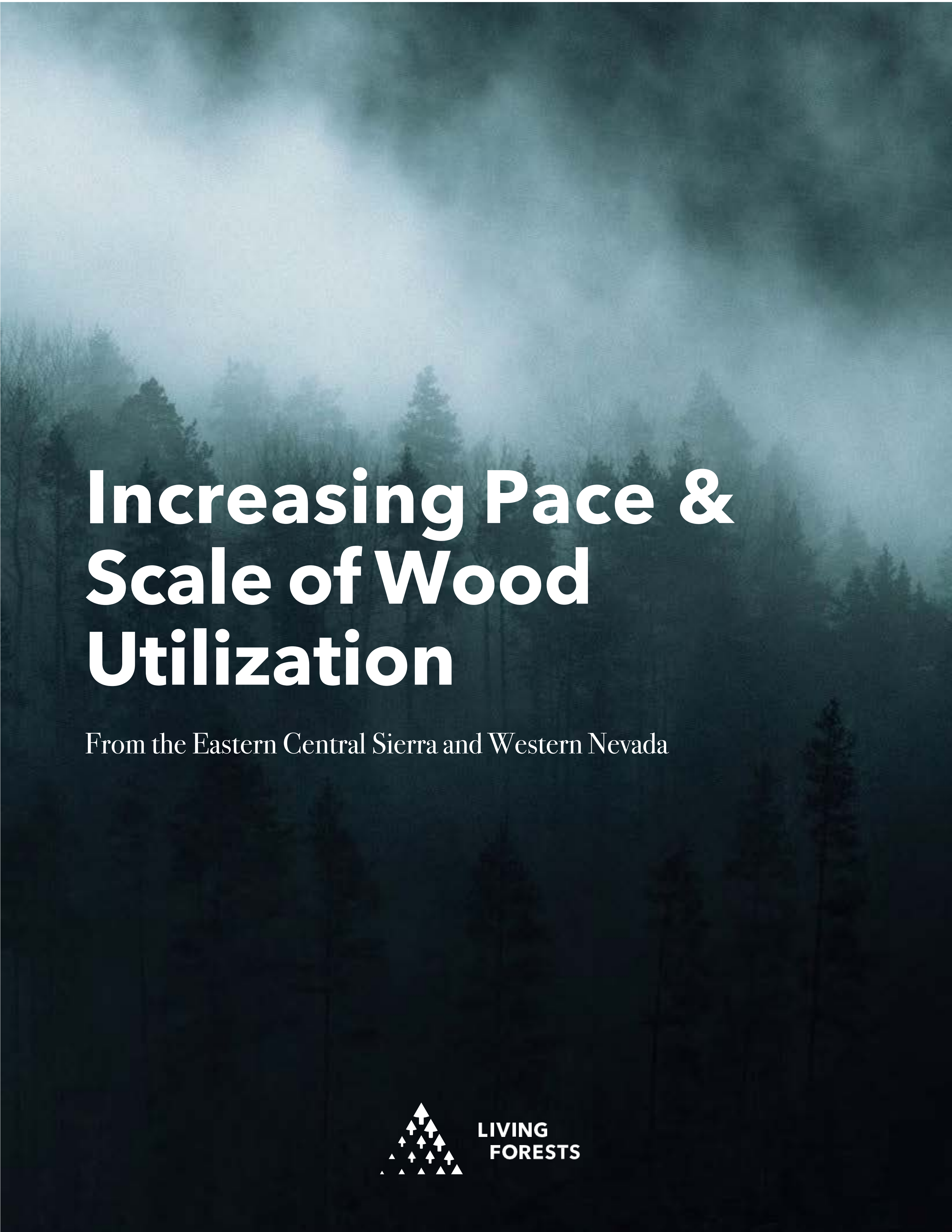

Increasing Pace & Scale of Wood Utilization

From the Eastern Central Sierra and Western Nevada

LIVING FORESTS

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Acknowledgements

This document was created by the Center for the Force Majeure and Living Forests:

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This report was developed with generous support of the Wood Innovations Grant program of the USFS along with additional support from the Annenberg Foundation and the Arts Division at UC Santa Cruz.

LIVING FORESTS

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CENTER FOR THE STUDY OF THE FORCE MAJEURE

The Center for the Study of the Force Majeure, based at the University of California, Santa Cruz, brings together artists, scientists, ecologists, planners, and visionaries to design mitigation systems and policies that respond to the issues raised by global temperature rise at the scale that they present.

We gratefully acknowledge the support of the many people who have helped shape this study and whose care and commitment to the health and well-being of western forests has been essential to the completion of this work.

Frank Aebly, Richard Anderson, Pete Anderson, Michael Barton, Elissa Brown, Stacy Caldwell, Lynn Campbell, Susan Clark, Don Clark, Scott Conway, Joe Desmond, Brett Dickson, Nic Enstice, Laura Fillmore, Benny Fillmore, Dorian Fougeres, Steve Frisch, Rich Gordon, Matthew Gregory, David Griffith, Sherry Hazelhurst, Don Hittenmiller, Tracy Hruska, Julie Kies, Zach Knight, Shane Lofgren, Sandra Lupien, David McConville, Kiel MIller, Mark Moulton, Steve Mueller, Lech Muszynski, Malcolm North, Lauren O'Brien, Lisa Podesto, Dan Porter, Colin Robertson, Joanne Roubique, Eric Roussel, Martin Scherr, John Shinn, Ed Smith, Larry Swan, Marcus Taylor, Elona Trogub, Cody Witt, Allison Wolff, Kristin York, Luke Zachmann, Teal Brown Zimring, Forest Products International, Conservation Science Partners

Acronyms & Abbreviations used in this document

BDT	Bone Dry Tons
BLM	Bureau of Land Management
Cal Fire	State of California Department of Forestry and Fire Protection
Caltrans	State of California Department of Transportation
Calveg	Classification of Californian Vegetation
CLT	Cross-laminated Timber
CSP	Conservation Science Partners
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
FIA	Forest Inventory and Analysis National Program
GAP	Gap Analysis Program
GHG	Green House Gas
GIS	Geographic Information Systems
HUC	Hydraulic Unit Codes
IPCC	Intergovernmental Panel on Climate Change
LEMMA	Landscape Ecology, Modeling, Mapping, and Analysis
LVL	Laminated Veneer Lumber
MBF	thousand board feet
NAIP	National Agriculture Imagery Program
NCS	Natural Climate Solutions
NOAA	National Oceanographic and Atmospheric Administration
ODT	Oven Dry Tons also referred to as BDT (Bone Dry Tons)
OSB	Oriented Strand Board
PJ	Pinyon-Juniper
PPA	Power Purchase Agreement
QMD	Quadratic Mean Diameter
SPI	Sierra Pacific Industries
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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Forests are in crisis in California and Nevada.

A century of fire suppression and extensive logging has created forests that carry high fuel loads, are more damaged by fire, have less biodiversity, and are less resilient to climate change than they were under a pre-European contact (natural) fire regime. Although these forests evolved with and are adapted to fire, fires are now behaving in ways never seen before. Since 1900, only six fires have burned more than 200,000 acres in the Sierra Nevada. All of those fires occurred in the past 10 years—and four of them in 2020 and 2021. In 2021, the Dixie Fire became the largest single wildfire in state history, burning nearly 1 million acres.[1] The fire season starts earlier and ends later each year. Wildfires have been spreading to higher elevations due to warmer and drier conditions caused by climate change. The first two wildfires to cross the crest of the Sierra Nevada in recorded history (Dixie and Caldor) occurred in 2021.

Large, intense wildfires + tree mortality are symptoms of poor past management practices.

The forests that have grown back after logging and without fire are significantly altered from what Euro-Americans found when they first came west. Today's forests have higher tree densities, a more homogeneous structure, and a different species composition than those earlier forests. The vast majority of large diameter pine trees that historically survived natural fire were removed by extensive logging operations. A century of fire suppression has resulted in forests composed of a higher percentage of highly flammable firs. As a result of higher tree densities, trees often do not have enough resources to grow vigorously and are unable to withstand drought, insects, and diseases.

[1] Another Historic Sierra Nevada Fire Season. Sierra Nevada Conservancy. January 2022.

Ecologists know how to treat forests to reduce wildfires, improve ecosystem health, and mitigate climate change.

Goals of science-based forest management practices include modifying fire behavior, improving wildlife habitat, and restoring the natural regime of low intensity frequent fires that are necessary for ecological processes. These forest management practices have the added benefit of reversing the massive contribution wildfires make to greenhouse gases, turning forests into factories for sequestering carbon instead. As temperatures continue to increase and droughts get longer and deeper, the urgency of accomplishing this work increases. Improved management and restoration of forests and other ecosystems reduce greenhouse gas emissions and increase carbon storage, with the potential to offset one-fifth of the net annual emissions in the United States.[2] Compared to agriculture, grasslands, or wetlands, forest management has the greatest potential to mitigate climate change. It also advances other societal goals – reducing the toxic air pollution of mega-fires, improving air quality, protecting biodiversity, enhancing soil productivity, providing for clean water and flood control.

The barriers to treating forests at the pace and scale needed are economic, technological, and administrative.

Despite knowing for years what management the forests require, managers have struggled to untie the gordian knot needed to treat forests on the scale necessary to reverse the trends in wildfire behavior. California authorized $1.5 billion toward forest management projects and efforts to reduce wildfires in the 2021-22 fiscal year, and the Infrastructure Investment Jobs Act (IIJA) allocates $3.4 billion for wildfire risk reduction, greatly expanding recent annual spending. Still, responding to wildfires takes more resources each year, making it difficult to get proactive forest management done, even as funding increases. Should increased funding lead to an acceleration of the pace and scale of forest fuels reduction projects, infrastructure and plans to utilize the increased volume of wood that will come out of the forests are woefully inadequate.

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[2] Fargione, J.E., et al. 2018. Natural climate solutions for the United States. Sci. Adv. Eaat 1869, 14 pp

Over the past four decades, the capacity of the California forest products industry decreased by 70%[3] due to conflict over increased enforcement of environmental laws, the shrinking inventory of large logs, builder preference for using Douglas Fir and other stronger fibers imported from Oregon, Washington, and Canada, and other factors. The Central Eastern Sierra and Western Nevada area that is the focus of this study once had a thriving forestry industry, but since Sierra Pacific Industries closed its sawmill in Loyalton, California in 2001, it has had virtually no large forest log operation. Today, the forest industry in California is either too far to the north or to the west to make it profitable to transport logs from the eastern Sierra, especially with the lower-value wood produced from forest thinning treatments.

Fresh approaches are needed to address the forest crisis effectively and comprehensively.

New innovative solutions are required to address the forest crisis effectively. Finding better uses for the wood and woody biomass generated by forest management projects in the Eastern Sierra and Western Nevada is needed to maximize overall reduction of life-cycle carbon emissions, and to realize more economic value from timber removed to reduce the risk of catastrophic wildfires. Without sufficient economic demand for the wood removed during forest thinning operations, and without adequate logistical support to remove it, hundreds of thousands of burn piles are left behind, as blankets of wood chips are left on the forest floor. Ecological forest management practices can change fire behavior by removing ladder fuels and encouraging some biomass to decompose more quickly.

However, thinning alone without wood utilization does not modify fire risk or mitigate climate change to the extent possible with other solutions. Wood utilization helps defray the cost of forest management by engaging the profit motive of the private sector and promotes sequestering carbon in wood products.

This study evaluates emerging wood technologies and growing markets for wood products. An array of options were assessed, which can be broadly classified as **"Build, Burn, or Bury."** *Burn* represents converting biomass to energy in various forms, ranging

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[3] Mass Timber and Other Innovative Wood Products In California: A Study Of Barriers And Potential Solutions To Grow The State's Sustainable Wood Products Sector; Sierra Institute for Community and Environment, P7

from firewood to small or large-scale biomass energy facilities; *Build* represents storing biomass in durable materials, commercial lumber and other primary building products, including community-scale mills and production of engineered wood. Finally, *Bury* represents returning biomass to the soil in various forms including compost, ground covers and biochar. The study evaluates each of the options through lenses of carbon sequestration potential, economic cost and benefit, scale, and feasibility.

(See Table 4-15. Matrix of Wood Products for a summary of findings).

Study Purpose

This research, funded by a U.S. Forest Service Wood Innovation Grant, aims to support policymakers, forest managers, advocates, and entrepreneurs seeking to increase the pace and scale of forest health and resilience management efforts, as well as wood utilization, in the Central Eastern Sierra Nevada and Western Nevada (see Study Area Map, Figure 1-1). Improved forest management is needed to reduce threats from wildfire, improve wildlife habitat, protect water supplies, and increase ecosystem resilience.

Communities east of the Sierra crest face the same threat of wildfire as those on the west slope of the Sierra, but there is currently little economic demand for timber removed to reduce fire risk and improve ecosystem health of these forests. This study addresses the question of whether emerging wood technologies and growing markets for wood products in the study area and beyond would make it feasible to support new forest manufacturing capacity to create demand for trees removed during forest thinning projects, while maximizing carbon sequestration.

The wood utilization project described in this report began in 2017 after timber marked for removal in the 9,000-acre Sagehen Experimental Forest (Sagehen Forest), located 10 miles north of Truckee, CA, initially failed to sell because it was located too far from timber mills. Soon it became apparent that other nearby forest projects faced similar problems. All these projects were located east of the Sierra crest in the central Sierra Nevada (described in detail below).

Project Rationale and Study Area

The eastern Sierra/western Nevada project area was defined by encompassing areas of both wood supply and wood demand to identify ways in which wood removed from forest restoration can be put to commercial use. As wood supply was initially defined by the mixed conifer forests east of the Central Sierra crest, forested areas of both eastern California and western Nevada were included.

Wood demand was viewed from the perspective of a regional economy. The Bureau of Economic Analysis defines regional economies using regional markets for labor, products, and information: "They are mainly determined by labor commuting patterns that delineate local labor markets and also serve as proxies for markets where local businesses sell their products."[4]

When the study was initiated, the Reno-Sparks community was the obvious economic node because it was just 32 miles from Truckee, California. In addition, the northern Nevada economy was booming as major companies such as Tesla, Apple, and Amazon recently located major operations there. As a result, the Reno-Sparks area was seeing a home building boom and rising housing prices, and corresponding increases in demand for wood products. However, the promise of the Reno-Sparks area has not yet been realized in terms of local wood development and utilization.

The western boundary of the study area is the crest of the Sierra Nevada because it forms a natural boundary to moving logs to market. The team selected the line between Sierra and Plumas counties as the northern boundary of the project area (see further discussion of the project area following the project area map, Figure 1-1). From a wood utilization perspective, including Sierra County in the project also made sense because it is the location of the 9,000-acre Sagehen Experimental Forest project, which was the impetus of this wood utilization study.

The boundary between Mono and Inyo Counties forms the southern boundary. Most of the forests in Inyo County are wilderness: the John Muir Wilderness, the Golden Trout Wilderness, the South Sierra Wilderness, the Inyo Mountains Wilderness, and the White Mountains Wilderness.

The eastern boundary is harder to define. The Carson Ranger District of the Nevada Bureau of Land Management, and the overstocked pinyon and juniper woodlands of concern to the Nevada Pinyon-Juniper Partnership are included because they are in the same regional economy: the project area needed to include the regional economic node of Reno-Sparks, given that the Partnership is pursuing landscape-scale restoration.

The study area is in the rain shadow of the Sierra Nevada, which creates a steep hydrological gradient from west to east. The easternmost area of the project qualifies as semi desert and is dominated by sagebrush. The wide range of environments supports various pine species, fir, hemlock, incense cedar and several non-commercial species.

The entire study area is nearly 18,343 square miles, of which the vast majority (<80%) is

[4] Kenneth P. Johnson and John R. Kort, November 2004 "2004 Redefinition of the BEA Economic Areas," accessed from https://apps.bea.gov/scb/ pdf/2004/11November/1104Econ-Areas.pdf on May 4, 2021.

federal land, mostly Bureau of Land Management and U. S. Forest Service, but also Army Corps of Engineers, Department of Defense, and U.S. Fish and Wildlife Service. (A breakdown of private vs. federal land ownership can be seen in Figure 2-7.)

A significant portion of the study area was eliminated to focus on forested areas., which resulted in a total area of about 624 square miles (over 400,000 acres, shown in Table 1-1 below).

LAND OWNERSHIP (Acres)

	Federal	Joint Ownership[5]	Local	Native American Land	Conserv.	Private	State	Total
Carson Desert	3,455							3,455
Crowley Lake	32,360	192	5	0	2	2,853	64	35,471
Dixie Valley	37,971			82		185		38,238
East Walker	51,638	5	2	2		6,543	403	58,593
Gabbs Valley	24,196					54		24,250
Lake Tahoe	17,354		12	20	35	5,827	1,398	24,646
Middle Carson	12,056					3,515	12	15,583
Mono Lake	40,392	2	32		10	2,243	319	42,998
Truckee	23,295		274	5	15	15,057	1,423	40,069
Upper Carson	31,334	484	42	217	2	12,017	1,050	47,144
Walker	3,164			4,577	2	462		8,205
Walker Lake	19,281					3,162	25	22,855
West Walker	35,044	86	2			4,090	538	39,760
Grand Total	**465,769**	**1,081**	**520**	**6,888**	**94**	**78,683**	**7,350**	**562,766**
%	**83%**	**0%**	**0%**	**1%**	**0%**	**14%**	**1%**	**100%**

Table 1-1. Land Ownership by Ownership Category - Source: USGS Protected Areas Database. Areas have been filtered from the larger study area.

[5] "Joint ownership" refers to geographic units of uniform character, part of which is owned by one entity and the other by a different entity.

Figure 1-1. Study Area Map. Study area indicated in orange.

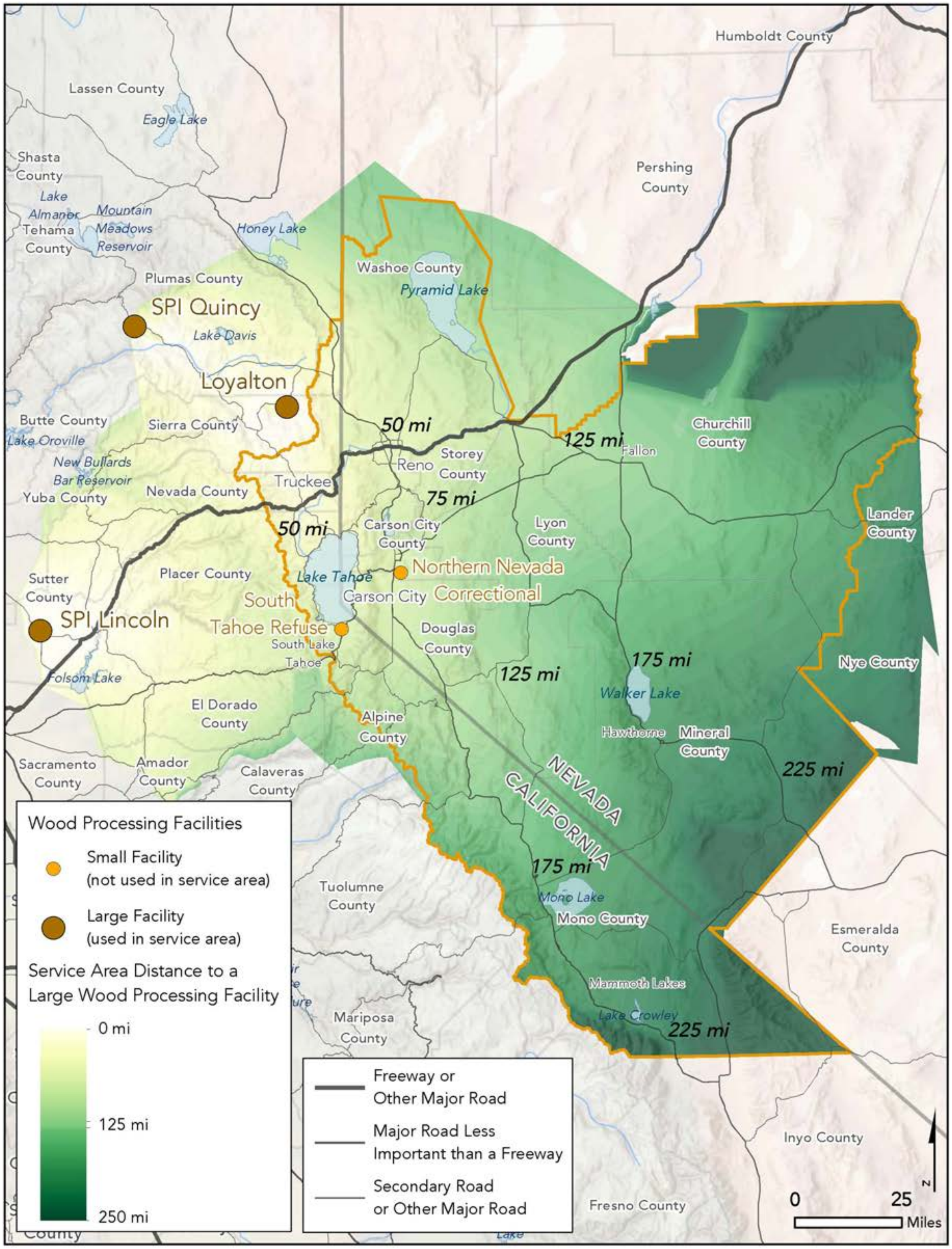

Figure 1-2. Network Travel Distance to Major Nearby Wood Processing Facilities

An assessment of treatments in the study area, designed to create healthier, more fire-resistant forests, found between 286,065 and 423,800 mbf of sawlogs could be removed, not sufficient to support a commercial sawmill. This work was estimated to cost between $60 and $86 million, with revenues offsetting that cost by $52 to $67 million. Therefore, the net cost to treat this land base would be between $8 and $20 million. Many options for using the harvested logs to reduce carbon emissions have been evaluated, along with economic costs and benefits, state of technology, carbon reduction potential, scalability, and feasibility of implementation. Different assumptions about infrastructure, economic conditions and public policy could improve the prospects for forestry in the study area.

