animal bedding, mulch); 6. Assumes 50% residues; 7. Based on industry participant interviews' assessment of the cost to harvest small and medium logs for a vertically integrated sawmill operation; 8. Based on industry participant interviews on processing and drying costs (~$115/MMBF); 9. Based on sawmill economics; 10. Low range of likely PPA contract given electricity is not the anchor of the business; 11. Remaining electricity after ~20K MWh utilized by sawmill; 12. Based on $10/BDT transfer price to sawmill for chips; 13. Accounts for $5M savings in utility bill due to on-site generation (20,000 MWh used at $250 per MWh avoided cost based on sawmill industry expert interviews and utilities' published rates) and 5% savings in overhead due to plant synergies.

Lumber construction. © Juanmonino/iStock

The Solution to California's Forest-Restoration Cost and Infrastructure Problem

Develop the Enabling Conditions Necessary to Support a Forest-Restoration Economy and Accelerate the Development of Landscape-Scale Restoration Projects and Supporting Wood-Processing Infrastructure

We believe there is significant opportunity for California to lead in the development of a forest-restoration economy. This section highlights several recommendations to create the enabling conditions for a forest-restoration economy and to advance landscape-scale restoration projects and associated wood-processing infrastructure development.

1. PREFERENTIAL POLICIES AND FINANCING

Stimulating a forest-restoration economy in California will require strong leadership from state policy makers, policy advocates, and other public and private partners to reduce barriers to infrastructure investment and unlock financing for project developers. Under current circumstances, the cost of removing hazardous forest fuels is prohibitive for many landowners, partially due to a lack of viable end markets for the material. Simultaneously, industry operators and financial institutions do not perceive an attractive risk-return trade-off for wood-processing infrastructure investment due to a number of challenges discussed in this paper. We see an important role for policy makers to play in bridging this gap by providing a strong mandate to accelerate forest restoration and securing financial support to sustain the economic viability of thinning projects and wood-processing infrastructure. Specifically, we offer the following recommendations for consideration:

- **Provide low-cost capital for wood-processing infrastructure projects through a state revolving loan fund.** Wood-processing infrastructure requires significant up-front capital investment and ongoing working capital, making it difficult for investors or industry operators to achieve an attractive payback period. Sawmill, biomass, and other mass-timber development projects can range from $20M–$300M depending on the facility size, whether it's greenfield or brownfield, and a number of other variables. In any scenario, access to low- or zero-interest loans for projects utilizing forest-thinned biomass could reduce barriers to undertaking these projects and unlock investor and operator interest.

- **Offer an upstream subsidy to landowners and land stewards to defray the cost of large-scale restoration projects.** Current costs to landowners and stewards to undertake restoration projects are typically higher than the delivered prices for small sawlogs and biomass. A significant driver of this is the cost of hauling low-value forest fuels. A subsidy to public land stewards or small private landowners based on the volume of hazardous fuels removed and distance transported could help address this gap, stimulate additional restoration projects, and incentivize removal of material otherwise burned or left on site. In addition, shifting subsidies closer to the stump has the advantage of providing a market-agnostic stimulus that can support a broader portfolio of wood-product technologies than subsidies applied further down the forest-products value chain.

- **Allocate direct funding for forest-restoration projects and supporting infrastructure.** Direct funding to stimulate a forest-restoration economy could take at least two forms: 1) funding to landowners, land stewards, or project managers for forest-restoration projects or 2) funding to industry operators and investors to expand processing capacity to absorb material from forest-restoration and fuels-reduction projects. Bain and TNC believe both approaches are important and valuable components to accelerating the pace and scale of forest restoration and should be prioritized in upcoming funding packages, including California's 2022 Climate Resilience Bond.

- **Implement a state directive to accelerate forest restoration and increase wood-processing capacity.** We believe there is a role for the state administration to play in guiding state agencies and signaling legislative priorities to accelerate forest restoration and encourage expansion of processing capacity for ecologically thinned forest material. We offer the following observations for further consideration:

  » Given Forest Service capacity constraints, the augmentation of state agency staffing, training and workforce development, and funding levels will be critical to enable the expansion of restoration projects under the Good Neighbor Authority (GNA).