One major limit to the amount of wood that can be removed is the percentage of the landscape that can be treated given the current road network, land management designations, and regulations. Government can and should provide incentives to encourage innovation in harvesting technologies and wood utilization to reduce or offset costs of forest management. Historically State of California incentives have focused on supporting the biomass to energy sector, but the catastrophic fire seasons of 2020 and 2021 have built state support for a broader range of utilization.[6] Public sector subsidies of forestry operations generate considerable public benefits: support for rural communities, increased resilience to wildfire and drought, reduced smoke impacts on public health, secured carbon storage and reduced greenhouse gas emissions, protection of water quality from post-fire erosion, and increased water supply.

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[6] https://calosba.ca.gov/funding-grants-incentives/financial-incentives/incentives-by-industry/

Historic Context

When Euro-Americans first came to the Sierra Nevada, they found yellow pine and mixed conifer forests dominated by ponderosa pines and Jeffrey pines, as well as red and white firs, sugar pines, and incense cedars.[7] These forests evolved with fire and were well adapted to burning five to ten times per century in low to moderate severity fires. There were more fire-resilient pines and fewer flammable firs than today because typical fires killed understory shrubs, small trees, and thin-barked species. Large pines were left alive and standing. As a result, the average tree diameter was twice today's average, and the range of diameters was much wider. Tree densities averaged one-fourth to one-half what they are today, and trees were arrayed in highly variable patterns across the landscape, including some small dense patches and open areas.[8] This forest and fire regime created a highly heterogeneous, fine-grained forest structure, with stands consisting of both young and old trees. Rarely did fires kill large groups of adult trees meaning that 250-acre expanses of even-aged tree regrowths were rare. After the fires, much of the carbon remained stored in the living trees, dead wood, and soil.

Today, Sierra Nevada forests are dramatically changed.[9] The official U.S. Forest Service policy adopted in 1910 to control forest fires before they reached 10 acres may be one of the most significant human-caused ecological disturbances currently shaping these yellow pine and mixed- conifer forests.[10] The list of damaging effects of this policy include altering species composition, changing which tree species are dominant, increasing the number of trees per acre, building up fuels, loss of important wildlife habitat, threats to human safety and infrastructure, and more subtle changes such as changing hydrological cycles and rates of carbon sequestration. Logging was another major factor that changed ecological processes and structure in the yellow pine and mixed-conifer forests of the Sierra Nevada. Although logging had occurred since the mid-19th century to support

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[7] Safford, Hugh D.; Stevens, Jens T. 2017. Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. Gen. Tech. Rep. PSW-GTR-256. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 229 p.

[8] Ibid.

[9] Ibid.

[10] Ibid.

mining activities and associated communities, the intensity of logging increased beginning in the 1890s when railroads created more access to timber resources.[11] The Lake Tahoe basin and Truckee River watershed were among the areas heavily affected. Because harvesting primarily occurred on private lands, by the 1940s nearly all the remaining unlogged forests in the Sierra Nevada were either in national forests or national parks.

After World War II demand for timber from federal lands increased dramatically to provide housing for returning soldiers and young families.[12] Before the war, Forest Service lands provided only five percent of national lumber supply, but by 1970 they were meeting nearly one-third of U.S. needs. In the Sierra Nevada, most of this logging occurred in the 1950s and 1960s. Large areas were clearcut. The forests that grew back are denser, evenly aged, and structurally homogeneous. They contain a higher percentage of tree species like white fir that are shade tolerant and easily killed by fire, and a smaller percentage of trees that are resilient to fire, such as large diameter pines.

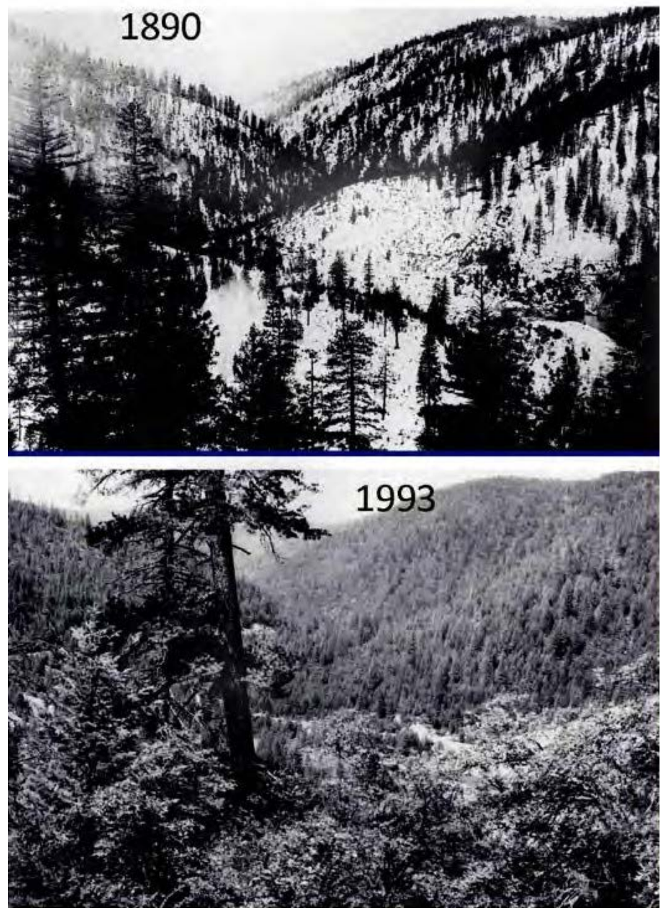

Figure 2-1. Clearcut Sierra Nevada Comparison, "Fire in Sierra Nevada Forests", George Gruell

[11] Ibid. p. 74.
[12] Ibid.

A BRIEF HISTORY OF HUMAN-FOREST RELATIONS

The changing perception of fire in the west

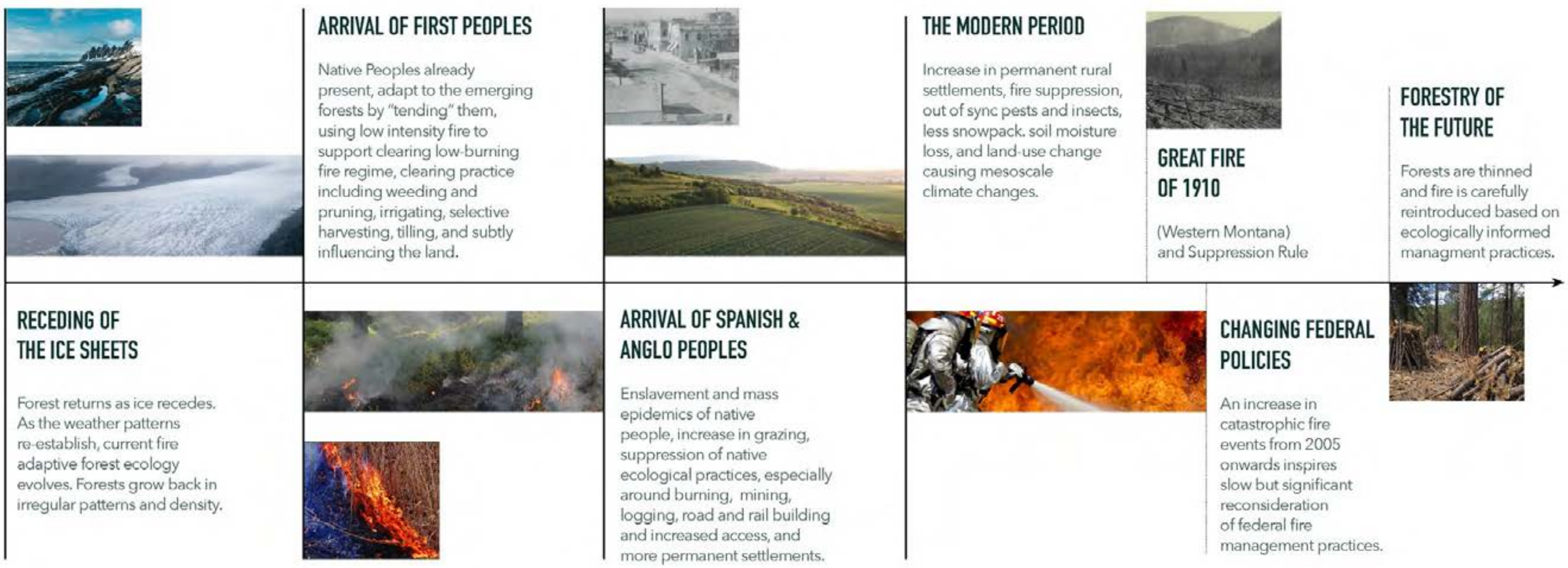

Figure 2-2. Timeline of Human Forest Relations

As a result of fire suppression practices, the different structure of the yellow pine and mixed conifer forests contributes to the advent of terrifyingly large wildfires instead of the gentler fires to which the forests were adapted. Extensive dense stands of white firs have doubled fuel loads.[13] Forests are more homogeneous, with nearly continuous canopy cover, more shade, and less biodiversity. Instead of burning 5 to 10 times per century, the average forest acre may burn once or not at all in a century.[14] But when fires do come, they are much hotter due to these large, accumulated fuel loads. For example, recent scorching fires killed about one-third of the trees in yellow pine-mixed conifer forests. Instead of creating a fine-grained pattern of openings of a few acres, areas without trees now average 1,200 acres. Individual fires are now five times larger than pre-settlement. Even so, the amount of forest burned each year is only a tenth of what it was before 1850. These modern hot, destructive fires and the heavy tree mortality are nature's way of pushing the reset button; the landscape is simply carrying more forest biomass than it can sustain. Further, rising temperatures due to climate change evaporate water more quickly, leaving less in the ground to support trees. That means there is less water to support forest structures that existed 100 years ago, much less the far denser forests of today. Droughts are expected to become more frequent and last longer. Further, the wet season is starting later in the fall and ending earlier in the spring. In 2021, vegetation ran about two months ahead of typical dryness values for June.[15]

From the perspective of climate change, these high-severity, tree-killing fires are a problem because they emit massive quantities of greenhouse gases and negate California's efforts to reduce greenhouse emissions. The 2018 fires in northern California's wine country emitted as much CO^2 in one week as all of California's cars and trucks do in a year. [16] NOAA has estimated that one very hot fire destroying 500,000 acres could emit as much CO^2 as six large coal-fired power plants in one year.[17]

Not only do these wildfires emit carbon from combustion, but they also suppress bio-

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[13] Ibid.

[14] Ibid.

[15] Swain, Daniel. June 25, 2021. California dodges worst of historic Pacific Northwest heatwave, but long-duration heatwave still likely inland. [1515] Plus: significant monsoonal surge next week? https://weatherwest.com.[15]

[16] Berwyn, Bob. "How Wildfires Can Affect Climate Change (and Vice Versa)." Inside Climate News, Aug 23, 2018. Accessed 27 September 2018.

[17] Ibid.

productivity following the fires.[18] It can take many decades for nature to rebuild that "natural factory." Extensive areas of high-severity fires can eliminate seed sources for forest regeneration, leading to transformation of a forest into shrub fields that persist for decades.[19] An area that no longer supports a forest has a diminished capacity to store carbon.[20]

Temperature and water supply trends are feedback loops that will not only increase fire and pests, but they will further depress the ability of forests to store carbon. Both high temperatures and limited water reduce photosynthesis rates, limiting a tree's ability to remove carbon from the air. Higher temperatures increase respiration rates, putting a higher proportion of assimilated carbon back into the atmosphere, leaving less nonstructural carbon to support tree growth.

Yellow pine and mixed-conifer forests, characteristic of forests in the eastern Sierra/western Nevada project area, are under severe stress leading to widespread tree mortality and larger, more damaging forest fires. Scientists have sought a new strategy for managing these forests to gradually restore forest structure and ecological processes that had been lost because of logging and fire suppression. The challenge is to change fire behavior, improve wildlife habitat, and encourage a more diverse and resilient forest ecology.

Fire is an important ecosystem process in California's yellow pine and mixed-conifer forests. In fact, these forests need fire to be healthy and sustainable.[21] Native Americans intentionally set fire or used cultural burning for thousands of years to manage western forests. In the long run, prescribed burning is the primary tool to manage forests to reduce the risk of high-intensity wildfire.[22] The primary carbon benefit from this kind of fire management is the avoidance of wildfires that kill trees and decrease ecosystem productivity.[23] The initial increase in emissions associated with prescribed fire treatments is more than offset over time by the avoided impacts of uncontrolled wildfires.[23] As a result of long-term fire suppression and other management practices, many forests areas must

[18] Fargione, op.cit.

[19] Welch, K. R., H. D. Safford, and T. P. Young. 2016. Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. Ecosphere 7(12):e01609. 10.1002/ecs2.1609.

[20] Fargione, op.cit.

[21] Safford, op cit.

[22] Fargione, op cit.

[23] Ibid.

be thinned before reintroducing fire because fuel loads are too high. In these places, climate impacts can be mitigated by thinning overly dense forests so fewer, but more vigorous trees can increase the rate at which they convert atmospheric carbon into tree structures.[24] Thinning these forests generates wood that can continue to store carbon, or offset carbon emissions when utilized for renewable energy, rather than being released back into the atmosphere from fires or decay.

Forest Management & Wood Utilization is Crucial Climate Change Mitigation

Trees are unique within the plant world because they produce wood and are long-lived. As a result, natural forests can continue to accumulate carbon for hundreds of years.[25] Fallen leaves and dead wood decay, adding carbon to the soil which can last for centuries or perhaps millennia.[26] Climate change experts have become increasingly interested in the potential of undeveloped environments to help meet goals to reduce greenhouse gas emissions.[27] This approach is known as "natural climate solutions", or NCS, which includes land conservation, restoration, and improved management of natural resources.[28] The IPCC Climate Change and Land Report found that all scenarios that limit climate change to 1.5° C rely heavily on improved management of natural resources in addition to transitioning to a low-carbon economy.[29] Another study found that 21% of net annual emissions in the U.S. could be offset by using NCS to increase carbon storage and avoid greenhouse gas emissions.[30] Nearly two-thirds (63%) of the potential to increase carbon storage comes from trees and plants, while another 30% comes from increasing carbon storage in soils.

Natural climate solutions provide other benefits in addition to helping achieve a more stable climate. Given concern about the cost of addressing climate change, it makes sense to implement least-cost options first – and two of the least expensive options are to improve natural forest management and avoid converting forests to different land uses or

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[24] Ibid.

[25] Fargione, op. cit.

[26] Ibid.

[27] Seddon, Nathalie, et al. 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. Phil. Trans. R. Soc. B 375: 20190120.

[28] Fargione, Joseph E. et al. 2018. Natural climate solutions for the United States. Science Advances 4:eaat1869.

[29] Seddon, op. cit.

[30] Fargione, op. cit.

ecosystems.[31] Biodiversity can be protected with better management of natural forests, unlike converting them to tree plantations or energy crops.[32] Restoring natural forests can also reduce risks of floods and protect water supplies from landslides and potentially toxic sediments.[33]

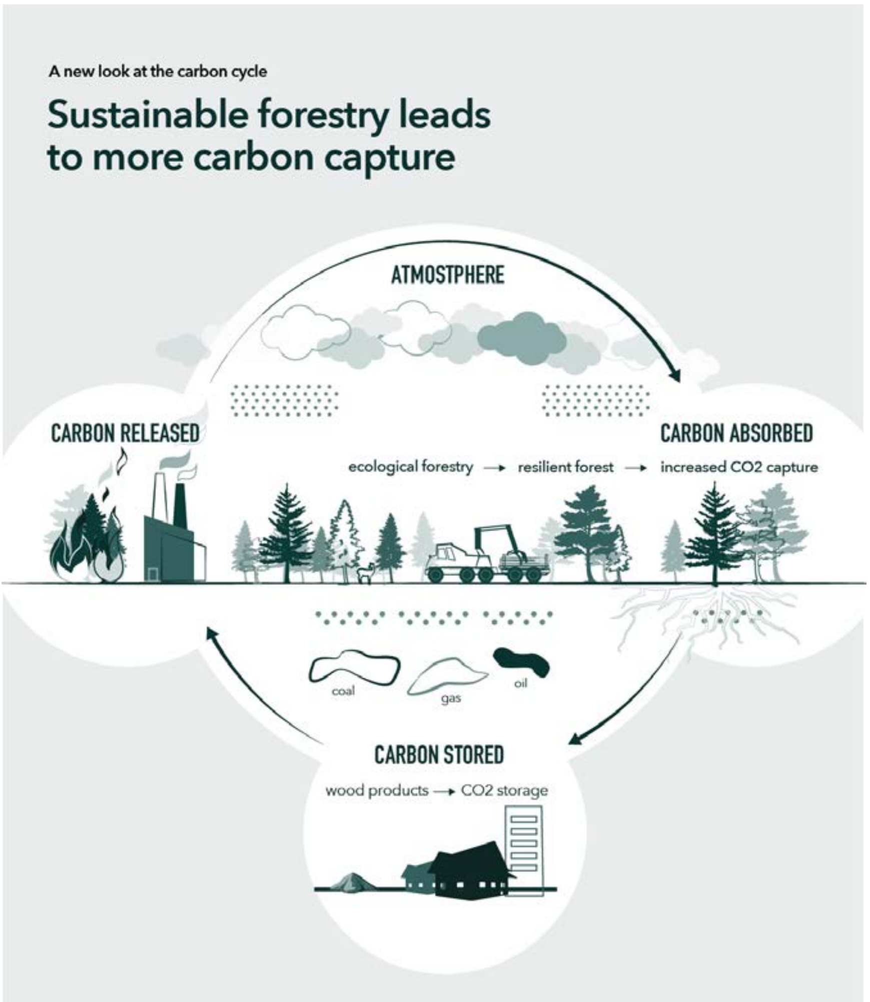

Figure 2-3. The Sustainable Forestry Cycle

Analyzing the full life cycle of carbon illustrates how forest management can help reduce greenhouse gases. First, photosynthesis takes carbon from the atmosphere and converts into nonstructural carbon-based molecules like glucose. Some of that carbon is used to build new plant tissue, increasing biomass. The rest is respired back to the atmosphere, some when plants grow and some to maintain living tissues. The ratio between carbon

[31] Ibid.

[32] Ibid.

[33] Seddon, op.cit.

stored and carbon released changes over time depending on things like availability of water, temperature, and space to grow.

Well-designed management of forest ecosystems can help address climate change. The Intergovernmental Panel on Climate Change (IPCC) issued a report that found that improved natural resource management could help limit climate change to 1.5 °C. In the U.S., improved management and restoration could reduce greenhouse gas emissions and increase carbon storage, with the potential to offset one-fifth of the country's net annual emissions.[34] Compared to agriculture, grasslands, or wetlands, forest management has the greatest potential to mitigate climate change. It also could advance other societal goals -- improve air quality, protect biodiversity, enhance soil productivity, and provide for clean water and flood control.

Life-cycle analyses show that beyond reducing greenhouse gas emissions and increasing carbon storage, improved forest management can further mitigate climate change if harvested wood is substituted for materials with higher carbon footprints, such as concrete and steel.[35]

Wood products capture carbon more effectively than non-wood building products because wood is composed of carbon captured from the atmosphere as a tree grows and furthermore, manufacturing wood products uses less fossil fuel than making concrete, metals, or plastics. For example, a 2,062 square foot home built from lumber plywood, Oriented Strand Board (OSB), and veneer lumber could sequester 38,500 pounds of CO^2 eq.[36]

Using wood, the University of Vancouver built an 18-story dormitory that sequesters carbon emissions equal to removing 500 cars for a year.[37] In producing such wood products, some wood waste is inevitably generated which can replace fossil fuels for creating energy, thereby avoiding moving carbon from the earth's crust into the atmosphere. And, wood is renewable, unlike fossil fuels.

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[34] Fargione, J.E., et al. 2018. Natural climate solutions for the United States. Sci. Adv. Eaat1869, 14 pp.

[35] Oliver, C. D., N. T. Nassar, B.R. Lippke, and J. B. McCarter. 2014. Carbon, Fossil Fuel, and Biodiversity Mitigation with Wood and Forests. Journal of Sustainable Forestry, 33:248-275.

[36] Bergman, R., M. Puettmann, A. Taylor, and K.E. Skog. 2014. "The Carbon Impacts of Wood Products," Forest Prod. 220-231.

[37] Lau, W. "The University of British Columbia's Brock Commons Takes the Title of Tallest Wood Tower." Architect Magazine. https://www. architectmagazine.com. Accessed 25 Oct 2018.

Sagehen Forest Project:

Origin of the Wood Utilization Study

Figure 2-4. Sagehen Creek Experimental Forest Restoration Work, 2017, Jeff Brown

The Sagehen Forest Project[38] was designed to remove smaller trees, and tree species that are too abundant and intolerant of fire. The treatment strategy also creates scattered openings, leaving small thickets for wildlife.[39] Forest capacity to hold water increases, replacing a little of the water storage lost from the vanishing snowpack. Thinning these forests generates wood that can continue to store carbon rather than release it back into the atmosphere from fires or decay.

The Sagehen Forest Project prescription described below forms the treatment basis for restoring forest ecosystems in the Eastern Sierra and Western Nevada. Like much of the yellow pine and mixed-conifer forests east of the Sierra crest, the Sagehen watershed had been heavily logged. A portion experienced a large wildfire in 1960 and was characterized by an even-aged plantation that accumulated fuels due to fire suppression. The history of timber harvesting, reforestation and fire exclusion had created a simplified, relatively homogeneous forest unlike forests created in a natural fire regime.

The existing Sagehen Forest posed threats to many values. Large tree densities made the forest vulnerable to drought stress and outbreaks of bark beetles and diseases, maladies which are likely to worsen from climate change. In the absence of fire, aspen stands, which play an important role in maintaining biological diversity, had been outcompeted by conifers and fallen into decline.

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[38] Forest Service NEPA project documents available at https://data.fs2c.usda.gov/nepaweb/nepa_project_exp.php?project=9156

[39] North, Malcolm, ed. 2012. Managing Sierra Nevada forests. Gen. Tech. Rep.PSW-GTR-237. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 184 p.

If a wildfire got started in the Sagehen Basin, it would have spread rapidly and threatened wildlife habitats. The parts of the Basin less accessible to logging still contained pockets of high-quality late seral habitat, meaning an association of species that indicated the area had not been altered by disturbances such as logging or wildfire in a very long time. The seral habitat supported denning of certain sensitive wildlife species such as Pacific marten, northern goshawk, and California spotted owl. But late seral habitat alone is insufficient to support wildlife needs.

A wildfire would also threaten other values such as water quality and cultural resources. It would increase erosion and sedimentation, thereby degrading the water quality of Sagehen Creek, a tributary of the Truckee River which was already polluted by sediment.

In response to the wildfire threat to the basin, a large and broad community collaborative effort supported by experts in forest ecology, fire science and wildlife biology was formed. This collaboration resulted in a sophisticated management strategy finely tuned to changes in topography, elevation, and aspect, and design of a treatment prescription that would:

1. Reduce hazardous fuel loads and modify wildfire behavior on a landscape scale
2. Maintain and enhance habitat for wildlife associated with late seral forest habitat
3. Restore declining aspen stands, and
4. Enhance the ecological role of fire

Figure 2-5. Sagehen Creek Experimental Forest Mechanical Treatments and Slash Piles, 2017, Faerthen Felix

The solution to achieving these goals simultaneously was to design a project that included a variety of treatments based on eight emphasis area themes. These emphasis areas were intended to reduce fuels while preserving the highest values for parcels defined by topography, rather than treating every acre the same as in the past. For instance, if the area was high-quality late seral habitat, the priority was to conserve and restore wildlife denning opportunities. In drainage bottoms, the priorities were to create foraging habitat, and restore patchy heterogeneous forest structure.

Areas that were not high-quality wildlife denning or foraging habitat had different priorities. For those wetter north-facing slopes, the priorities were ecological restoration and habitat enhancement. For dry, fire-prone south-facing slopes and ridges, the priorities were first to reduce fuels and then to increase the heterogeneity of forest stands. The only goal for aspen stands was to restore them. In all emphasis areas, large trees were to be retained for their ecological and cultural values. This emphasis area approach would create a more heterogeneous forest that would increase resilience to wildfire, disease, insects, and climate change, while meeting the needs of all forest stakeholders, from environmentalists to loggers.

SILVICULTURAL PRESCRIPTIONS FOR EMPHASIS AREAS

Existing Condition	Emphasis Area	Location	Priority of Goals
High-quality late seral habitat	E1	Ridges and North-facing slopes	Conserve and restore wildlife habitat
	E2	Drainage bottoms	1. Create foraging habitat 2. Restore heterogeneous forest structure & ecosystem functions 3. Reduce fuels
	E3	South-facing slopes	Represented little area so combined with either E1 or E2
Not high-quality late seral habitat	E4	Drainage bottoms	Same as E2
	E5	North-facing slopes	1. Ecological restoration 2. Enhance wildlife habitat 3. Reduce fuels
	E6	South-facing slopes	1. Reduce fuels 2. Increase heterogeneity of forest stands
	E7	Ridges	Same as for E6
Aspen stands	E8	--	Restore aspen stands

Table 2-1. Silvicultural Prescriptions for Emphasis Areas

Within each emphasis area, the prescriptions were applied stepwise, with the goal of mimicking the forest structure that would result from the natural fire regime and considering what forest structure would remain after prescribed fire.

The first step was to identify dense cover areas and early seral openings. Dense cover areas were about 3 acres with continuous vertical and horizontal cover, a mixture of shrubs and trees, and a variety of snags, stumps, and other woody debris. Early seral openings were less than an acre of early successional habitat within larger stands of late seral habitat. The proximity of these two landscape features would provide denning and foraging habitat for wildlife species associated with late seral forests, putting the kitchen next to the bedroom as these animals prefer.

The second step was to locate the largest or oldest trees in a stand, typically greater than 24 inches in diameter, and mark them as “legacy trees” for retention. These trees would represent species that would survive in an active fire regime. Trees up to 30 inches in diameter could be removed from around legacy trees, but in no case would trees larger than a legacy tree be removed. For example, if a legacy tree was 28 inches dbh, trees up to 28 inches dbh could be removed. This treatment would make legacy trees more resilient because they would have more access to water, nutrients, and sunlight.

After dense cover areas, early seral openings, and legacy trees were identified, the rest of an area was marked for variable thinning. This would generally favor pines over firs, and red fir over white fir. Individual and small groups of codominant and subdominant trees were retained or removed until the desired metrics for basal area, canopy cover, species composition, and fire behavior were met.

The result of this variable thinning strategy yielded a proposed timber sale with a wide diameter distribution of logs contrary to the impression that forest ecosystem restoration treatments remove only small diameter trees (See figure 2-6 below).

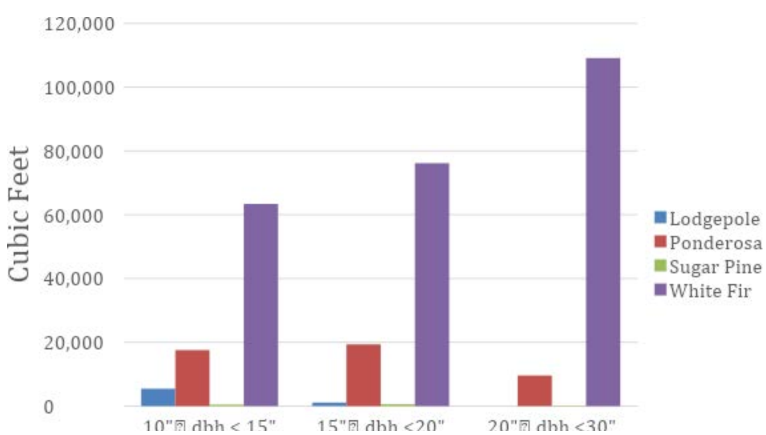

Figure 2-6. Sagehen Creek Experimental Forest Timber Sale by Species and Diameter Class (inches)

The preference for retaining pines over firs was reflected by the fact that fire-prone white fir represented 80% of the cubic feet removed, half of which were between 20-30 inches in diameter. Fire-resistant ponderosa pines represented only 15% of the harvest, of which

80% was equally distributed between 10-to-15 inch and 15-to-20 inch diameter logs. Riparian Lodgepole pine represented only 2% of the sawlog harvest, most of which was 10-to-15 inches in diameter. Sugar Pine was a negligible component of the harvest, about half of which was in the 15-to-20 inch diameter range.[40]

In areas without sawlog-sized diameter material, extensive fuel treatments focusing on cutting trees between one and 12 inches in diameter were applied using mastication; in some places, hand thinning either lopped and scattered material or created burn piles. Fuel treatments did not remove wildland fuels, but they changed the size, continuity, and arrangement of fuels to speed decomposition.[41] Despite formidable fuel treatment costs, the Sagehen Forest Project was largely completed: sawlogs were harvested, fuel treatments applied, and some, but not all areas were broadcast burned as of 2022. The results are being monitored with further data collection, but the project already highlights the twin challenges of overcoming wider community resistance to even low levels of smoke, and the narrowing of acceptable prescribed burn conditions. It should be noted that this information was filtered from the larger service area, and only includes areas where tree cover was present (see figure 2-7 below).

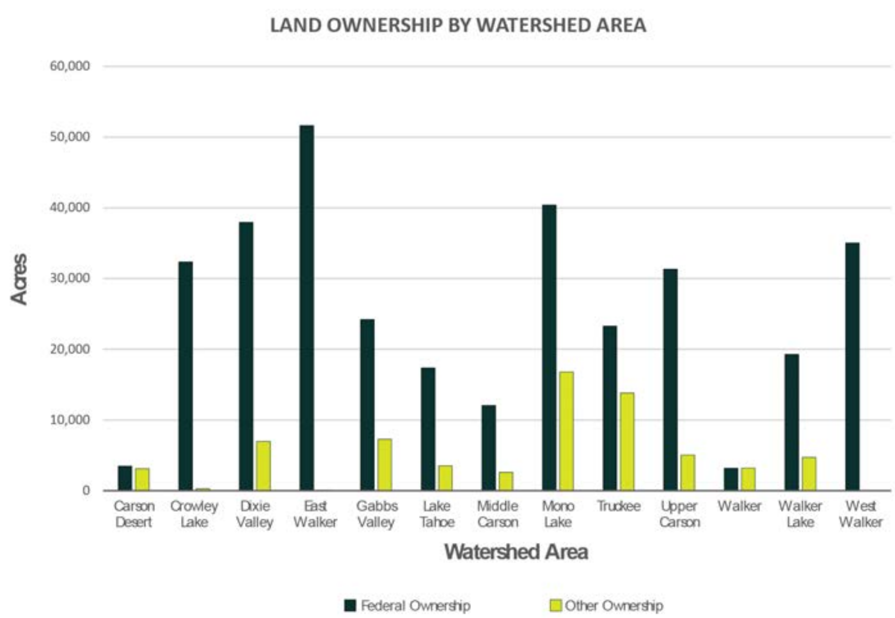

Figure 2-7. Federal vs, Private Land Ownership by Watershed Area

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[40] Environmental Assessment: Sagehen Project, Collaboration with USDA, USFS Pacific SW Region, Tahoe National Forest Ranger District, and the Pacific Southwest Research Station. March 2013.
[41] Conway, Scott D. 2012. Silviculture Specialist Report. 133 pp.

Wood Utilization Study Methodology

This section describes how the forest database was built, and how treatments patterned after the Sagehen Forest Project prescription were applied to models restoring forest ecosystems in the Eastern Sierra and Western Nevada, and estimating the wood yield of these hypothetical treatments.

Building the Project Area Forest Database

Because the study area spanned two states, complete forest structure metrics were not available from either USFS Region 5 Calveg or from Landscape Ecology Modeling Mapping and Analysis (LEMMA),[42] which is a database developed by USFS Pacific Northwest Research Station and Oregon State University.

To build seamless forest structure statistics for the study area, the team used 13,578 USFS Forest Inventory and Analysis (FIA) samples from the California and Nevada parts of the study area. Conservation Science Partners (CSP) implemented a custom convolutional neural network architecture that merges climate, terrain, and National Agriculture Imagery Program (NAIP) datasets as predictors to classify tree type (none, deciduous, conifer, mixed, dead) and simultaneously performs regression analysis on four continuous forest metrics (biomass, basal area, canopy cover, and quadratic mean diameter).[43] Plot data were randomly subdivided into training and validation samples.

Most of the forest statistics came from LEMMA because it contains data needed to apply the Sagehen Forest Project silvicultural prescriptions, such as tree species, diameters and canopy cover. One limitation of LEMMA is that it provides data only for California, which meant compatible and consistent forest statistics for Nevada had to be imputed. Tree species and diameter were deduced by matching CSP and LEMMA statistics and developing a crosswalk for forest types between Calveg and GAP data in Nevada. A forest type is a forest ecosystem of generally similar composition that can be differentiated from

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[42] Landscape Ecology, Modeling, Mapping & Analysis. See Ohmann, JL, and MJ Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon. Canadian Journal of Forest Research: 32(4):725-741. Website: https:// lemma.forestry.oregonstate.edu.

[43] Zbontar, J. and U. LeCun. 2015. Computing the Stereo Matching Cost with a Convolutional Neural Network. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2015, pp. 1592-1599.

other types by their composition of tree and understory species, productivity, and crown closure. LEMMA data was used because it is well correlated with Calveg and GAP. More detailed information about how the database was built can be found in Appendix A.

Treatments

Certain treatment prescriptions from the Sagehen Forest Project were not applied to the western Nevada/Eastern Sierra study area, because specific trees were not marked. Instead, the focus was on metrics that can be applied at the landscape scale: topographic position, forest type, leaving trees 30 inches in diameter or larger, and quadratic mean diameter, a measure of average tree diameter. Subtractions were made from forest statistics until residual stands meet certain basal area and canopy cover metrics. These subtractions were made using targets that left the desired amount of residual stands undisturbed. Site-specific components of the Sagehen Forest Project treatment such as leaving dense cover areas or creating early seral openings were replicated in the study area.

After the Sagehen Forest Project was completed, forest scientists believed more biomass should have been removed to meet the objectives for fire behavior and wildlife habitat. Accordingly, Malcolm North, of the USDA Southwest Forest Experimental Station, who had been involved in designing the Sagehen Forest Project, was consulted.[44] North advised on how to modify the prescription based on what he had learned since the Sagehen Forest Project. These minor adjustments are reflected in Appendix A, which contains the tables used for the silvicultural prescriptions.

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[44] Personal communication with Malcolm North, July 2021

	Forest type
Group 1	Lodgepole Pine Red Fir White Fir Eastside Pine[45] Ponderosa Pine Ponderosa-White Fir[46]
Group 2	Mixed Riparian Hardwoods[47] Mixed Conifer-Fir[48] Hardwoods Mixed Conifer-Fir General

Table 3-1. Forest Type by Regional Dominance Groupings

Treatment areas were defined by unique combinations of terrain, forest type, and wildlife habitat quality. High-quality wildlife habitat had two different prescriptions depending on forest type

Group 1 included the forest types of lodgepole pine, red fir, white fir, eastside pine, Jeffrey pine, ponderosa pine, and ponderosa-white fir. Within Group 1, emphasis area 1 was on ridges or northeast-facing midslopes, emphasis area 2 in drainage bottoms, and emphasis area 3 for southwest-facing midslopes with Quadratic Mean Diameter (QMD) of ≥ 10 inches.

Group 2 included the forest types of mixed riparian hardwood, mixed conifer-fir, and mixed conifer-fir-general.

Treatment table 3-2 shows the residual basal area and percent canopy closure goals for each emphasis area. For these associations, to be in emphasis areas 1, 2, or 3 QMD had to be ≥ 20 inches. Emphasis areas 4, 5, 6, and 7 were those that did not qualify as high-quality wildlife habitats. Prescriptions for these emphasis areas did not differentiate between Group 1 and Group 2 forest type. Emphasis area 4 was for drainage bottoms that did not qualify for emphasis area 2; emphasis area 5 was for northeast-facing slopes not qualified for emphasis area 1; emphasis area 6 was for southwest-facing slopes not in emphasis area 3; and emphasis area 7 was for ridges not in emphasis area 1. Emphasis area 8 was to restore aspen stands and it included mixed riparian hardwoods not in

[45] Eastside Pine has a combination of Jeffrey and ponderosa pine.

[46] Ponderosa Pine-White Fir has at least 50% ponderosa pine and at least 20% white fir.

[47] Mixed Riparian Hardwoods has at least 50% of riparian tree species of aspen, alder, and Fremont or black cottonwood.

[48] Mixed Conifer-Fir has at least 30% of white fir and/or red fir, and also Jeffrey pine and/or lodgepole pine.

emphasis area 1 and quaking aspen stands. The treatment in emphasis area 8 was to remove conifers. Emphasis area 9 applied to pinyon-juniper, a forest type not found in the Sagehen Forest Project, but a major component of the western Nevada/eastern Sierra project area because of involvement of the Nevada Pinyon-Juniper Partnership. The treatment in emphasis area 9 was to remove trees until basal area per acre equaled 45 square feet per acre.[49]

TREATMENT TABLE

Emphasis Area	Forest type	Terrain	Residual Basal Area (Square feet per acre)	Residual Canopy Closure (%)
1	Group 1 Group 2	Ridge, NE Midslope	120 178	~35 ~45
2	Group 1 Group 2	Drainage bottom	150 190	~50 ~55
3	Group 1 Group 2	SW Midslope	140 185	~40 ~45
4	Group 1 Group 2	Drainage bottom	100 130	~25 ~35
5	All	NE Midslope	135	~40
6	All	SW Midslope	135	~40
7	All	Ridge	135	~40
8	Aspen	All	Remove conifers	~50
9	Pinyon-Juniper	All	45	--

Table 3-2. Forest Unit Treatments by Terrain

[49] The treatment for pinyon-juniper of residual basal area of 45 square feet per acre was based on advice from Coreen Francis, NV BLM Lead Forester at Bureau of Land Management.

BEFORE TREATMENT

Homogenous, dense forest is prone to hotter fires

Thick homogenous forests are prone to catastrophic fire

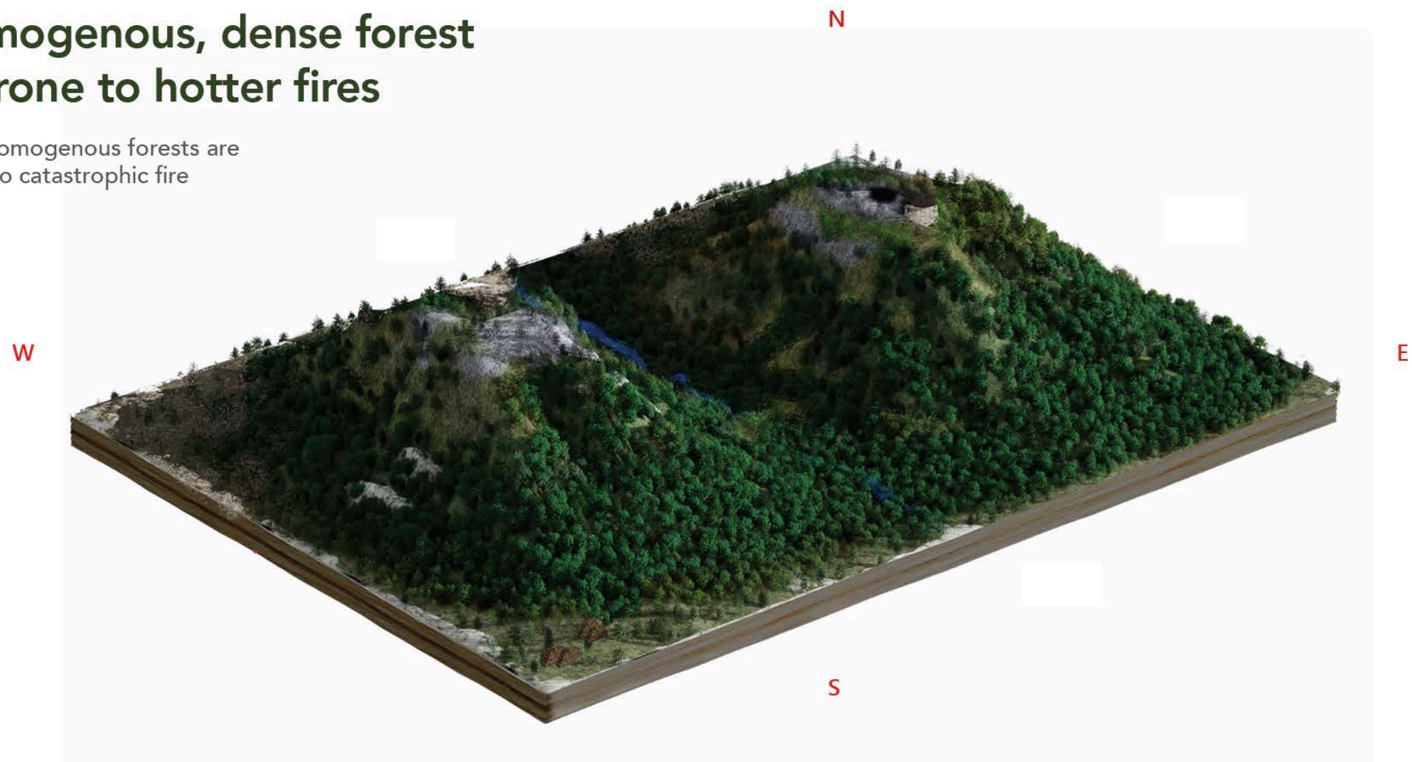
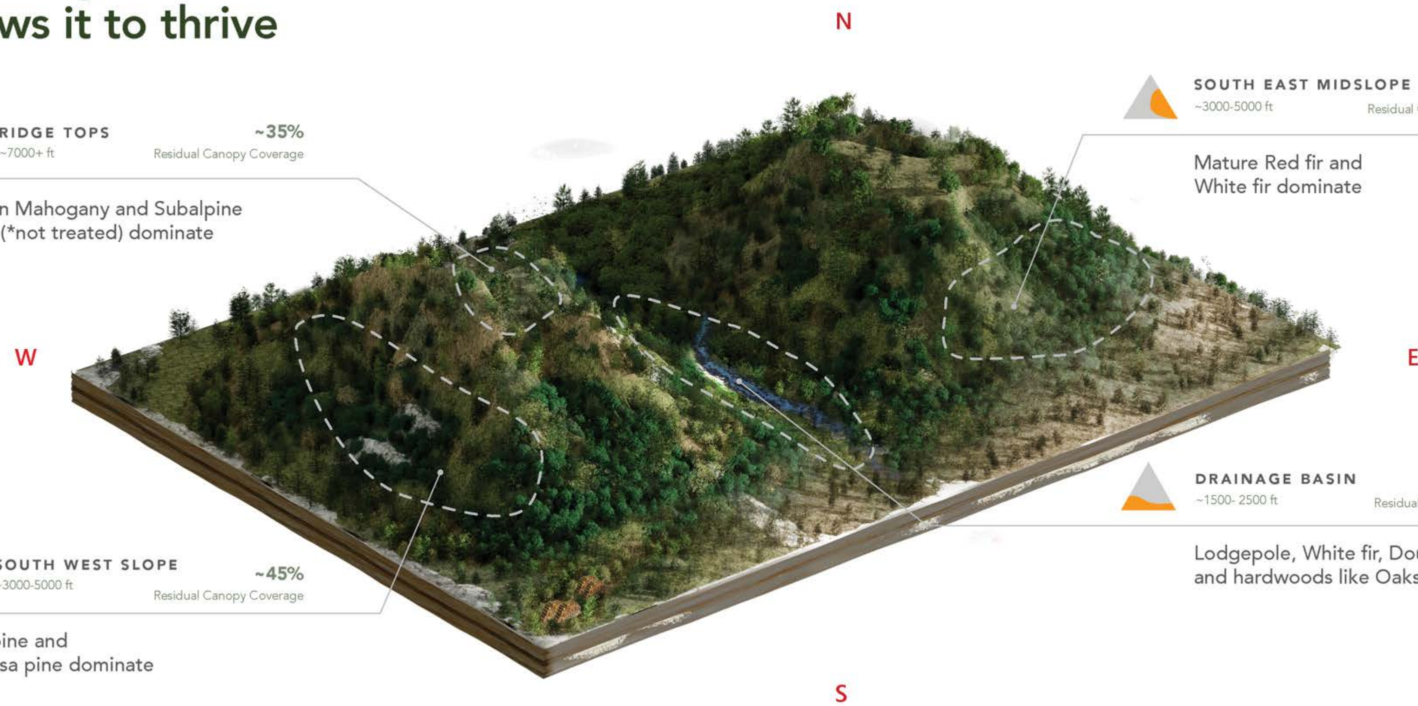