  » Expanding and enforcing the biomass energy procurement mandate is critical to ensure the viability of the state's current biomass infrastructure and to incentivize the development of new wood-processing capacity to absorb hazardous forest fuels.

  » Funding, incentives, and/or streamlined approvals for other wood-processing facilities (e.g., small- to medium-log sawmills, integrated campuses, and associated businesses) are important to accelerate the development of additional capacity with higher-value end uses and carbon sequestration benefits. The state revolving loan fund mentioned above is one potential funding mechanism to drive this.

  » There is opportunity for the state to lead in defining and driving forward direct incentives for forest-restoration projects, such as the upstream subsidy mentioned above.

  » For projects that meet clearly defined ecological criteria, there may be opportunities to streamline state planning and surveying requirements.

Wood-processing infrastructure requires significant up-front capital investment and ongoing working capital, making it difficult for investors or industry operators to achieve an attractive payback period.

2. SECURE SUPPLY

Industry participants consistently cited the need for predictable, long-term, and economical fiber supply as the most critical barrier to investing in California wood-processing infrastructure. This typically means a 10- or 20-year contractually guaranteed supply of feedstock from the landowner, with predictable diameter classes and species mixes.

In other regions of North America with mature timber markets, such as the southeastern U.S., industry players typically have access to large swaths of privately owned land that are relatively flat, ecologically homogenous, and easy to operate in.[37] As a result, contractual supply guarantees are typically easier to execute. In Canada, on the other hand, the vast majority of timberland is publicly owned (about 94%).[38] As a result, it is quite common for industry operators to rely substantially or entirely on public lands for timber supply; the associated policies, processes, and resources to enable this are well-established. Furthermore, given the forest industry's significant contribution to the country's economy (about 1.2% of GDP[39] and about 7.2% of total exports[40]), industry players may benefit from a more favorable operating environment. For example, while the federal government sets annual harvest limits, provincial governments set stumpage prices (typically below market rates) and directly or indirectly subsidize lumber through numerous grants for job creation and sustainability.

In California, about 56% of timberland is publicly owned, of which the Forest Service controls 95%.[1] As such, a significant portion of the California forestland requiring ecological thinning is owned by the Forest Service. Furthermore, much of this terrain is steep and mountainous, making ecological thinning more challenging and costly relative to other regions in North America. Taken together, these factors suggest a critical need to reduce barriers to long-term sources of supply and improve the attractiveness of operating on federal land in California. We propose the following ideas for consideration:

- **Expand use of long-term stewardship contracts.** Exhibit 10 summarizes current Forest Service contract types. While the Forest Service is currently authorized to offer 20-year stewardship agreements and contracts, adoption of these mechanisms has been limited for several reasons. First, Forest Service capacity remains constrained by federal budget decision making and resource demands for wildfire suppression. Second, there is limited social license for the Forest Service to engage in the type of large-landscape timber contracting required to offer 10- to 20-year supply guarantees for private industry. We offer the following possible solutions:

  » Establish a collaborative working group across Forest Service, state, tribal, NGO, and industry partners to define appropriate ecological guidelines needed to enable long-term stewardship contracts. We believe there is common ground between what's required for ecologically based forest restoration and what's required for economic viability of wood-processing infrastructure, but reaching consensus on that common ground will require open and productive collaboration across a diverse group of stakeholders.

  » Augment state staffing levels, expertise, and cost-sharing funds needed to undertake additional Good Neighbor Authority (GNA) agreements and associated supplemental project agreements. Given constraints on Forest Service staff levels and budgets and competing agency priorities, it will be critical to expand the role of the state in accelerating forest restoration. Currently, state agency capacity and expertise to undertake GNA agreements are limited. Therefore, we encourage an expansion of the state's resources and capabilities to administer such agreements and provide longer-term stability to associated contractual supply agreements.