Figure 3-1. Visualization of Forest Treatments

AFTER TREATMENT

Thinning the forest allows it to thrive



RIDGE TOPS ~35%
~7000+ ft — Residual Canopy Coverage

Mountain Mahogany and Subalpine conifers (*not treated) dominate

SOUTH EAST MIDSLOPE ~40%
~3000-5000 ft — Residual Canopy Coverage

Mature Red fir and White fir dominate

DRAINAGE BASIN ~50%
~1500- 2500 ft — Residual Canopy Coverage

Lodgepole, White fir, Douglas fir and hardwoods like Oaks dominate

SOUTH WEST SLOPE ~45%
~3000-5000 ft — Residual Canopy Coverage

Jeffrey pine and Ponderosa pine dominate

* REGIONAL DOMINANCE ALLIANCES, PERCENT COVER AREAS, RESIDUAL BASAL AREA, AND RESIDUAL CANOPY COVER MODIFIED FROM SAGEHEN FOREST PROJECT PRESCRIPTIONS BASED ON THE ADVICE OF MALCOLM NORTH, 2/18/2019 AND 5/24/19'

Global Constraints

Treatments were not applied to areas in:

- **The wildland-urban interface (WUI) defined as high density urban areas or medium density areas with more than one house per five acres.**
- **Wilderness and inventoried roadless areas**

Since wilderness and designated roadless areas represent a large percentage of the forested study area, these two constraints significantly reduced the amount of accessible, merchantable timber in the region. Treatments were applied at the level of small geographic units having the same unique combinations of characteristics. For each unit, basal area removed, stand height, distribution of tree sizes, and distribution of species were calculated. These units were then aggregated to a total for each sub-watershed (HUC 12).

With the land base that remained, two scenarios were set up to bracket the range of material that could be accessed with mechanized equipment. The Tight scenario assumed harvest could occur up to a 35% slope and logs could be skidded 1,000 feet to the nearest road. The Loose scenario assumed harvest could occur up to a 45% slope and skidding distance could be as much as 2,000 feet.

Scenario	Distance from Roadside	Maximum Slope
Tight	1,000 feet	35%
Loose	2,000 feet	45%

Table 3-3. Additional Constraints used for the Tight and Loose Scenarios

Tight Scenario

Under the Tight scenario 252 watersheds had forest lands that met the criteria of distance from road and percent slope.

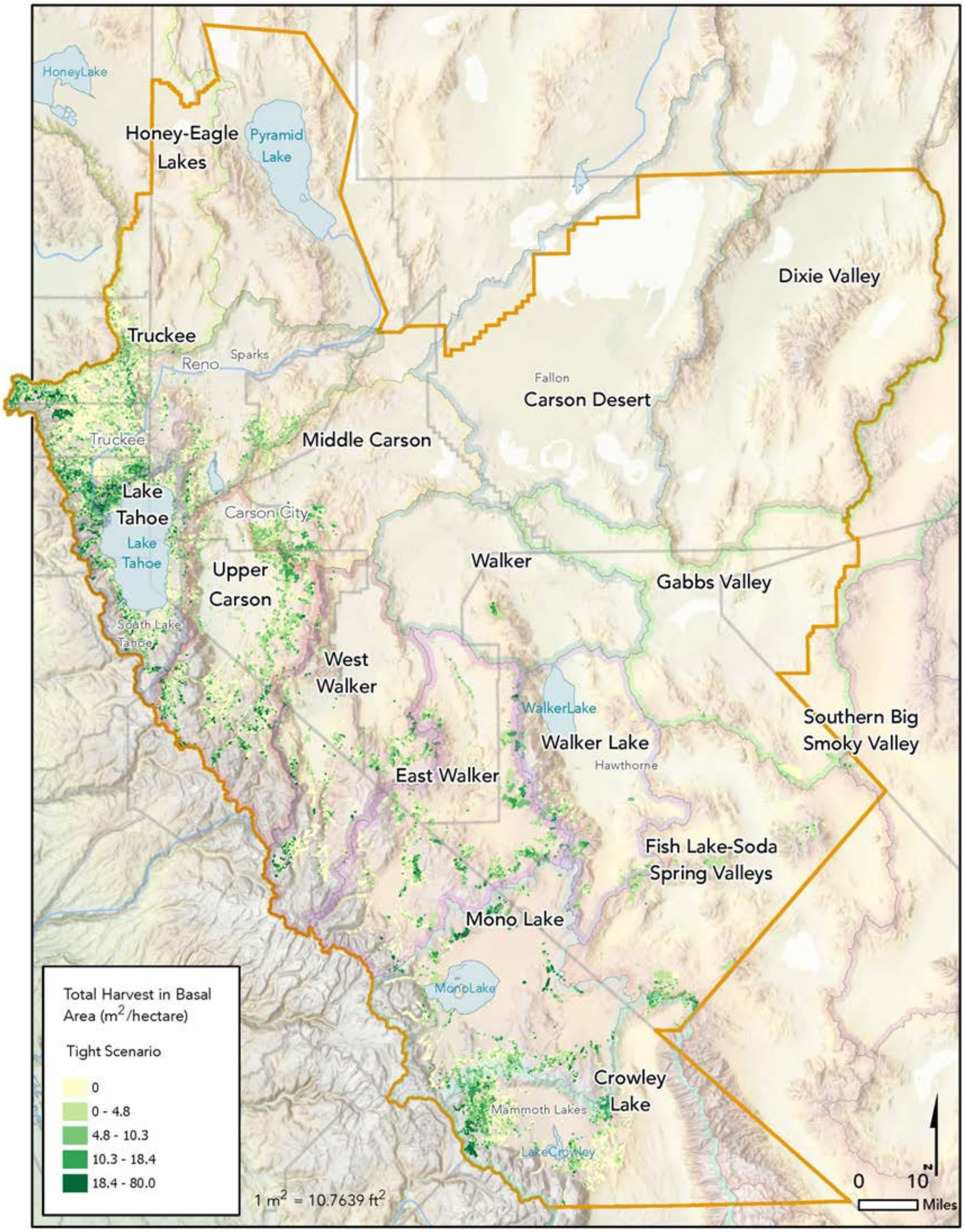


Figure 3-2. Total Harvest (basal m²) under the Tight Scenario

Loose Scenario

For Loose constraints, the number of watersheds meeting the criteria rose to 262. Less than 25% of a watershed was treated in about 227 watersheds in either scenario. Even though less than 25% of these watersheds were treated, they represented 79% of the wood volume removed in the Tight scenario, and 62% in the Loose scenario.

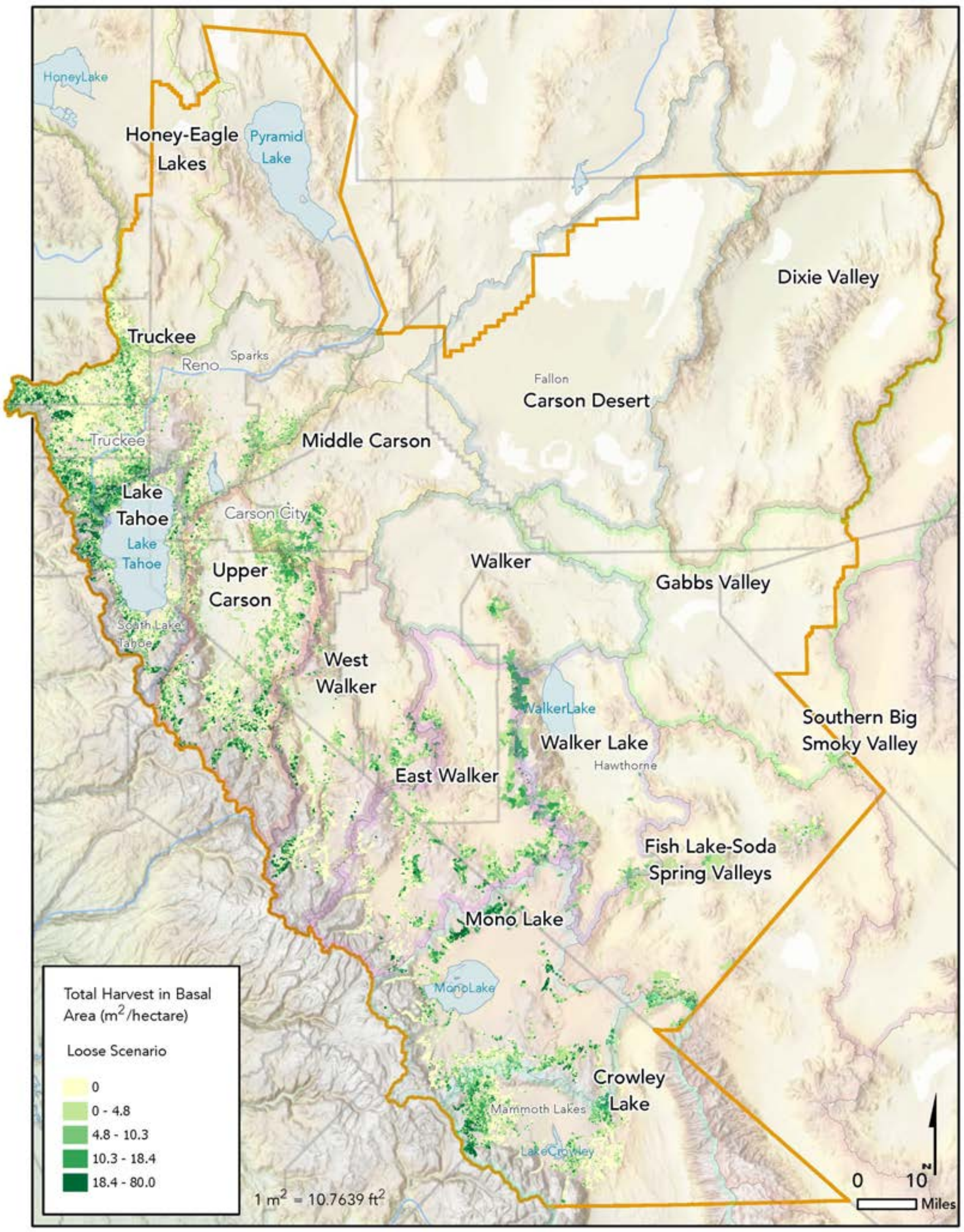


Figure 3-3. Total Harvest (basal m²)

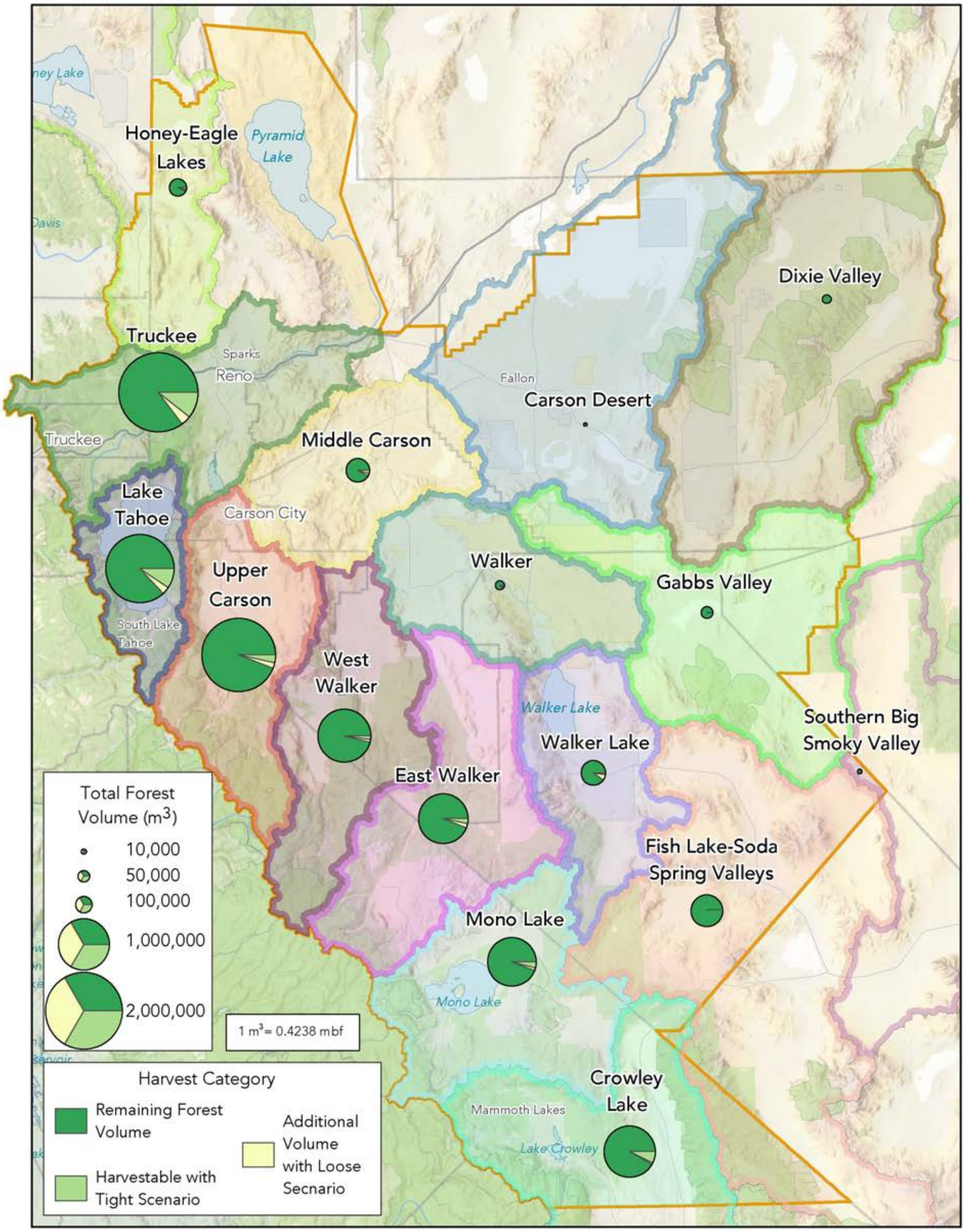


Figure 3-4. Total Forest Volume (m3) and Harvest under the Tight and Loose Scenarios

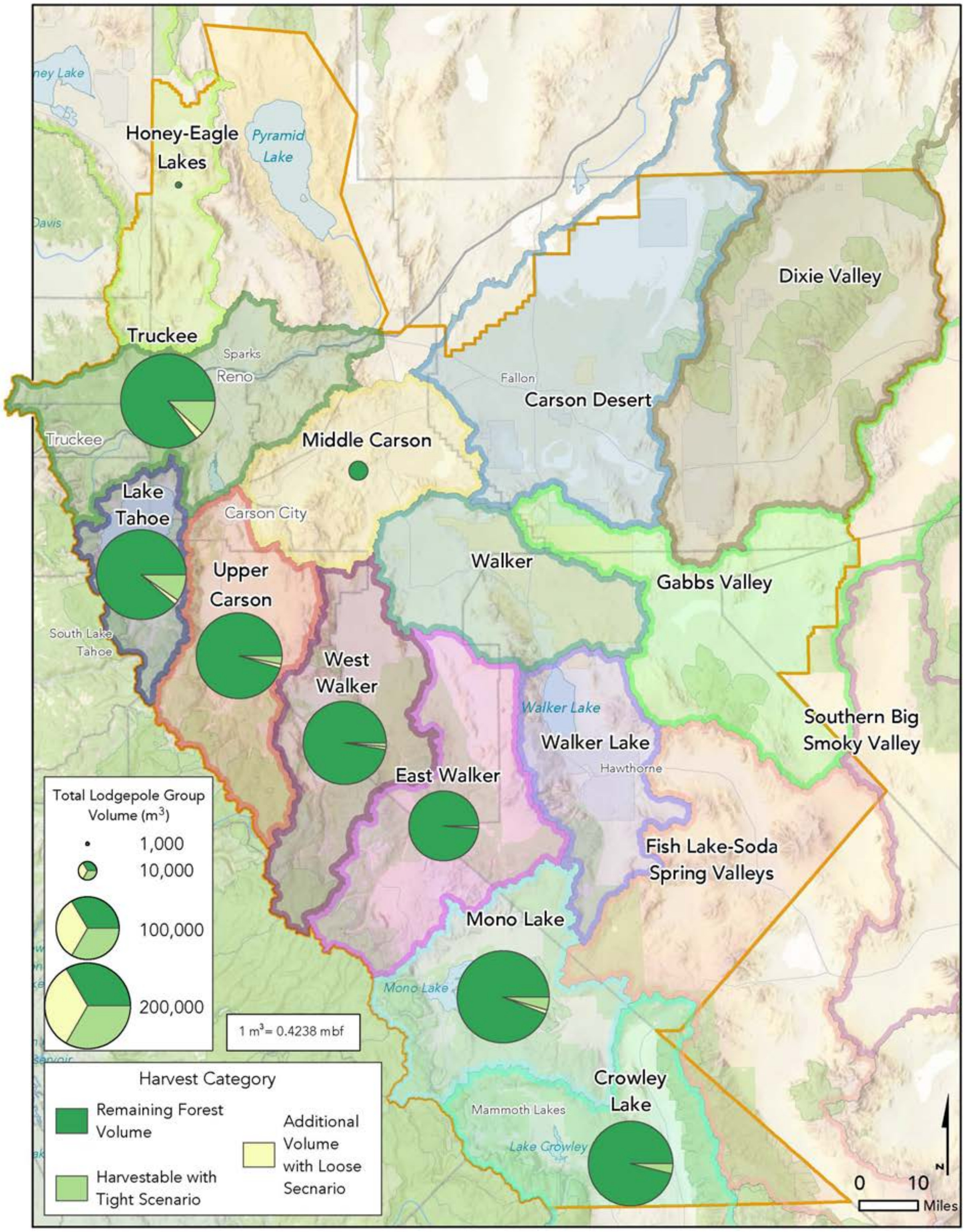


Figure 3-5. Total Lodgepole Forest Group Volume (m3) and Harvest under the Tight and Loose Scenarios

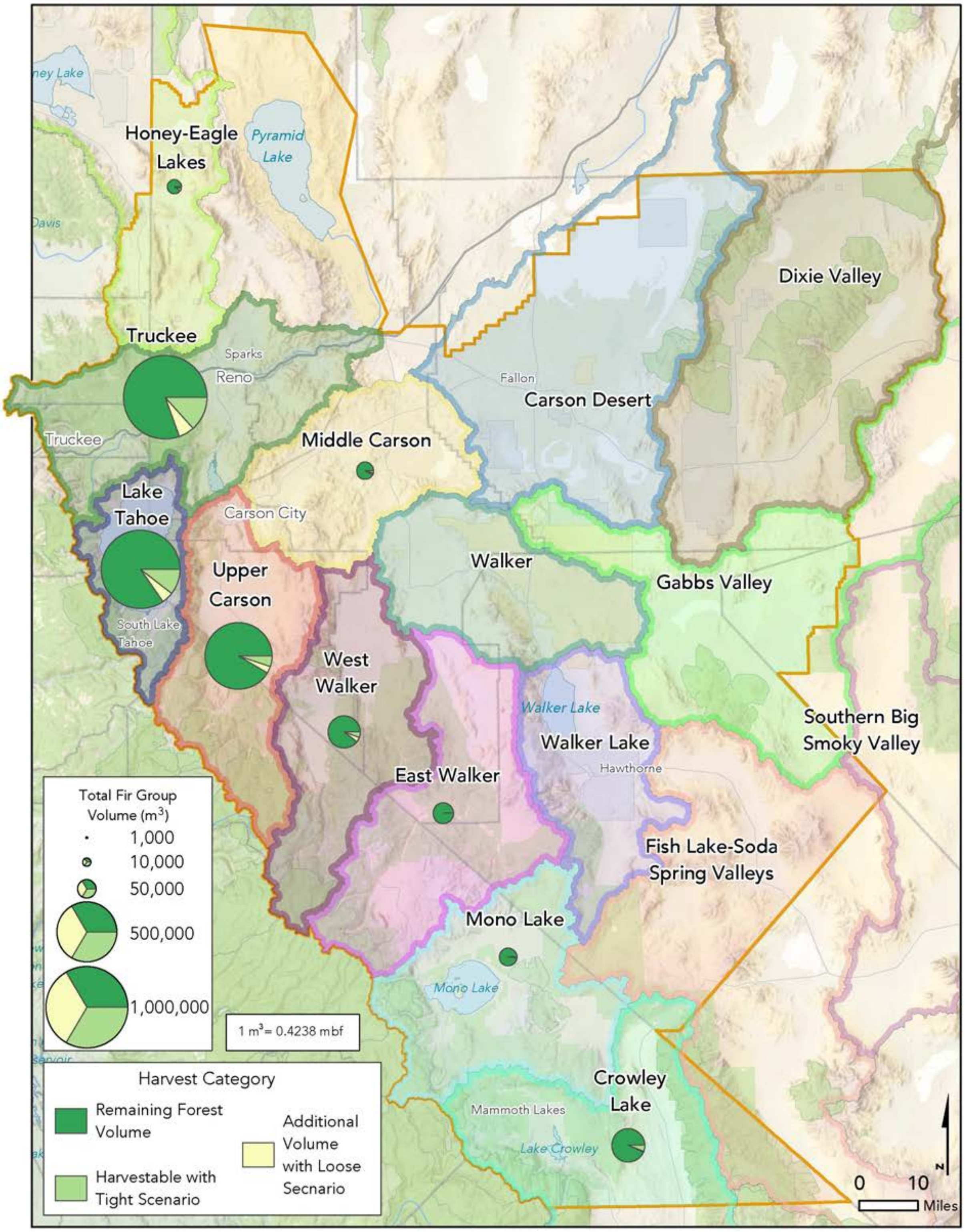


Figure 3-6. Total Fir Forest Group Volume (m3) and Harvest under the Tight and Loose Scenarios

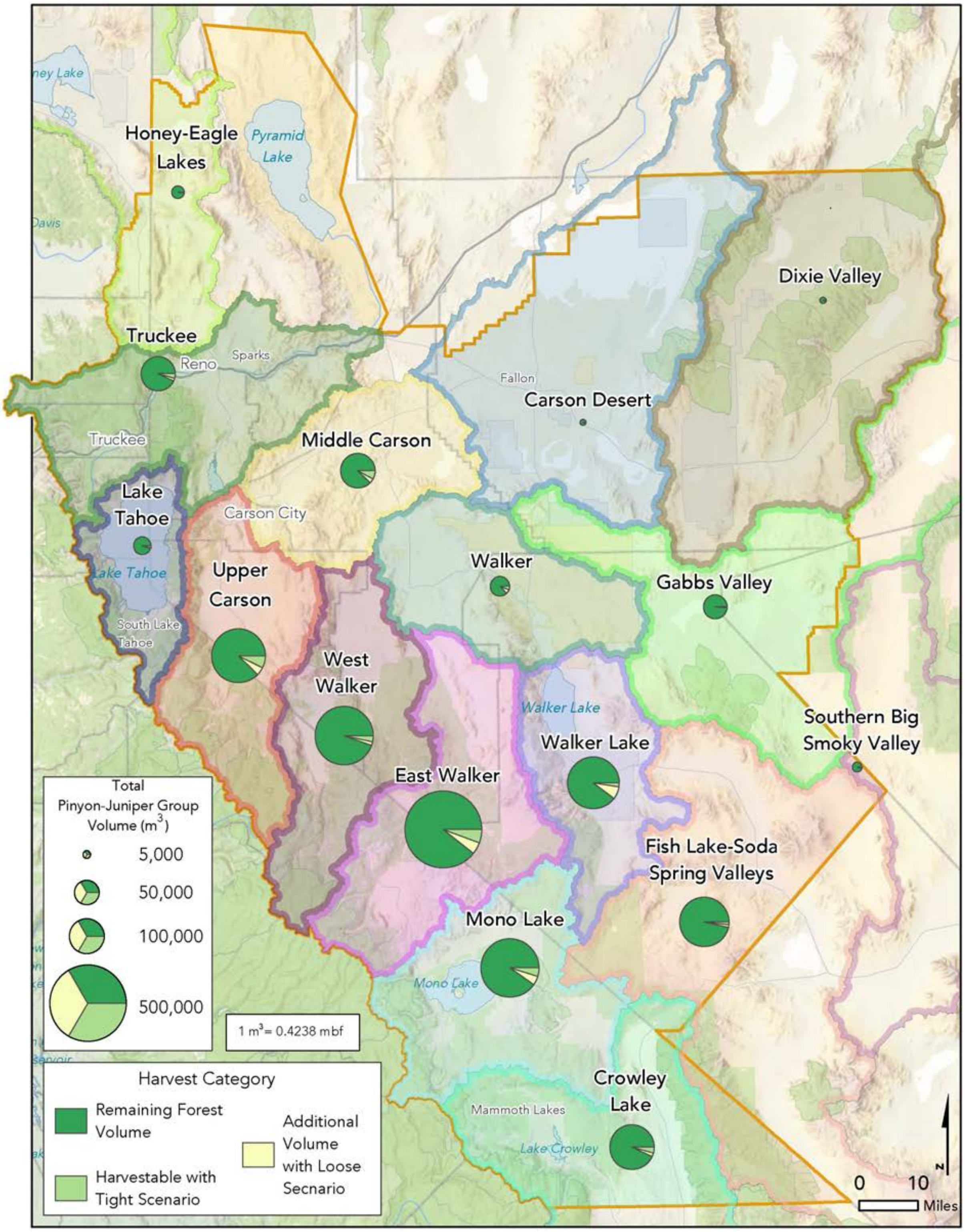


Figure 3-7. Total Pinyon-Juniper Forest Group Volume (m3) and Harvest under the Tight and Loose Scenarios

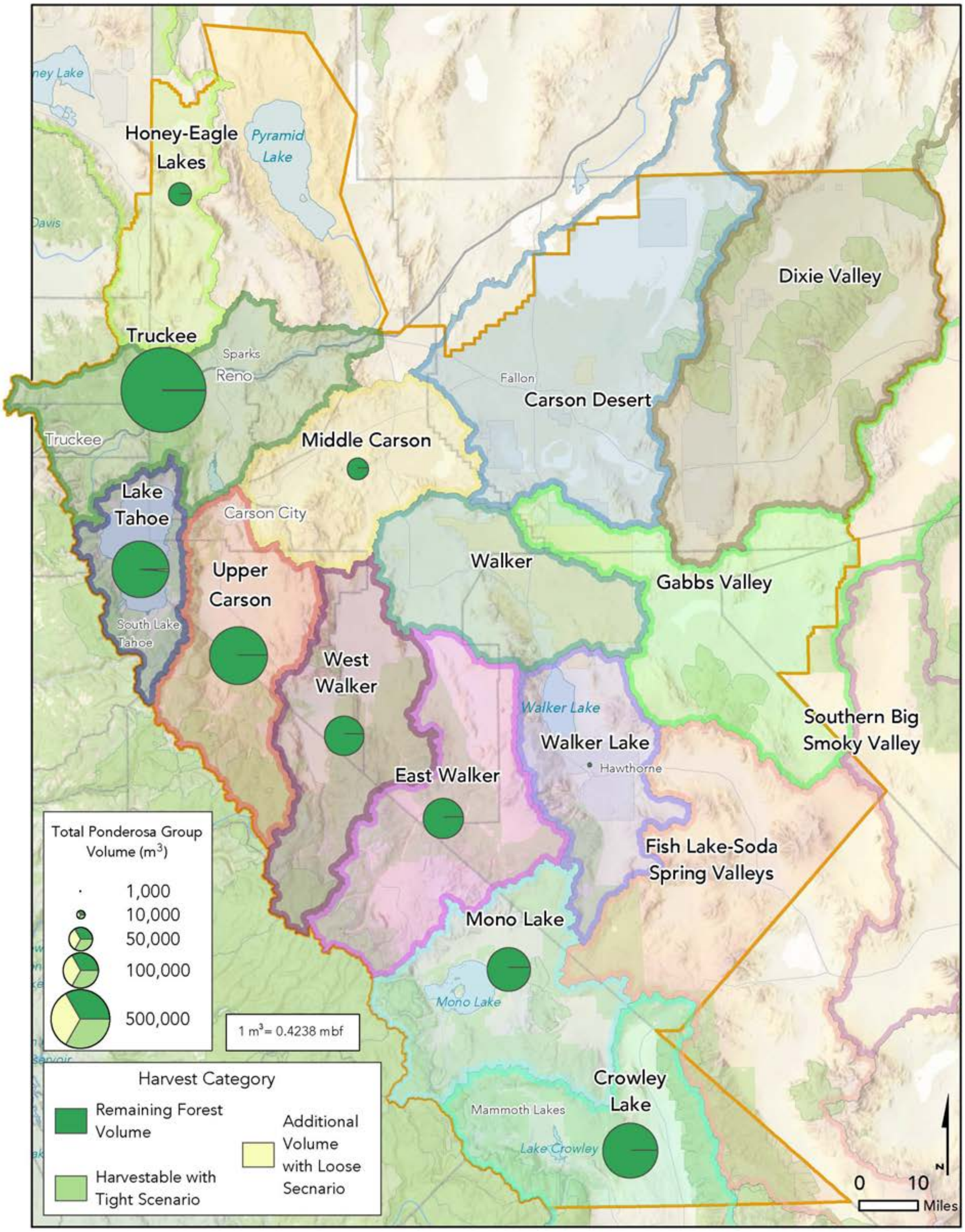


Figure 3-8. Total Ponderosa Forest Group Volume (m3) and Harvest under the Tight and Loose Scenarios

Results of the Study: Analysis

The 376 sub-watersheds included in the project area covered about 456,950 acres with 4.15 million mbf of trees. However, given the accessibility constraints, the Tight scenario accessed only 252 sub-watersheds covering 27,452 acres with about 809,352 million mbf of trees. The Loose scenario accessed slightly more forest, with 262 sub-watersheds covering 40,444 acres with about 1,101,880 mbf of trees.

	Study Area	Tight Scenario		Loose Scenario	
Number of sub-watersheds	376	252	67%	262	70%
Total area (acres)	456,950	27,452	6%	40,444	9%
Total volume (mbf)	4,150,000	809,352	19%	1,101,880	27%

Table 4-1. Comparison of Sub-Watershed Harvest by Scenario

Further inspection of the results revealed that in 87% to 90% of the watersheds less than 25% of the acreage would be treated. The Tight scenario would generate a harvest of 288,184 mbf, and in the Loose scenario 423,148 mbf would be harvested. Most of this harvest would occur in eastern California, generally around Lake Tahoe. There would also be pockets of harvest south of Lake Tahoe and around Mammoth Lakes. Neither scenario would generate enough harvest to sustain a full-scale commodity sawmill, especially if the harvest would be completed over a number of years. This means harvest from this area would have to be sold to various facilities and would make up a part of their log diet or be utilized by one of the other recommendations for wood utilization contained in this study.

Scenario	Total Volume	Treatment Harvest	% Harvested
Tight	809,352	288,184	36%
Loose	1,101,880	423,148	38%

Table 4-2. Total Volume and Harvest by Scenario (mbf)

We combined tree species into groups used by the California Department of Tax and Fee Administration to determine harvest values.

CDTFA Species Category	Qualifying Species in Project Area
Ponderosa Pine	Ponderosa Pine, Jeffrey Pine, Sugar Pine, Western White Pine
Lodgepole Pine	Lodgepole Pine
Fir	White Fir, Red Fir
Incense Cedar	Incense Cedar

Table 4-3. CDTFA Species Categories

The Truckee watershed accounts for 36% of the total volume to be harvested, followed by the Lake Tahoe basin (23%). The only other watersheds containing significant amounts of harvest are Upper Carson (12%) and Crowley Lake (8%). Aspen groves exist close to the Sierra crest from Truckee south into Mono County and near Carson City. Aspen restoration projects that remove encroaching conifers may yield some merchantable timber as well.

White and red fir are the dominant species to be harvested, of which nearly half (47%) would be taken from the Truckee watershed and a third from Lake Tahoe Basin (33%). The only other watershed with significant amounts of fir is the Upper Carson with 13%.

For the pines – Jeffrey, ponderosa, western white and sugar -- three watersheds account for most of the trees to be harvested: Truckee (40%), Lake Tahoe (22%), and Crowley Lake (20%). The Upper Carson would contribute 9% of the harvest, and only minor amounts are contributed by the Mono Lake, West Walker, East Walker and Middle Carson watersheds.

The distribution of lodgepole pine harvest is similar to the other pines, with Truckee containing 36% and Lake Tahoe 26%. Mono Lake has the next highest amount with 13%, and minor amounts of lodgepole are removed from the Upper Carson, Crowley Lake, West Walker, and East Walker watersheds.

Incense cedar logs are primarily derived from the Truckee (51%) and Lake Tahoe (47%) watersheds. Only a small amount of Incense cedar could be harvested from the Upper Carson watershed.

The distribution of harvested pinyon-juniper is very different than the distribution of commercial sawlog species. Four-fifths of the pinyon-juniper comes from five watersheds: East Walker, Mono Lake, Upper Carson, Walker Lake, and West Walker. Minor amount of pinyon-juniper is also taken from the Middle Carson, Crowley Lake, Fish Lake, Truckee, Walker, and Lake Tahoe watersheds. Commercial value for Pinyon-juniper was not significant.

Watershed	Total Harvest	Incense Cedar	Ponderosa Pine	Lodgepole pine	Fir	Pinyon-juniper
Truckee	63,496	1,280	18,549	5,934	36,521	2,859
Lake Tahoe	41,359	1,179	10,423	4,155	0	568
Upper Carson	50,389	67	4,280	1,514	24,028	12,531
Crowley Lake	35,213	5	22,193	3,338	4,829	4,848
East Walker	23,976	<1	915	663	222	22,172
Mono Lake	23,027	<1	4,926	5,093	460	12,548
West Walker	17,279	3	2,335	1,896	6,589	6,456
Walker Lake	9,562	<1	10	<1	1	9,551
Middle Carson	7,417	4	663	53	1,455	5,242
Walker	1,680	<1	1	0	0	1,679
Gabbs Valley	362	0	0	0	0	362
Dixie Valley	65	0	0	0	0	65
Carson Desert	33	0	0	0	0	33
Total	273,858	2,539	64,295	22,646	74,104	78,914

Table 4-4. Major Watersheds by Treatment Volume (mbf)

Implementation Scenario

In discussions with FPInnovations (FPI), based in Canada, it was determined that sub-watersheds would have to have at least 25 tons, or a truckload, of harvestable trees for mechanized harvesting to occur. To set up harvesting equipment in a sub-watershed would cost a minimum at $15,000. Then moving logs from the stump to a truck would cost $200 per mbf. It was further determined that 70% of trees less than 10 inches in diameter would be chipped for biomass and 30% would be made into poles. The minimum cost of biomass chipping was set at $5,000 for setting up equipment, plus $25 per ODT. Consideration was given in this study to how the logs could be used if they went to existing facilities. An examination of the result of shipping biomass, poles, and small sawlogs to Loyalton was conducted, larger diameter logs shipped to Quincy or Lincoln, whichever was closer. The outcome was that 136,000 to 195,000 mbf would be to Loyalton over the life of a treatment program, along with 32,000 to 53,000 bdt of biomass. Another 410,000 to 615,000 mbf of logs would go to Quincy, and 30,500 to 45,000 mbf would go to Lincoln. In addition, 12,300 to 15,700 mbf of logs could go to either Quincy or Lincoln. For trucking from the sub-watershed to Loyalton, Lincoln, or Quincy, the minimum truck cost was determined to be $1,000 per day and $120 per hour. Trucks were assumed to hold 25 tons, and to have an average speed of 50 miles/hour.

Because the Loose scenario identified a total harvest of 423,148 mbf, it was not enough to support a new commercial sawmill. This is because a new commodity sawmill typically consumes between 318,000 and 425,000 mbf of logs per year.[50] For a facility to be created it would need a reliable wood supply for at least 20 years. Even with the more relaxed harvesting constraints of the Loose scenario, this area could only supply about 22,000 mbf per year.

Scenario	Loyalton		Quincy	Lincoln
	Logs (mbf)	Biomass (odt)	Logs (mbf)	Logs (mbf)
Tight	136,174	32,673	74,224	30,766
Loose	195,155	53,418	110,368	44,831

Table 4-5. Assumptions of Logs and Biomass to the Major Mills by Scenario

[50] FPInnovations, October 29ty, 2020. Impact of Restoration Treatments in Eastern California / Western Nevada. Final Report. 49 p.

The table below presents the delivered log cost curves to Loyalton, Quincy, and Lincoln for the Loose scenario. For Loyalton, there are 1,907 mbf available below $50 per mbf, and 173,760 mbf below $100 per mbf. For Quincy, 174 mbf are available below $50 per mbf, and 109,760 mbf below $100 per mbf. And Lincoln has a similar pattern, with no wood below $50 per mbf and 80,000 mbf below $100 per mbf.

Depending on log quality, most mills would not target buying wood above $75 per mbf unless it was a high-value species or a high-grade log. They would prefer logs below $50 per mbf. Given that the bulk of the logs have a delivered cost above $75 per mbf, supporting a commodity sawmill is challenging. Nonetheless, there are some groups working to re-establish local mills. See p. 62 for a case study of a commodity sawmill close to operation in the project area (Mercer).

Delivered Log Cost ($/m3)	Loyalton	Quincy	Lincoln	Quincy or Lincoln
	10”– 20”(dbh) logs	20” (dbh) log or larger		
< $50	1,893	175	--	66
$50 – $74	39,849	25,025	2,098	1,966
$75 – $99	134,075	234,788	31,788	8,636
$100 – $150	19,299	99	10,970	5,352
$151 and up	39	97	8	47
Total mbf	195,155	260,184	44,865	16,067

Table 4-6. Delivered Log Cost to the Major Mills by Log Size Class

Economic Results

While it would be valuable to know conservation outcomes for biodiversity, carbon, and water, this is beyond the scope of this report. Given the very high delivered log costs, the economics of treating the entire project area is very challenging. Using the stumpage values from the California Department of Tax and Fee Administration Harvest Values Schedule (effective January 1, 2020 through June 30, 2020), very few of the watersheds would be considered profitable to harvest. A treatment program to remove both biomass and logs would generate between $50 and $67 million in revenue, but harvest and transportation costs would be between $8 and $18 million more.

Scenario	Revenue	Harvest Cost	Transport	Margin to Harvest	# of Profitable Watersheds	% Profitable
Tight	$51,513,558	$52,729,691	$6,725,072	-$7,941,205	15	6%
Loose	$66,858,729	$75,373,215	$11,151,504	-$19,665,990	--	0%

Table 4-7. Economic Margins by Scenario

Biomass harvesting is considered very expensive, especially as shipping distance increases. In this case, biomass harvest is expensive and negatively affects the overall economics. However, most of the losses come from harvesting logs. Using standard economic models, logging in the study area produces a net loss in raw dollars. Of course, this does not include the co-benefits of land treatments including, but not limited to, fire reduction.

Margin to Harvest	Tight	Loose
Logs Only	-$7,143,188	-$18,821,466
Logs and Biomass	$7,941,205	-$19,665,990
Difference	-$798,017	-$844,524

Table 4-8. Margin to Harvest by Scenario

Why isn't there more available wood out there?

Treatments to improve forest ecological health across the study area would generate too little wood volume to support production of conventional wood products, given the harvesting constraints of the terrain. Therefore, consideration was given to whether the fundamental problem was not enough wood volume or had something to do with various limitations. Could easing of political constraints, such as permitting work in accessible protected wildlife areas, improve the prospect for supporting wood industries? Table 4-9. Total Forest Volume (mbf) by Major Watershed shows the total amount of forest biomass in each watershed.