  » Accelerate the adoption of 20-year stewardship contracts and agreements for forest restoration through a regional Forest Service directive. Given the limited adoption of 20-year stewardship contracts and agreements at the Forest Service today, there is limited agency expertise in how to effectively administer these arrangements. We believe that a Forest Service directive to encourage adoption of longer-term contracts should be accompanied by systematic training, tools, and dedicated resources for executing such contracts.

  » Explore opportunities for third-party entities (e.g., state agencies, NGOs, financial institutions) to de-risk long-term supply contracts on federal lands. Even if all of the above can be accomplished, it is not clear that industry operators and investors will perceive a sufficient level of de-risking in the fiber supply. Unexpectedly low harvest volumes, changes in the predicted feedstock mix, or uncontrollable wildfires or insect outbreaks all present additional risks to an institution considering a long-term infrastructure investment. Thus, we believe it is important to explore potential opportunities for a third-party entity to further de-risk supply, whether through "buffer zones" to augment product supply in challenging times (e.g., during high levels of forest loss due to wildfire), financial backstops to support struggling industry operators, or some other means. A cross-functional working group to determine the role and required resources and capabilities for such an entity would be an important first step in this process.

- **Revise Forest Service business practices.** Industry players, NGOs, state agencies, and other potential land stewards currently perceive barriers to taking on longer-term stewardship contracts and agreements. Specifically, comprehensive surveying requirements and the difficulty of operating in mountainous terrain drive up the costs of restoration projects. In some cases, contracts have been put out for bid at costs upwards of $10,000 per acre, driven by both challenging terrain and other service requirements embedded in the contract. In addition, common policies and practices around contracting, planning, and implementation are costly and time intensive. For example, the Forest Service indicates that, on average, environmental assessments take 687 days to complete.[41] As such, there are specific policies that the Forest Service can update to lessen the time and resources needed to develop long-term supply contracts:

  » Re-classify forest-thinned material from restoration projects as a liability, rather than a commodity. Doing so would allow the Forest Service to exempt low-value small-diameter timber and woody biomass from costly custody-tracking practices meant to protect high-value logs from theft. Similarly, the change would relax the Treasury Department requirement to sell all timber (including low-value small-diameter timber) for a profit, which would give the Forest Service more flexibility in scoping and pricing stewardship contracts or similar instruments.

  » Streamline log-accountability tracking and reporting requirements that drive up operational costs for offtakers. Under current practices, sawtimber from Forest Service land must be weighed on Forest Service-certified weigh stations, manually hammer stamped, and tracked using separate Forest Service lockboxes, record books, and load tickets. These requirements reflect a decades-old paradigm in which significant amounts of high-value, large-diameter timber were being harvested from Forest Service land and log theft was a major concern. This paradigm does not apply to the by-products of forest-restoration activities that yield relatively low-value, small-diameter woody material. Revisiting these requirements could significantly reduce a steward's hauling and overhead costs, especially for projects located away from Forest Service–certified weigh stations.

  » Reduce the 20% funding match requirement in Master Stewardship Agreements (MSAs) for forest-restoration projects and allow stewards to apply National Environmental Policy Act (NEPA) costs to the funding match requirement. Current cost-matching requirements can be prohibitive to potential land stewards. Lowering the requirement could lead to more stewardship agreements and open the door for alternative funding sources to be applied to restoration projects.

  » Reduce the probability of "no-bid" contracts by limiting service requirements in stewardship contracts to only those critically necessary for forest restoration. Currently, not all stewardship contracts that the Forest Service offers in California receive bids because of the high costs of stewardship activities on mountainous terrain. In order to improve the economic viability of these contracts, the required stewardship activities should be balanced with the high costs of extracting timber through ecological thinning.

  » Develop and embed mechanisms to enable longer-term Supplemental Project Agreements (SPAs). Current SPAs are typically designed for one- to three-year periods, which may not provide adequate supply security to de-risk an industry or financier investment. One challenge in developing longer SPAs is the need to set timber-appraisal values at fair-market rates, which can fluctuate significantly over longer periods. The Forest Service should work with industry and NGO partners to develop timber-appraisal guidelines and re-evaluation mechanisms (e.g., every three years) that provide price visibility to contract partners while ensuring timber is sold at prevailing fair-market rates.