Location	Sum of Species Volumes	Fir volume (mbf)	Pine volume (mbf)	Lodgepole volume (mbf)	Cedar volume (mbf)	PJ volume (mbf)
Carson Desert	1007	0	19	0	0	988
Crowley Lake	393,372	65,275	168,023	74,079	128	85,867
Dixie Valley	12,409	184	1,320	0	0	10,905
East Walker	438,002	34,790	112,471	58,900	60	231,781
Gabbs Valley	34,629	5,084	2,313	604	70	26,558
Lake Tahoe	910,313	385,712	407,431	82,887	16,241	18,042
Middle Carson	93,205	16,333	30,355	2,899	196	43,422
Mono Lake	401,430	33,901	133,121	99,986	16	134,406
Truckee	1,164,708	420,153	591,849	90,497	19,307	42,902
Upper Carson	1,000,617	367,033	401,109	119,363	4,669	108,443
Walker	10,044	86	95	1	1	9,861
Walker Lake	67,166	170	858	186	1	65,951
West Walker	426,418	82,384	139,940	87,635	195	116,264
Grand Total	4,953,320	1,411,104	1,988,904	617,036	40,885	895,389

Table 4-9. Total Forest Volume (mbf) by Major Watershed

Two of the three watersheds with the highest amount of forest biomass are still able to remove substantial amounts of biomass, despite administrative and terrain constraints: Truckee 34%, and Lake Tahoe Basin 26%. These 2 areas contain enough biomass to be profitable on a stand alone basis. However, the total value is not sufficient to fully subsidize other regions of the study.

The Upper Carson watershed is only able to remove 10% of the biomass; whether this is enough to change fire behavior will depend on where specific treatments are located. Another challenge for the Upper Carson is that the potential mix of species able to be removed is less favorable with lower amounts of fir and pine and higher amounts of cedar and pinyon-juniper.

Location	Fir vol (%)	Pine vol (%)	Lodge pole vol (%)	Cedar vol (%)	PJ vol (%)
Carson Desert	--	<1	--	--	<1
Crowley Lake	5	11	6	2	4
Dixie Valley	<1	<1	<1	--	3
East Walker	2	1	1	2	3
Gabbs Valley	<1	<1	<1	<1	3
Lake Tahoe	11	6	11	14	3
Middle Carson	3	1	0	1	7
Mono Lake	3	8	5	8	3
Truckee	15	10	17	16	6
Upper Carson	5	3	3	10	6
Walker	<1	2	<1	23	6
Walker Lake	2	3	<1	8	2
West Walker	3	1	1	2	3
Percentage of Total	28	40	12	8	18

Table 4-10. Percent of Total Forest Volume Harvested in filtered study area after all constraints are applied, Tight Scenario

Bury, Burn or Build:
Wood technologies and growing markets for wood products

One of the primary objectives of this project is to determine the technical feasibility of manufacturing high-value products, such as engineered wood, from the wood supply generated by forest ecosystem restoration activities within the Eastern Sierra/Western Nevada project area. The rationale is to see whether value generated from such products could help pay for the enormous investments in restoration these forests need to make them more resilient to climate change, fire, and insect outbreaks.

FPInnovations, based in Canada, was contracted to determine whether cross-laminated timber, wood fiber insulation, laminated veneer lumber (LVL), and other high-value or niche products could be produced from this wood. FPInnovations is a private not-for-profit organization that specializes in the creation of solutions in support of the Canadian forest sector's global competitiveness. Its mission is to accelerate the growth and transformation of the forestry sector by creating new market opportunities and by developing opportunities for innovation. The results of this research are reported below, along with some case studies of forestry-related businesses operating within the project area.

The report also analyzed community and utility-scale biomass energy opportunities, along with soil amendment options. Together with production of building materials, these wood utilization opportunities are analyzed below as "Burning, Building, and Burying."

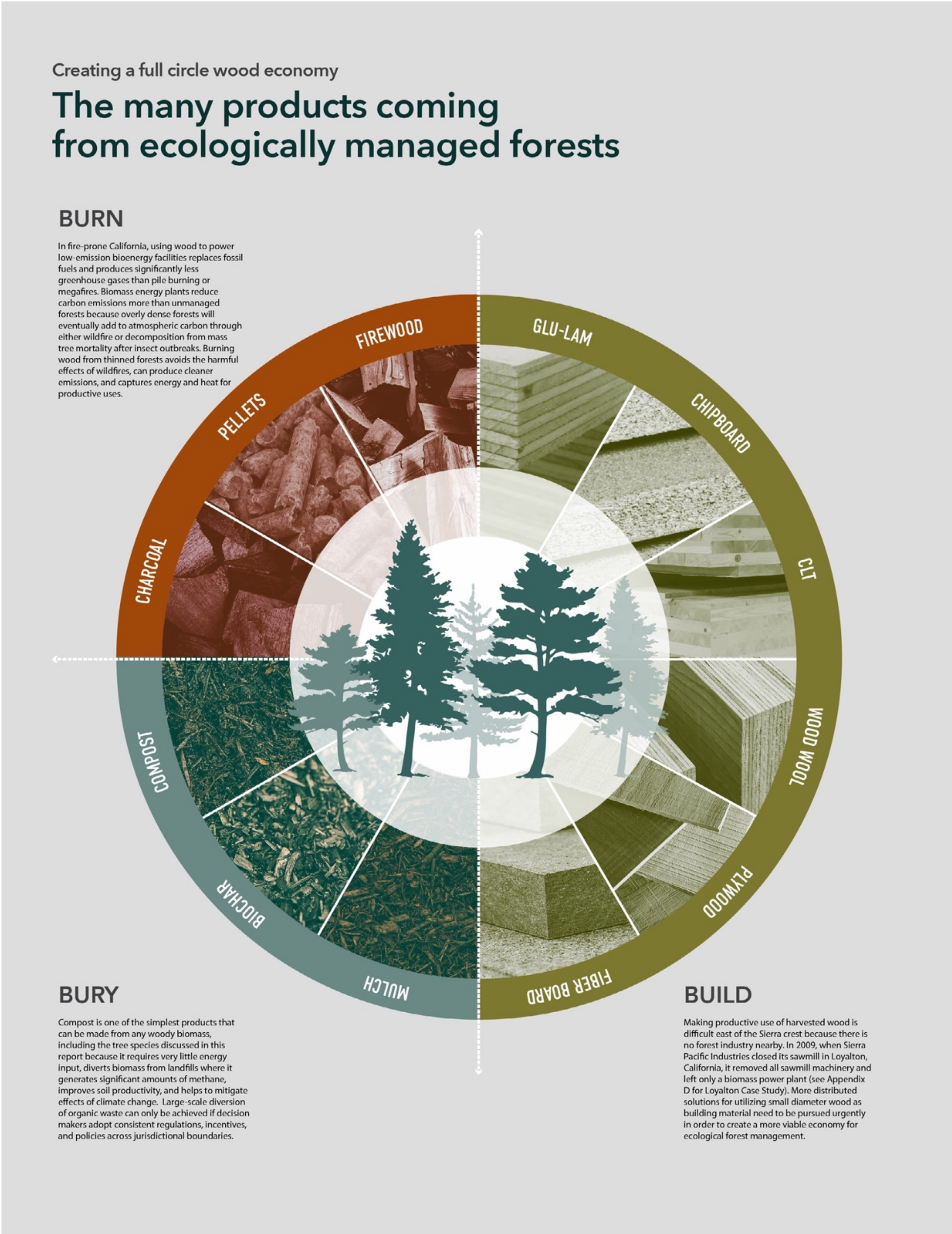


Figure 4-1. Potential Products from Ecologically Managed Forests

Bury
Compost

Compost is one of the simplest products that can be made from any woody biomass, including the tree species discussed in this report because it requires very little energy input, diverts biomass from landfills where it generates significant amounts of methane, improves soil productivity, and helps to mitigate effects of climate change. Compost, or even just raw wood chip, as surface mulch can also displace the need for herbicide in some landscaping and agricultural applications.

Large-scale diversion of organic waste can only be achieved if decision makers adopt consistent regulations, incentives, and policies across jurisdictional boundaries. Such approaches support the compost industry by encouraging communities to gain more of the benefits of fire safe forests, carbon sequestration, reduced greenhouse gases, increased water retention, and more successful projects offered by using compost. Sustainable, long- term markets for compost can only be achieved if decision makers and consumers support the industry on a bio-regional basis.

BENEFITS OF COMPOST

Sequesters carbon
Significantly reduces methane emissions
Enhances water retention in soils
Promotes higher crop yields
Reduces need for irrigation and chemical fertilizers
Helps revitalize habitat, and restore forests and wetlands
Can remediate soils contaminated with hazardous waste
May be less expensive than conventional ways to reduce soil, water, and air pollution

Table 4-11. Benefits of Composting

Full Circle Compost in Carson City is an example of an innovative business model that can charge premium prices by producing high-quality compost customized to specific soil conditions (see Appendix B for more detailed information on Full Circle's model, and its applicability to the Eastern Sierra/Western Nevada project area.) In Nevada, the cost of disposing organic matter in landfills is $12 to $52 per ton, lower than the $40 to $75 per ton Full Circle must charge to make a profit. Because it's cheaper to dispose of organic material in a landfill, people are discouraged from taking it to Full Circle.

	Full Circle	Nevada Landfills	California
Tip Fees (average per ton)	$40 - $75	$12 - $52	$50
Product Price (average per yard)	$40 - $75	$25 - $40	

Table 4-12. Full Circle Compost Cost Comparison

Meanwhile, just across the state line in California, most landfills charge $36 to $50 per ton. But more important than the cost of disposing of organic matter is California's mandate to recycle organic materials as part of its climate change strategy. New regulations are being developed to reduce sending organic waste to landfills by 75% in 2025; this includes reducing food waste currently going to landfills by 20%. The enforcement provisions of the regulations became effective in January 2022 and by January 2024 local jurisdictions must impose penalties for non-compliance. California's policies result in large amounts of organic materials going to compost facilities, likely increasing contamination, and increasing production costs.

California's mandate to increase composting has led to large quantities of low-quality compost being produced. This in turn has driven down the price of the product. Because products move freely across state boundaries, the lower-cost compost produced in California is flooding into Nevada, lowering compost prices, and increasing competition to Full Circle. On the other hand, California's policies also encourage the use of compost through programs such as Healthy Soils.

Burn

Pyrolysis and Biochar

Pyrolysis is one of the ways to produce energy from biomass. When organic material is heated in anaerobic conditions, the result is three products: liquid bio-oil, syngas, and biochar. Biochar is a potential multi-solution approach to reducing forest fire risks, climate change impacts and forest health. Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. It persists longer than the uncharred biomass. It can be used as a product itself or as an ingredient within a blended product, with a range of potential applications for improving soils. When the right biochar is added to the right soil, biochar can, among other benefits, improve resource use efficiency, remediate, and protect soils from environmental pollution, and become an avenue for mitigating greenhouse gases. [51] In Europe, biochar has been recently approved for use in animal feed, a practice not yet authorized in the U.S., although there are some calls for it to be authorized in California. The benefits of biochar are potentially high reaching, especially when used in particularly poor soils.

Sequestering Carbon by application of biochar to the soil [52]

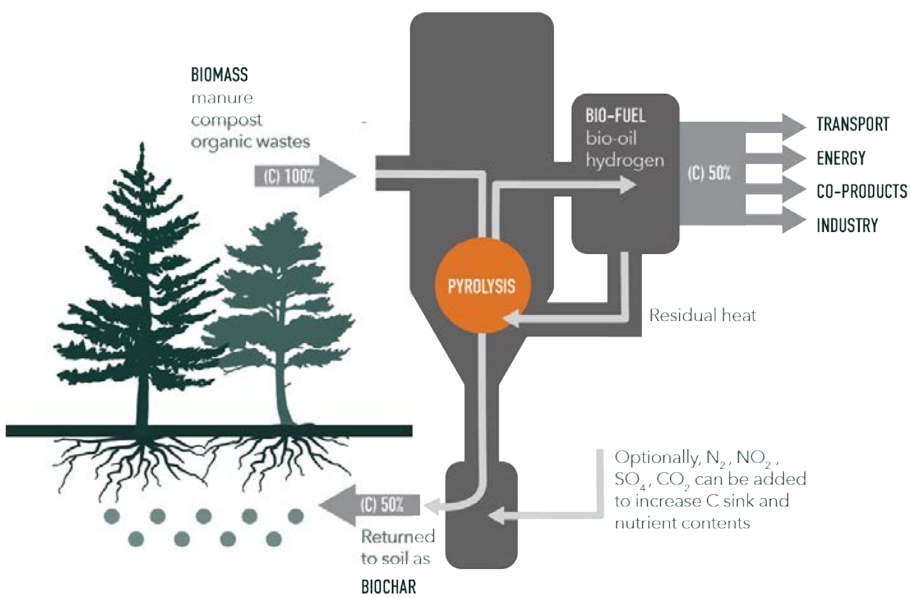


Figure 4-2. Illustration of the Pyrolysis Process

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[51] International Biochar Initiative; February 2015; www.biochar-international.org

[52] https://www.ars.usda.gov/northeast-area/wyndmoor-pa/eastern-regional-research-center/docs/biomass-pyrolysis-research-1/what-is-pyrolysis/ - https://biochar-international.org/biochar-technology/

A survey and analysis of the US biochar industry[53] found two trends – a "growth in sales supported by a general optimism in the strength of the marketplace" and the desire for more information, support and in particular biochar-related research. The same survey reported a request for certification of biochar for animal feed, and a loud call for policy to recognize biochar as carbon negative and to give financial credit accordingly.

There are multiple possible uses of pyrolysis and biochar,[54] and most of the current and developing ones are explored in Appendix C.

Biomass Energy

In fire-prone California, using wood to power low-emission bioenergy facilities replace fossil fuels and produces significantly less greenhouse gases than pile burning or megafires.[55]

Biomass energy plants reduce emissions more than unmanaged forests because overly dense forests will eventually add to atmospheric carbon through either wildfire or decomposition from mass tree mortality after insect outbreaks. Burning wood from thinned forests avoids the harmful effects of wildfires, can produce cleaner emissions, and captures energy and heat for productive uses. In addition, biomass plants recycle carbon that is already above ground, unlike burning fossil fuels which extracts carbon sequestered in the earth's crust and adds to atmospheric carbon.

Community-Scale Biomass

There is long-standing support among forest managers in the Tahoe area for deploying wood energy to support forest management, fire mitigation, and community fire safe activities. Large-scale projects have met public resistance and contributed to permitting restrictions. Distributed, small-scale projects are more flexible, have a smaller footprint, shorter development timeframe, and more public acceptance.

Wisewood Energy is developing a proposal for wood energy at a resource recovery

[53] commissioned by the US Forest Service, via a Wood Innovations Grant, for which the preliminary report was published in 2018

[54] Schmidt HP, Wilson K, The 55 uses of biochar, the Biochar Journal 2014, Arbaz, Switzerland.
ISSN 2297-1114, www.biochar-journal.org/en/ct/2, Version of 12 th May 2014

[55] Springsteen, B. et al. (2015). Forest biomass diversion in the Sierra Nevada: Energy, economics and emissions. California Agriculture (69(3), 142-149. 10.3733/ca.v069n03p142.

facility, where woody material is already collected, chipped, and hauled out of state. One Tahoe area ski resort community is also actively exploring a biomass gasification operation to both manage wood produced by fuels reduction projects, and to lower electrical bills for area residents. A small wood energy system will offset fossil fuels, reduce transportation out of state, and provide the demonstration project needed to enable other projects in the Basin.

Utility-Scale Biomass

Located about 40 miles north of Truckee in Loyalton, California, the Loyalton Biomass Power Plant is in a former lumbering boomtown. The first sawmill in the current location was built in 1901.[56] After passing through various ownerships, the site was eventually bought by Sierra Pacific Industries (SPI).[57] After SPI closed the facility in 2009 it eventually removed all the sawmill machinery, leaving a biomass plant that can, at peak production, produce up to 20 megawatts of electricity but is targeted to run in the range of 15-18 megawatts, based on conversations with plant operators. American Renewable Power subsequently bought the biomass power plant but operated it sporadically, before entering bankruptcy. Sierra Valley Enterprises, the current owners of the Loyalton biomass plant, is now exploring whether it is feasible to restart the power plant.

An operational biomass plant at Loyalton is a vital asset for the region as its relatively central location allows it to absorb a significant amount of the biomass that will be generated on an annual basis from a balanced long-term forest management program in the Tahoe Basin as well as the entire Eastern Slope of the Sierra.

The 210-acre site is envisioned as a wood utilization campus and includes critical infrastructure to support a variety of related businesses, including roads, power, water to 13 individual subdivided parcels and a railroad spur. Related businesses that utilize small diameter material could both increase the demand for small diameter material that is the product of increased forest management activity while also providing a source of lower priced biomass for the power plant, lowering their operating costs, and assuring viability of the operation.

The biomass power plant alone, without any ancillary or related businesses on the

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[56] Truckee-Donner Historical Society, "Tracking the Railroad from Boca to Loyalton," accessed 9/15/2021 from https://www.truckeehistory.org

[57] Loyalton's Milton Gottardi Museum, "A Brief Overview of Loyalton's History," accessed 9/15/2021 from http://loyaltonmuseum.org

campus, would generate demand for up to approximately 150,000 bone dry tons (approximately equivalent to 20,000 - 30,000 mpf) of chips annually, which if sourced from forest management activities in the region could support 15,000 acres of forest thinning per year.

The amount of biomass that could be shipped to Loyalton from the forest treatment programs analyzed in this report is not enough on its own to support the long-term operational needs of the Loyalton plant, as financial investors generally require visibility to a decade or more of feedstock. This lack is largely due to the constraints imposed on the analysis, which restricted study focus to relatively accessible public lands, near roads and on lower inclines. A larger effort that incorporates private land, particularly in the WUI will need to be considered to assure access to sufficient wood and biomass to make the powerplant and any related wood-utilizing businesses viable over the long term.

The study identifies between 135,616 and 194,948 mbf of smaller diameter logs and biomass that can be shipped to Loyalton. Ideally this material would be utilized for a higher value-add use, such as a small diameter wood mill or a post and pole mill. However, such higher value uses utilize a fraction of that material, with the remainder most likely becoming wood chips to be used by the plant. For instance, a post and pole mill generally only converts 40% of the raw material to a finished product and the other 60% becomes wood chips to feed to the mill (this speaks to the logic of the wood utilization campus concept discussed above.) Assuming 50% waste conversion, those logs would result in between 500,000 (Tight scenario) and 750,000 (Loose scenario) bone dry tons of biomass for the plant. This would supply between three and five years of supply for a biomass plant, a significant supply that, while not sufficient to justify financing a new plant, might be enough to justify re-starting already existing infrastructure.

In addition to the biomass facility at Loyalton, there is also a 5 MW biomass operation at the Northern NV Correctional Center.

***Read a Case Study on the Loyalton Biomass campus in Appendix D.**

BUILD

Making productive use of harvested wood is difficult east of the Sierra crest because there is no forest industry nearby. In 2009, when Sierra Pacific Industries closed its sawmill in Loyalton, California, it removed all sawmill machinery and left only a biomass power plant (see Appendix D for Loyalton Case Study). More distributed solutions for utilizing wood as building material are explored below.

Sawmills

Commodity Scale Sawmills

Unlike traditional forestry practices, a silvicultural prescription designed to restore forest ecosystems in the yellow pine belt of the Sierra Nevada removes a higher proportion of smaller diameter trees, in the range of 10" to 20" QMD. Many places around the world manufacture lumber from small diameter logs, for example, regions in Quebec may run a log diet in the 6"-12" range. Commodity scale sawmills for small logs can produce a range of sizes, but typically produce higher volumes of 2"x 3" or even 2"x2". This smaller material is targeted towards industrial uses or furniture instead of the construction lumber market.

The technology to mill smaller diameter logs requires specifically designed log processors, and these processors generate more byproducts such as sawdust and wood chips. To be profitable, these sawmills must operate at high speeds because the percent of each log that can yield merchantable lumber is so small. The estimated volume of material generated by forest ecosystem restoration on accessible lands in the project area is not enough to feed a commodity scale sawmill over the lifetime of the investment. Accessing a bigger volume of timber may change this perspective but that was beyond the scope of this report.

Case Study: long-time Truckee forester Dave Mercer is in the process of setting up a 20 million board feet per year commodity-scale sawmill using equipment imported from Slovenia on a 100-acre parcel north of Truckee. He plans to be in full operation by the end of 2022. His goal is to supply locally sourced commodity timber to the regional luxury and 2nd home market. Based on initial success, he is also planning to add a 5 mbf per year community-scale small diameter CLT mill also from Slovenia. He intends to supply builders with prefabricated wall sections and other structural elements that take advantage of CLT's fast installation characteristics. The speed of assembly of a CLT or prefabricated structure is a major advantage in the region which has both a limited building season and a current severe shortage of skilled labor.

Case Study: Tahoe Forest Products LLC (TFP), in a partnership with Washoe Development Corporation (WDC), an affiliate of Washoe Tribe of Nevada & California, recently announced the lease of 40 acres of Washoe-owned land near Carson City, Nev. to build the first significant sawmill in the region in decades.

By creating a local market for green and burned logs, the mill will help to reduce fire fuels to help slow and prevent future fires.

"This project came about because there was no reasonable market for salvage logs and thinnings from the Tahoe Basin or from the Humboldt Toiyabe National Forest," said Jon Shinn, CEO of TFP. "A local sawmill is one of the critical missing links in beginning to address forest health and resilience, not to mention critical post-fire cleanup efforts from catastrophes like the Caldor Fire."[58]

[58] https://www.2news.com/news/new-sawmill-coming-to-carson-city-to-help-address-forest-health-and-resilience/article_2b150a3c-1d9a-11ed-b441-f3e9a0d3667c.html

Smaller Scale Sawmills

Given the geographic scope, range of log sizes, and low timber volumes in the project area, smaller scale sawmills may offer a way to recoup some economic value from more remote or unprofitable watersheds. One option is a stationary small-scale sawmill; another is a portable sawmill. All these systems range in size and cost. To show a range of the kinds of systems available, we discuss some examples below without endorsing any product or manufacturer.