Exhibit 10 | Forest Service contract types, benefits, and considerations.

CONTRACTING TYPE	DESCRIPTION	BENEFITS	ADDRESSABLE GAPS
Timber sale contract	• Sale of timber or biomass material through a commercial bidding process	• More economically viable for industry partner because there are no restoration service requirements.	• Currently only offered for 2–3 years. • Lengthy timber–appraisal process. • Doesn't include other restoration activities.
Stewardship contract (IRTC/IRSC)* *Up to 20 years*	• Contract where partner performs land-management services in exchange for timber and/or payment	• Guaranteed supply to contract holder. • Contract holder is timber offtaker (no middleman). • Third-party NEPA (A-to-Z contract).	• Competitive bidding process may not fit low-value material from thinning. • Difficult economics for offtaker due to service requirements, land operability, other costs.
MSA with supplemental project agreements *10–20 years*	• Large-scale agreement in which both partner and Forest Service contribute resources to mutually beneficial stewardship projects	• No competitive bidding requirements. • Partner can do the NEPA planning (vs. Forest Service). • Multiple contracts can be established within larger MSA framework.	• 20% cost-matching requirement for contract holder and cannot be applied to up-front NEPA planning. • Partner can't make profit.
GNA with supplemental project agreements *Up to 10 years*	• Large-scale agreement (usually state- or forest-wide) that allows state, county, or tribal entities to perform authorized restoration activities on federal land • SPAs tiered to master agreement define specific project terms**	• Longer-term potential for "self-sustaining" programs where income is rolled over to fund NEPA planning for future work. • Large scale of master agreement facilitates addition of program-level work.	• Start-up investment required to complete initial NEPA planning; state may need to pay for staff up front while waiting for program income. • State can't transfer funds to the Forest Service for NEPA or restoration work. • Limited to 10 years. • Counties and tribes not currently authorized to undertake timber sales.
Standalone stewardship agreement *Up to 10 years*	• Large-scale agreement in which both partner and Forest Service contribute resources to mutually beneficial stewardship projects	• No competitive bidding requirements. • Partner can do the NEPA planning (vs. Forest Service).	• One-time contract that needs to be planned completely before implementation. • No agreement for further projects with partner.

*Integrated Resource Timber Contract/Integrated Resource Service Contract
**Supplemental Project Agreement

Additionally, there may be advantages to separating biomass- and sawtimber-supply contracts—for example, by protecting long-term biomass contracts from volatility in timber prices. These proposals require further investigation and piloting, but they have the potential to significantly improve supply security for operators reliant on Forest Service land.

3. LANDSCAPE-SCALE PROJECTS AND SUPPORTING WOOD-PROCESSING INFRASTRUCTURE

The majority of restoration projects completed or underway are small in scale (e.g., tens of thousands of acres or less) relative to the land in California requiring treatment (about 9–10 million acres).[1,18] Continuing on a similar trajectory imperils the future of California forests and the communities that depend on them. We must act urgently to accelerate the number and pace of landscape-scale forest-restoration projects throughout the state. TNC believes there are opportunities to make landscape-scale planning and analysis more efficient without compromising environmental standards. Furthermore, we acknowledge that close collaboration with a broad coalition of partners, including industry operators, will be critical to encourage the expansion of wood-processing capacity needed to offtake low-value forest material and defray the high cost of forest restoration. With respect to the above, we offer the following recommendations for consideration:

- **Increase the size of forest-restoration projects.** There are potential economies of scale in planning and implementing larger projects. In addition, the threats facing our forests, such as wildfire, drought, and climate change, are generally operating at a landscape scale, and some of the sensitive wildlife species that are a focus of planning, like the California spotted owl, have extensive home ranges and live within populations that are far bigger than the typical Forest Service project. For all these reasons, it makes sense to develop policies and practices to support landscape-scale planning and implementation.

- **Make project planning for restoration projects less costly and more efficient.** Many of the current planning requirements, particularly for federally owned forests, were established to provide procedural and substantive environmental safeguards against logging of large trees and other commercial logging practices. Compliance with these planning requirements means that project planning typically requires multiple years and costs millions of dollars. While these planning requirements serve important purposes, there are opportunities to make planning more efficient, especially with respect to ecological forestry projects for which there are significant public benefits. A prior TNC report[42] summarizing the lessons learned from the French Meadows project offers more detailed suggestions for changes to current surveying and NEPA planning policies and practices that could provide efficiencies. These suggestions could serve as a starting point for determining which requirements to streamline for projects that meet the right qualifying criteria.

- **Expand the use of and facilitate better collaboration with third-party NEPA contractors.** Third-party NEPA contractors allow project partners to significantly accelerate project timelines, especially given the Forest Service's limited staffing and budget and competing priorities. However, opportunities remain for improving collaboration across consultants and Forest Service staff. Clear guidelines for survey protocols and environmental analysis, defined roles and responsibilities, frequent communication, and transparency about review processes and timelines would go a long way to ensuring a more productive and collaborative relationship between agency staff, contractors, and project partners. More detail on these recommendations can also be found in the French Meadows paper.[42]

- **Accelerate the development of wood-processing infrastructure through broad partnership collaboration.** Under the right circumstances, landscape-scale restoration projects present a unique opportunity to align interests across a diverse coalition of stakeholders. In particular, they create an opportunity to expand wood-processing capacity if the landscape's wood basket is of the right size and feedstock mix to support industry infrastructure. We believe California can pioneer the creation of a forest-restoration economy by pairing landscape-scale restoration projects with industry commitments to invest in wood-processing capacity of an appropriately matched size and type. This will require broad and open collaboration across government, industry, NGO, and tribal interests but has enormous potential to accelerate progress toward our forest health and climate goals while providing numerous other benefits, including economic revitalization, job creation, and local community resilience.[43]

Yurok forest managers create a “fire shade” to lessen the chance of wildfires, California. © Kevin Arnold

Conclusion

While it is a daunting challenge, stimulating a forest-restoration economy in California would provide many benefits. Expanding wood-processing infrastructure would help defray the high cost of ecological thinning, incentivizing more landowners and land stewards to undertake critical restoration projects. Ramping up investments and training in forest products could supply jobs in ecological forestry, bioenergy, and small-diameter wood products that could revitalize struggling rural communities. Providing valuable end uses for woody biomass would offer better alternatives to open pile burning and chipping-and-spreading practices that are detrimental to the climate, environment, and communities where they take place. Most critically, accelerating landscape-scale restoration projects would help ensure we are able to protect the natural diversity and beauty of California’s fire-prone forests. Done thoughtfully, it would protect critical wildlife habitats, prevent extreme losses of carbon storage, help secure California’s largest supply of clean water, make forests more resilient to drought, and protect lives and communities from catastrophic wildfires.

To achieve this, we believe three critical actions are required. First, appropriate funding, incentives, and preferential policies must be put in place to bridge the gap between the cost of ecological thinning and the economic viability of wood-processing infrastructure. Second, Forest Service, state and local government, industry, NGO, and tribal interests must come together to define efficient, ecologically sound processes and mechanisms to provide secure, long-term sources of fiber supply. Third, efforts should be made to advance landscape-scale projects and to make project planning more efficient and less time consuming while maintaining environmental safeguards.

California’s fire-prone forests are in crisis: Catastrophic wildfires, drought, disease, and insect outbreaks threaten to dramatically and permanently degrade one of California’s most critical biomes. Our research suggests that with the right enabling conditions in place, a forest-restoration economy can play an important role in expanding the pace and scale of ecologically based forest restoration and promote healthier, more resilient forest conditions. We urge our partners in government, industry, tribal entities, academia, and the environmental community to collaborate openly and act urgently to pursue the necessary political, economic, and cultural reforms needed to catalyze change.

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