At the smaller end of sawmill options are small bandsaw mills. As an example, Wood-Mizer manufactures a variety of these sawmills, in both portable and stationary models. Their electric stationary sawmills are generally less expensive to buy, operate and maintain than their portable mills. Because they are electric, stationary mills are quieter, cleaner, and last longer than the portable sawmills powered by gasoline or diesel fuel. One model uses thin-kerf narrow band blades (see Figure 4-3) that provide more material recovery and less waste. It can be adjusted to saw logs ranging from 12" to 67" in diameter and it can handle hardwood species.

Figure 4-3. Wood-Mizer's WM1000

Stationary Small-Scale Sawmills

Most stationary small-scale sawmills feed logs through fixed saws or sets of fixed saws. A wide range of equipment is available from Europe, where it is used in smaller operations. These systems can process large runs if the logs are presorted by diameter and fed through on a continual ribbon basis. Some systems are designed to be indoors and have a simple infeed and outfeed arrangement to manage logs and lumber handling. Manual or automated log handling systems can be put in front of the primary sawing unit to facilitate production. Even if a system does not have a de-barker in front of it, the chips and sawdust produced can be used in biomass energy facilities or to make pellets. Although it is not possible to put these systems out near forests, other systems are designed to be operated in the open. The two systems shown below are typical of the log breakdown component of these systems.

Skywood : MS-260 DOUBLE-SHAFT RIG

Mebor Double Arbor SDH 320

Figure 4-4. Skywood MS-260 and Mebor Double Abor SDH 320

The Skywood Multi Saw Double Shaft Rig MS-260 combined with a head rig forms a single production line capable of processing approximately 25 to 40 mbf of round timber per shift. The rig can saw logs accurately to within 1/50th of an inch in one pass with good surface quality.

The Mebor Double Arbor SDH 320 is a gang saw, meaning it has several adjustable parallel blades for making simultaneous cuts. This machine can handle logs up to 13" in diameter. Manufactured in Slovenia, it is a heavy duty, high production stationary machine.

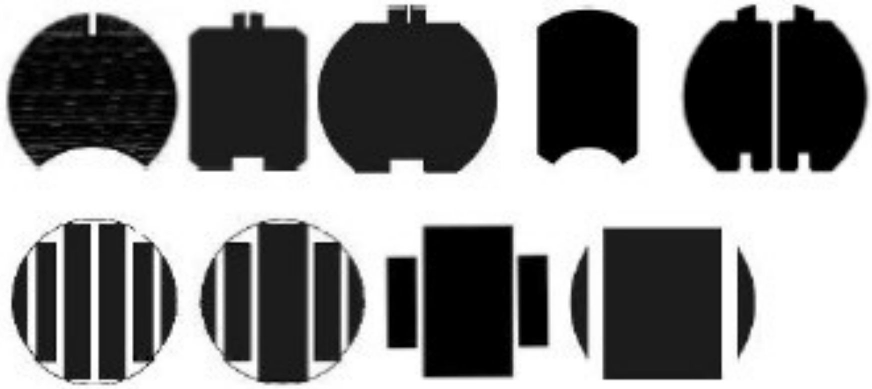
Portable Systems

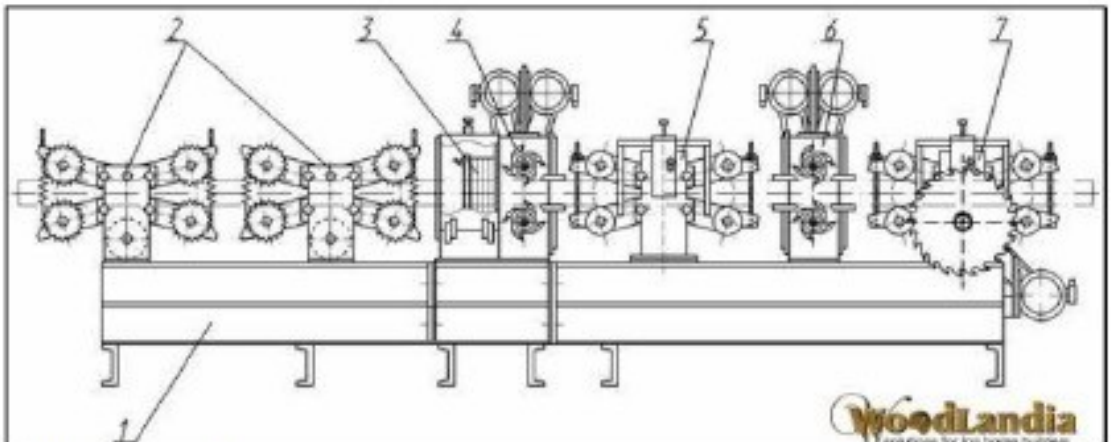
Several portable systems are available which can get equipment closer to the harvest. They range from $100,000-$1,000,000 depending on the equipment selected, the vendor and other equipment needed to operate. If mobile equipment, installation, and a building are required, the total cost of a facility can be as much as $5,000,000. If an existing contractor is available and the equipment is specified for mobile operations, it may be possible to establish capacity much more cost effectively.

Examples of these systems are the Woodlandia and the Micro Mill approaches discussed below.

Woodlandia

Woodlandia manufactures multi-function sawmills that can produce products in one pass if logs are pre-sorted by size and quality. These sawmills can produce a multitude of products, ranging from dimensional and custom lumber, to cants, squared timbers and pallet boards, round dowels, posts, poles, fencing, log home materials, and wooden siding. The operator sets up the saws for each category of logs, and then feeds in the batch of logs that produces a specific output of lumber. Woodlandia machines are suitable for small and medium-sized businesses, businesses that want to diversify, and businesses that want one machine that can produce different types of products. Woodlandia machines can mill building materials from trees killed by bark beetles. The models range from those that can handle logs with butts up to 9.5 inches, or 10.5 inches, 16 inches, or the most versatile machine which can handle logs up to a 17.25-inch butt diameter. Woodlandia also manufactures log sawmills and systems for primary wood breakdown, machines for manufacturing log and timber homes, and round dowel milling systems.





1. Base frame
2. Log infeed unit. Function: proper infeed of the log into rotary milling head
3. Rotary milling head with knives. Function: log debarking, milling of perfect cylindrical shaped log
4. Milling unit. Function: log alignment and milling of portion of profile
5. Outfeed alignment unit. Function: proper log orientation and infeed into next milling unit
6. Profile milling unit. Function: form required log profile
7. Sawing unit. Function: rip sawing of log (if necessary

Figure 4-5. Woodlandia Wood Processing Equipment

The top photo, below, shows the Woodlandia system set up in a clearing with a manual log infeed and lumber outfeed. The logs in the background range from 4 to 8 inches in diameter.

Here the system is cutting pulp logs into industrial lumber. The blue equipment on the right is a diesel generator producing power to run the unit. The unit is not fixed down on a foundation.

The lower photo shows the blower system moving residue away from the processing center. This simple system could blow residuals into a chip truck or bin. According to Woodlandia's promotional material, at least one system has been sold in the United States.

Figure 4-6. 150ME Mobile Installation

Micro Mill

Micro Mill offers a different approach to small scale processing. The Micro Mill system is based on shifting saws rather than the fixed saws of the Woodlandia system. This provides processing flexibility because logs do not need to be sorted as accurately; it may also enable the system to handle a wider range of logs with the same equipment.

The Micro Mill seen below does not have a debarking system, so it produces a mixed residual hog fuel (chips and sawdust) like the Woodlandia system. It also has a blower system that can move chips into a storage bin or transportation equipment. Although this does provide a lot of flexibility, it is a more complex system and likely more expensive than the Woodlandia system.

Micro Mill packages their systems in industrial containers which can be placed in a clearing or, as in the image below, a roadside landing. The Micro Mill system promotional video indicates that it has been used to support fire treatments in Utah.

Photo 3: Model SLP5000D Remote Road Side Landing, BC Canada

Figure 4-7. Remote Wood Processing Setup

Application of Small-Scale Sawmills to Project Area

Given the geographic range of the treatment area and location of existing milling facilities, these smaller-scale technologies may be particularly suitable in three situations:

1. South of the Tahoe Basin
2. Areas which are too far away from existing sawmills
3. In small watersheds

One option is to establish a stationary system south of Topaz Lake, where lower-value logs could be processed closer to the harvest site and high-value logs could be sent to existing lumber mills. Another option is to use a portable system to address remote and unprofitable watersheds and process logs onsite in forests.

Other Wood Products

Scrimber

Scrimber is a product made from crushed logs. The bark is removed and then the small diameter logs are crushed and pressed into a block or a beam. Originally invented in Australia where products are made from Monterey Pine (also known as radiata pine), there is no commercial facility in North America. The Scrimber approach has been proposed to produce either structural products or nonstructural products (furniture, flooring, etc.) This approach is being used in China to manufacture products from bamboo. Producing a nonstructural product, this technology can be done a smaller scale and it might be possible to use a this technology with some of the low-value species in this study.

Figure 4-8. Scrimber made from Southern Yellow Pine[59]

[59] Wan Tarmeze Wan Ariffin, 2019, Scrimber from Sustainable Malaysian bio-Resources, Accessed 5/3/21 from https://www.ResearchGate.net.

Pressed Wood Composite

Pressed wood composites are made by pressing wood particles and resins into various shapes. These products can be made as a base material or as final shape. One example is the engineered molded wood pallet made by Litco, the first pallet to receive Cradle to Cradle Certification from McDonough, Braungart Design Chemistry (MBDC), a company founded by the authors of Cradle to Cradle: Remaking the Way We Make Things. It earned certification because it achieved "a high level of strength and stiffness while using fewer resources."[60]

Figure 4-9. Traditional Shipping Pallets

A comparison of Litca's molded wood pallet and the most common wood pallet used in North America found Litca's pallet improves the efficiency of supply chain operations, reduces product damage and contamination, results in fewer injuries to workers, and significantly increases the efficiency of shipping and materials handling. These pallets can be reused and are "nestable," requiring less space for storage than conventional pallets.

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[60] Dr. Marshall S. White, "A Comparison of Pallet Strength and Functionality: Litco's Engineered Molded Wood Pallets Compared to GMA-Style New and Repaired Wooden Pallets, revised 3/12/2020. Accessed 5/3/21 from https://www.litco.com.

Figure 4-10. Scribner Products

Wood Wool Cement Board

Wood Wool Cement Board, also known as cement excelsior board, is one of the oldest insulation materials made from renewable raw materials. It is a promising opportunity for trees removed from forest restoration projects because it specifically calls for small diameter softwood logs, 4″ to 11″ and 6 to 15 feet long. It is a mineral bonded, natural fiber product widely used in Europe and Asia.

Figure 4-11. Wood Wool Cement Board Product

Wood wool cement boards have many properties that make them attractive for manufacture and use in California. Most importantly, they increase the fire resilience of a building over standard building materials. They have a lifespan of more than 100 years and are resistant to water, frost, termites, mold, fungi and rot. They provide both acoustic as well as thermal insulation and thermal mass, thereby increasing the energy efficiency of a building. Composed of natural materials, the boards are recyclable and can even be composted.

The raw materials are simply wood, water and Portland cement in a 1:1:2 ratio by weight. Preparing logs for processing is simple, because they can be stacked and dried for up to 6 months. Commonly the material is made from pine, spruce, or aspen.

Wood Wool Cement products can be manufactured in a 200 by 600-foot building, on an 8 to 12-acre plot. Capital investment for hardware is between $6 and $7 million depending on the product line and level of automation. Each 8-hour shift employs between 16 and 26 people, consumes 20 tons of wood and 33 tons of Portland Cement. The logs are first cut into 2-foot lengths, then sliced into wood strands. The strands are then mixed with the binding agent of Portland Cement and water. Up to 45,000 square feet of product can be made in each shift. Next the mixture is put into molds and pressed. After drying for 24 to 48 hours, the boards are finished and cut to size.

	Per 8-hour shift		@ 1 shift/day, 5 days/week, 50 weeks/year
Wood (@25% moisture content)	20 tons	44,092 lbs	5,000 tons 833 MBF
Portland Cement (Type III)	33 tons	72,751 lbs	8,250 tons
Water	22 m3	777 ft^3	1,942 ccf
Sodium Silicate	1.4 tons	3,086 lbs	350 tons
Electric Power	4.17 MWh		1,042 MWh
WWC-LE	167 m3	5,885 ft^3	

Table 4-13. Wood Wool Cement Inputs

The standard product used in most applications is manufactured as boards 2-feet wide, 8-feet long, and 0.6 to 4-inches thick. These boards provide acoustic insulation useful in settings such as parking garages, athletic venues, and livestock barns. Treated with colors and textures, the boards can provide aesthetic appeal for walls and ceilings in meeting rooms and other interior spaces.

Figure 4-12. Wood Wool Cement Applications

Because wood wool cement boards can withstand the elements, they have many useful applications outdoors as well. They can be attached to structural frames to form the shell of a building. It is a good product for noise abatement along highways and railroads, and so could be very useful to Caltrans or NDOT.

Figure 4-13. Wood Wool Cement Applications

Wood wool cement boards can be combined with CLT and mass timber to increase fire resilience, and also provide thermal and acoustic insulation. The thermal and sound insulation properties of wood wool cement boards increase with thickness of the board. The R-value/inch is approximately 1.8. See table below.

		Thermal Transmission	Sound Absorption
mm	Inch	R-value	Noise Reduction Coefficient
38	1.5	2.63	0.55
51	2	3.50	0.60
64	2.5	4.38	0.60
76	3	5.25	0.65

Table 4-14. Wood Wool Cement Performance Characteristics

Traullit, a company in Sweden, now produces wood wool cement in large wall elements at least 1 foot thick, up to 10 feet wide and 20 feet long. These walls can be assembled like cross laminated timber panels in prefabricated, modular construction that can be built quickly with little waste on-site. The walls can be easily handled because they have a low specific weight of only 21 pounds per cubic foot. The R-value of these thick walls is high; a 12-inch-thick wall exceeds California's Title 24 Building Code requirements for high performance walls.

Figure 4-14. Wood Wool Cement Building Application

Laminated Veneer Lumber (Plywood)

Even though some of the species in the project area are approved materials for making laminated veneer lumber (LVL), there are not enough suitable logs to support a commercial facility. Average LVL plant capacity is about 72,000 to 85,000 mbf of logs each year. Further, the market is already heavily consolidated, with Boise Cascade and Weyerhaeuser representing 60% of the capacity. Small diameter logs are generally not used for LVL because they are less efficient to process and have lower recovery. Under the Loose scenario, about 45% of the total log supply would be medium sized or large diameter logs, of which only 20% of the total harvest would be suitable for peeler if they met the specific grade requirements for shape and quality. Although data does not exist about the quality of these trees, given the growing conditions it is unlikely enough logs would be straight, have limited taper, be free of defects and have sound knots. Current spindleless lathe plywood technology does allow peeling smaller diameter logs but given the quantity and quality of the wood supply in the project area, the technology does not make manufacturing LVL practical.

Cross Laminated Timber

If sufficient volume was secured an interesting product opportunity that could be produced from small logs is Cross Laminated Timber. Although generally produced from 2"x 6" lumber in North America, a 2019 announcement of a joint venture between F.H. Stoltze Land and Lumber Company, and Wooden Haus Supply, highlights the opportunity to produce CLT from slow grown small diameter trees. F.H. Stoltze has announced a new facility designed to utilize these small diameter trees. They are specifically targeting slow grown trees which they claim will bring higher strength properties to their CLT allowing for higher performance. F.H. Stoltze has not announced its capacity, but world scale facilities today are between 25,000-50,000 mbf of final product which means they need between 34,000-64,000 mbf of lumber supplied to them per year. This lumber can be sourced from any sawmill in the region so if Quincy, Loyalton or Lincoln were processing the timber from this study a sufficient supply of lumber would be available.

Although a world scale facility is quite large, Xlam in New Zealand, Smartlam in Montana, and Element 5 in Ontario all started CLT production on small manual presses (2,200 mbf). All three of these companies have now established world class CLT facilities. What is key to a CLT facility is having the engineers and designers to partner with the design and construction communities, and access to a tree species composition that is suited to CLT production. The State of California is currently engaged in testing red and white fir, and is going to test ponderosa pine, for suitability in CLT production.

A comprehensive review of environmental performances of CLT buildings using life cycle assessments showed that all CLT buildings had better environmental performance such as lower impact on global warming compared with corresponding building alternatives.[61] Life cycle assessment is "a scientific approach to analyze and quantify the environmental burdens associated with resource extraction, manufacturing, use and disposal of a product." Compared to traditional wood products, the manufacturing stage of CLT contributed the most to global warming, but still outperformed buildings made using non-wood materials.

Log Homes and Outdoor Living Spaces

Potential market opportunities are tool sheds, outdoor living spaces, and log homes. Using technology like Woodlandia, logs could be profiled into specific shapes that can be assembled into kits or finished products. The variety of structures ranges from tool sheds to picnic shelters, bunkhouses to small cabins, and larger homes or vacation properties.

A range of species can be used to construct outdoor spaces and log homes. On the west coast of North America, the most prominent species is old growth western red cedar, but other species used include lodgepole pine, ponderosa pine, Douglas-fir, western hemlock and Englemann spruce. On the east coast, eastern hemlock and eastern white pine are also used. With technology such as Woodlandia, logs could be profiled into a cylinder or a large rectangular shape (see images below). Many log home kit manufacturers prefer a rectangular shape because they are easier to handle and make construction go more quickly. Smaller logs also make assembly easier and allow manufacturers to offer solutions to a wider range of customers.

Figure 4-15. Woodlandia Log Profile

[61] Sahoo, K, R. Bergman, S Alanya-Rosenbaum, H. Gu and S. Liang. 2019. "Life Cycle Assessment of Forest-Based Products: A Review." Sustainability. 11, 4722.

The equipment to produce these profiles could be either in a central facility or portable equipment in remote locations. In a remote operation, logs would likely be broken down to a simple profile then shipped to a central location for processing into a final building or kit. If the logs are poor quality, they would have to be processed as close to the site as possible to minimize transportation costs. At the central site, final production would add other materials such as doors, windows, and finishing lumber.

For both remote and central locations, site requirements are minimal. You would need to be able to operate in the location for one or two years, and to connect to the electrical grid or run a generator. You would also need space for a portable office and two or three pieces of equipment, including a chipper or firewood splitter.

One advantage of using logs to make these structures is that the logs are simpler to access and are available for local/near onsite construction. Most manufacturers season logs by stacking them and letting them air dry for a year. This reduces moisture content but does not completely dry the log. Final moisture content of the logs will depend on the tree species and relative humidity of the drying location. Some manufacturers kiln dry logs. In either case, log homes will settle over time because horizontal logs shrink more than vertical logs. Once a building is constructed the logs dry and season in place.

Log homes are designed to accommodate the logs shrinking. Spaces above windows are left so the windows are not damaged as logs shrink. Openings are left to accept doors.

Steel fixtures, and screw jacks can be used to manage differences between posts and floors. The screw jack image below shows how a column can be lowered as the outer walls shrink to keep the building in alignment. Because logs shrink, small buildings without interior posts are easier to design and build. The same techniques can be used whether homes are built from logs or squared timbers.

Figure 4-16. Detail of a Screw Jack Installation at the bottom of a Log Post
Source: The Illustrated guide to Log Home Construction, FPInnovations

Heartland Timber Frame Homes, in British Columbia, prefers post-and-beam construction because the result is strong and structurally stable. Unlike homes built of logs laid horizontally, post-and-beam houses do not settle and do not require special designs around doors and windows or special hardware to deal with shrinkage. Instead of tree-length, large diameter logs, a timber frame is built from logs in 8 to 12-foot lengths. Two people can build a wall without using any heavy equipment. These homes can be built so quickly that a 1,400 square foot home can be completed to lockup in 9 to 12 days. The result is a home that is affordable to build, inexpensive to maintain, and healthy to live in. Heartland has a program for First Nations to address their shortage of quality homes.

Homes built from logs or by post-and-beam might be an alternative to trailers to help address housing shortages in California and Nevada for many reasons. Built from solid wood, such homes would be more resistant to fire than trailers or conventional homes. They could be a way to create demand for high-value products made from locally grown wood that needs to be removed from the forests to increase fire safety and improve forest health. Someone who lost a home in a wildfire could build a new shelter quickly and relatively inexpensively on their own property. These homes could be added onto later when people have the resources to do so. If an enterprising person could find a new way to make homes from these trees, it might be the highest value, environmentally beneficial product that could be made from them.

Figure 4-17. Timber Frame House

Figure 4-18. Timber Frame House Joins

Summary of Opportunities Using for Small Logs

The table below summarizes findings about potential technologies for making use of the material harvested from the project area. The biggest challenge remains scale, since most existing processes need sufficient scale to be cost-efficient. In some cases, innovative approaches to sawmilling may work.

If commercial scale cannot be achieved by developing partnerships to exploit fiber supply, then the target may need to be a higher-value product with enterprises located closer to consumers. Technology alone will not solve the economic challenge. The biggest challenge is finding entrepreneurs and investors prepared to take the risks needed to establish a new business in a high risk environment. Government incentives and policy could also help redirect resources to the proactive, prevention side of the ever-increasing wildfire budget.

The table below scores a variety of technologies using three categories: Commercial (currently or in the near future), Community (or local scale operations) or Artisanal (individual or small scale), with an estimate of near-term feasibility (on a scale of 1-5, with 5 being most feasible). This list is necessarily incomplete but is designed to show the general state of utilization in the region evaluated in this study.

Category	Product	Challenge/ Opportunity	Scope of Opportunity	Feasibility	Solution	Notes
Build	Small log commodity mill	Sourcing sufficient volume (5m -20m board feet/year)	Commercial	(5) 2 facilities in active development	Log swaps, additional volume	As of 2021 at least 2 new mills starting with Summer 2022 operations in Truckee CA & in Gardnerville NV and a 3rd scheduled to open in 2022 in the former Loyalton site
Build	Log Homes	Market knowledge/ entrepreneur	Artisanal	(1) Low	Need Market	Potential for artisanal development
Build	Small log CLT	Needs lumber supply	Community	(4) 1 project in near term financing	Partnership with existing facilities for supply	Local Small Mill operator already in negotiation to bring in community scale CLT plant to Truckee by summer 2023
Build	Veneer/ Plywood/LVL	Insufficient volume/ capital intensive	Community	(2)	Need to source additional volume	Need to source additional volume
Build	Scrimber	Technology knowledge	Community	(2)		New technology to the US although long track record in China/Australia
Build	Pressed wood composites	Technology knowledge	Commercial	(2)	Need to source additional volume	
Build	Wood Wool Cement Board	Technology knowledge	Community	(2)		

Build	Posts/Poles	Can pick up off-take of traditional timber mills	Community			
Burn	Bio Energy	Price of electricity - no guarantees on long term contracts	Community	(4) 1 project in near term financing	Coordinating Biomass Energy with Solar and other renewable energy sources	System in development in South Lake Tahoe
Burn	Pellets	Low-cost feedstock	Commercial	(5)	Broad range of uses from artisanal to export	Burning chips is the lowest value usage

Table 4-15. Matrix of Wood Products

Other Potential Commercial Uses for Small Logs

It should be said that this list is not exhaustive, but represents the products with the most generally agreed upon near-term potential. Additional wood products like torrefied pellets, wood flour, 3D printed wood architectural elements, highly engineered wood products like carbon fiber and nano-crystalline cellulose from wood precursors, and other innovative wood-based products may indeed prove to be part of the long-term solution.

Wood Utilization Outlook

Executive Summary

- There are no simple answers for the crisis in western forests
- More precise calculations at every stage will help create adaptive protocols for rising temperature and prolonged drought
- Administrative boundary issues are impeding progress
- Implementing nature-based solutions will require joint partnerships at all levels from local to federal
- We can stimulate forest management by partnering with private sector and providing incentives
- There should be an emphasis on nearby projects to get local industry involved and decrease emissions by minimizing shipping

It is clear that there are no simple answers to solving the forest crisis in the Sierra Nevada and western Nevada. Many people have worked very hard to find ways to increase the scale of treatment programs as an essential part of resilient forest management. Trends in temperature and drought increase the urgency for getting this work done. More creative thinking is required.

A more favorable picture of the potential for forest industry east of the Sierra crest could emerge with more precise calculations. More timber could be removed from the forest if prescriptions are adjusted to anticipate the impacts of rising temperatures and increasing drought on the amount of forest biomass that can be sustained in a healthy condition. Estimates in this study of chips generated are likely understated because they do not include the fact that 50% of the wood used for sawtimber would generate chips as well. We also may want to consider management by watershed with fewer carve outs for protected areas, therefore increasing the percentage of forest accessed. This would set limits based on the desired result or condition instead of a fixed number of feet from a road, percent slope, or dates of the season for forest activities.

Some potential for improved forest management is being missed by administrative boundaries. Both state and federal forest management end at the state boundary which can miss forests that cross state lines. In California, the Sierra crest can be another barrier, as there is greater focus west of the Sierra crest because the forests and water supplies are more lucrative. In addition, the facilities for processing timber are located closer to the wood source, which means that the costs of transporting logs from the east slope to a mill is prohibitive.

Nature-based solutions often involve multiple actions taking place over broad landscapes, crossing jurisdictional boundaries. To be successful, governance of nature-based solutions requires joint decision-making across different local, regional, or even national governments and among multiple sectors such as agriculture, forestry, and environment, finance, development, and transport.[62]

Routine forestry practices that include planning isolated, small-scale projects within jurisdictional boundaries will not be sufficient in the long run. A narrow focus on cherry-picked timber species that fetch high enough market rates to finance the project will not accomplish the goal of whole-forest health and resilience. We need to think differently and find new ways of planning and working at landscape scale. That expanded perspective is what we hope this Wood Utilization Study ultimately models.

Governments should consider additional ways to stimulate forest management. Other studies have considered costs that could be avoided with better forest management such as decreased property damage, improved water quality, and lower insurance payments. One way to increase pace and scale is to subsidize forest management costs to communicate to the private sector a more accurate signal of the value of removing more wood. Another idea is to provide incentives to use locally grown and produced wood products. One way to do this is to label wood products with emission savings per unit of carbon. This might increase demand for utility poles and solid wood doors. More highly processed wood products such as engineered wood floors and OSB would not compare as well.

Including information about the emissions associated with transporting wood products would also make locally produced products more attractive.

[62] Seddon, op. cit.

Appendices

Appendix A: LEMMA data[63]

LEMMA reported all forest statistics in metric units, including all live trees greater than 2.5 cm (~ 1 inch) diameter at breast height (dbh). For each tree species, basal area was reported as mean square meters per hectare, or for sums in a unit in meters squared.

Forest canopy was reported in cover, for tree volume, out of 100. Tree density was measured in trees per hectare and number of trees per unit. Tree volume LEMMA'S categories of tree sizes were broader than what foresters typically use and were based on QMD dominance and canopy cover. A sapling was defined as any live tree between 1 and 10 inches in diameter; a small tree was between 10 and 15 inches; a medium tree was between 15 and 20 inches; a large tree was between 20 and 30 inches; and a giant tree was any tree over 30 inches in diameter. (See table A-1 below.)

QMD Size Class	Centimeters	Equivalent Inches
None	0	0
Shrub	0<QMD<2.5	0<QMD<~1"
Sapling	2.5≤QMD<25.0	~1"≤QMD<~10"
Small Tree	25.0≤QMD<37.5	~10"≤QMD<~15"
Medium Tree	37.5≤QMD<50.0	~15"≤QMD<~20"
Large Tree	50.0≤QMD<75.0	~20"≤QMD<~30"
Giant Tree	75.0≤QMD	~30"≤QMD

Table A-1. QMD Size Class. Anything less that 1-Inch was not included.

63 LEMMA contains estimates of species compositions above 1-inch DBH only. The dataset does not include other lifeforms such as shrubs, herbaceous communities, or dead biomass. (Marin Forest Condition Assessment, 2022) More information available from the Oregon State Lemma at: https://lemma.forestry.oregonstate.edu/data

Another variable in the dataset included Hydrologic Unit Codes at the sub-watershed level Hydrologic Unit Codes 12 (HUC 12). To make the data manageable, data at the larger 10-digit watershed scale is analyzed. The database also included variables needed to apply silvicultural prescriptions from the Sagehen Forest Project. In addition to variables already mentioned, topographic position and aspect were included. Topographic positions were drainage bottoms, ridges, and mid-slopes. Drainage bottoms and ridges were defined by an area's deviation in average elevation from its neighboring area's elevation, using a 30-meter resolution DEM; mid-slopes were the areas in between drainage bottoms and ridges. Mid-slope aspect was defined as either southwest (136-315 degrees) or northeast (316 to 135 degrees).

Variables that influenced where mechanized harvesting was possible were included: wildland-urban interface (WUI), wilderness designation (including inventoried roadless), degree slope, and distance from road. We assumed mechanized harvesting would not occur on high-density and medium-density WUI areas (high-density is defined as urban areas, and medium-density is more than one house for five acres). Road data came from the US Census Bureau's TIGER Line Data 2007-2018 and included unpaved dirt roads. No assumptions were made about how California's SB 901 which allowed building temporary roads for fuel treatments would affect the road network.

Geographic units were defined as adjoining cells that contained all the same unique combinations of characteristics, including those affecting silvicultural prescriptions and mechanized harvesting.

Appendix A1: Geoprocessing

Detailed Description of the Study Area Boundary

From the southern corner, the study area boundary travels northwest along the Sierra Crest. In Sierra County, the boundary then jogs east along the Lahontan Regional Water Board Boundary toward Lassen County. In southern Lassen County, the boundary then follows the Nevada BLM Field Office Boundaries north and then east into Nevada. The study area boundary then picks up the Stillwater Field Office boundaries on the eastern end of the study area and travels east, then south before reaching the California State line at Mono County. The boundary then follows the southern extent of the Mono County line before intersecting the Sierra Crest again at the southern corner of the study area. The entire study area encompasses approximately 18,342.94 square miles, or ~160 miles along a northwest axis running parallel to the Sierra Crest, and ~160 miles along a northeast axis running perpendicular from the crest.

Forest Unit Areas Geoprocessing

The purpose of generating forest unit areas is to create distinct spatial areas that share the same unique land cover, vegetation, ownership, terrain, and other legal and regulatory classifications. For each unit, statistics on forest structure and climate are derived from the appropriate regional model. These units are created by a process of geographically intersecting multiple spatial variables, while also integrating very small “sliver areas” that may be created in this process to ensure that each final unit area is greater than 400 square feet. (See Figure A-1)

The following spatial variables were used to generate each forest unit:

1. Political Boundaries and Land Ownership
2. Wilderness Urban Interface (WUI) Classification
3. Terrain Data
    i. Encompassing both slope and aspect
4. Existing Vegetation Classifications
    i. Calveg (encompassing California and parts of western Nevada) or
    ii. USGS GAP from the Landfire National Terrestrial Ecosystems data (Nevada only)

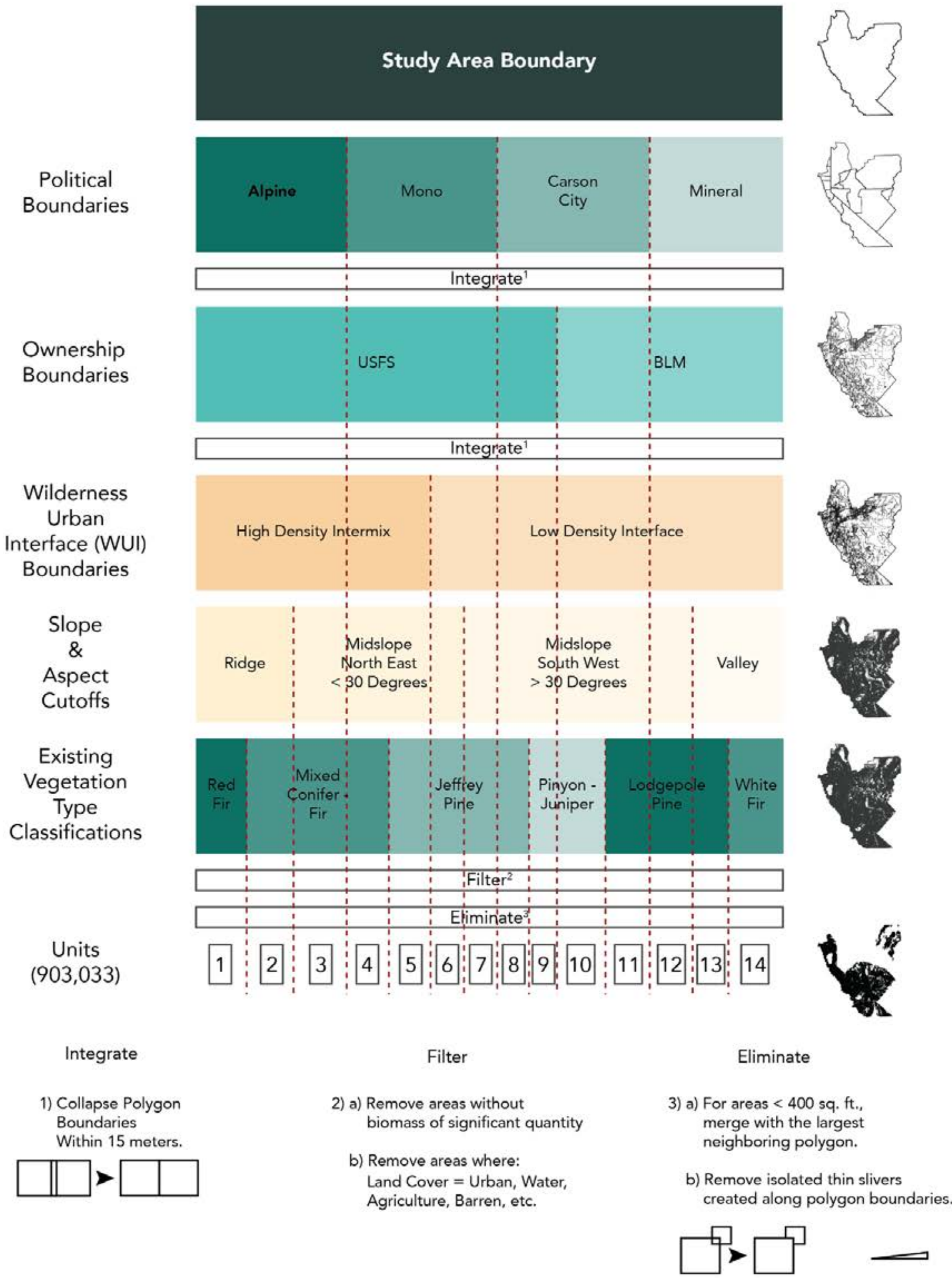


Figure A-1. Boundary Analysis Paradigm

Once the forest units were generated, a filter was run in order to select only regions of the study area with significant vegetative biomass. Using a seamless biomass map developed by the CSP team, regions without significant biomass were filtered from the study, thus removing many shrubland and grassland areas, as well as areas with no terrestrial vegetative cover such as open water, alluvial and alkaline flats, and rocky alpine areas. Further, agricultural areas, as well as high density developed land was also filtered based on the land use classifications from Calveg and GAP.

Determining Forest Unit Characteristics

For each unit, statistics have been derived for a series of relevant forest characteristic and climatic variables. These include:

1. Climatic
    a. Temperature
    b. Precipitation
    c. Evapotranspiration
    d. Aridity Index
2. Forest Structure
    a. Basal
    b. QMD
    c. Canopy Cover
    d. Density
    e. Volume
    f. Stand Height
    g. Size Classification

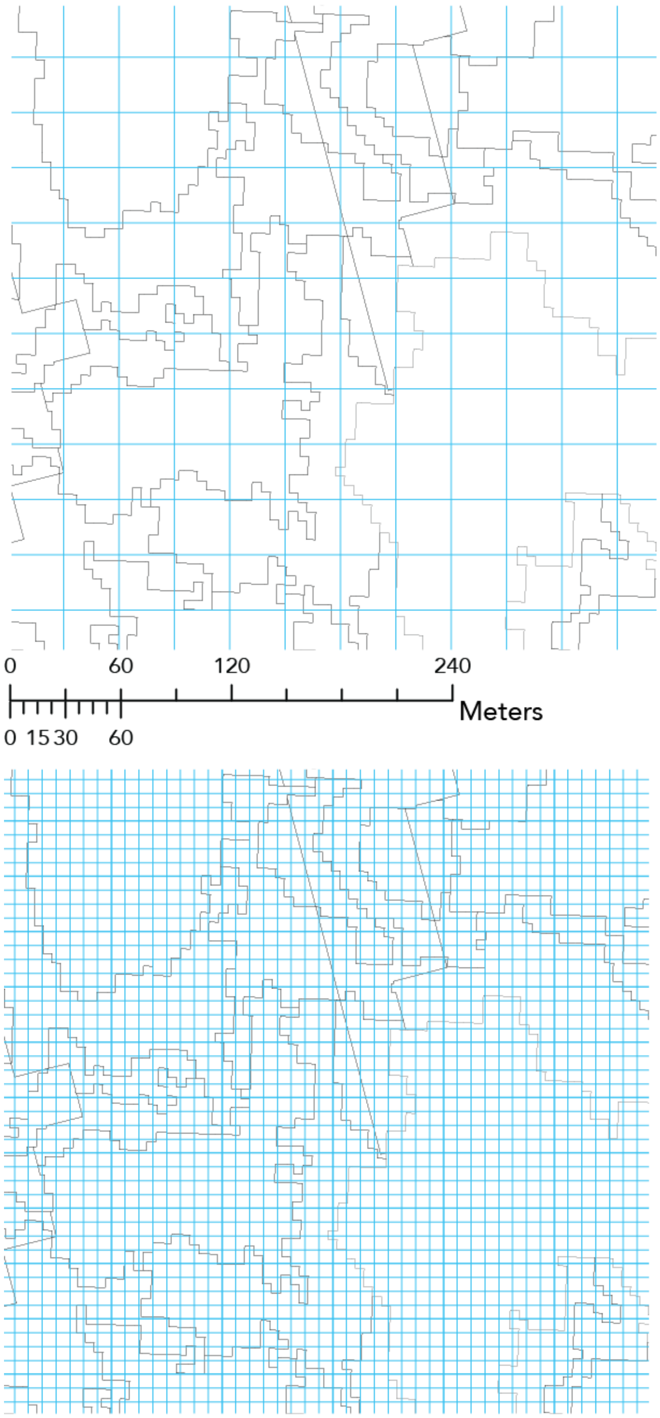
Forest structure statistics were generated for each of the following major eastern Sierra species' categories:

a. quaking aspen
b. bristlecone pine
c. foxtail pine
d. incense cedar
e. jeffry pine
f. limber pine
g. lodgepole pine

h. mountain hemlock
i. ponderosa pine
j. red fir
k. single-leaf pinyon pine
l. sugar pine
m. washoe pine
n. white fir
o. western juniper
p. all hardwoods
q. all conifers

Statistics were generated using a spatial process known as 'zonal statistics.' In this process, each of the climatic and forest structure variables were resampled to a higher resolution (7.5 meters) and each forest unit was assigned a series of summary statistics (min, max, mean, etc.) representing each variable. (See Figure A-2).

Original Data Resolution - 30 meters



Resampled Data Resolution - 7.5 meters

Datasets

Forestry Statistics:
- Basal Area
- Quadratic Mean Diameter
- Canopy Cover
- Biomass
- Volume
- Density
- etc..

Landscape:
- Slope
- Elevation

Climatic:
- Precipitation
- Tempurature
- Potential Evapotranspiration

Statistics Generated
- Mean
- Max
- Min

Registration point is based on the center of the cell

Figure A-2. Forestry Statistics

Appendix B: Case Study: Full Circle Compost, Carson City, Nevada

Craig Witt, a fourth generation Nevada dairyman whose family had farmed in Northern Nevada since 1870, founded Full Circle Soils & Compost in 1990 when he was unable to find high quality, all-natural ways to manage soil fertility on his farm. The increase in corn prices in the 1980s inspired him to grow his own feed, but the farm's mixture of sandy and dense clay soil hindered his plan. This inspired Craig to take a long journey of studying agriculture and soil microbiology, learning from top scientists about soil sustainability.

He traveled across North America, observing and learning about soil and composting processes. When he returned home, he addressed the soil quality on his farm using manure from his herd, green waste, tree trimmings, food waste and wood construction debris.

Craig sold the farm in 2003 because large industrial farms were forcing small family farms out of the dairy business. Combining what he learned from world-renowned soil scientists and the Luebke Composting Method, he also worked with Midwest Bio Systems, which provides technical advice, soil analyses, and equipment that helps produce better quality compost, at lower cost, and in less time. Then Craig's son Cody joined the business and together they expanded the operation on land adjacent to the Northern Nevada Correctional Center.

In 2018, the Witts sold Full Circle Compost to Terra Firma Organics, a recycling and composting company founded in Jackson, Wyoming by long-time family friend, Dane Buk. Dane began in landscape design, so he understood how hard it was to grow plants in Western soils. From there, Dane found his way into soil science, developing various blends of compost and mulch for his clients. At Terra Firma, Dane conducted successful composting pilot projects on a capped landfill but was unable to expand because of the high cost of land in Jackson. Dane is now the "Head Inspiration and Worker Bee" at Full Circle.

Now working under the title of "Soil Mixologist", Craig continues to fine-tune compost recipes to create custom "super soils" and comprehensive soil amendments to meet growers' needs. His son Cody, whose title is "Strategic Everything", has taken over most of the day-to-day aspects of running the business. A fifth-generation farmer, Cody adds MBA credentials to the business and manages projects large and small. Cody has set up a "Full Circle" sustainable community of suppliers and producers by connecting organic materials recycling, soil fertility programs, sustainable food production and education.

The key to Full Circle's success is producing high quality compost. Full Circle Compost is the only producer in northern Nevada of compost, soil and mulch approved by the US Composting Council's Seal-of-Testing-Assurance program. This program requires Full Circle to give customers product analyses, which at a minimum test for pH, soluble salts, plant nutrients, moisture content, organic matter content, particle size, pathogens, and trace metals. Their blends integrate different proportions of fine and coarse composted materials, and at least 50% forest debris from the Lake Tahoe Basin. Through partnering on projects such as roadways, parks, conservation efforts, and wildland rehabilitations, Full Circle has developed blends of fine compost tailor-made to generate good results. Regulatory agencies approve these blends, including the Tahoe Regional Planning Agency, CalTrans, and the Nevada Department of Transportation. Full Circle also offers organic growers compost that meets strict organic regulations.

Full Circle was among the first compost producers to offer packages customized to meet specific soil requirements and application challenges of a customer's project. Because Craig has compiled detailed soil information across much of Nevada and parts of California, customers can commission Full Circle to develop specific blends of nutrients and minerals for their projects. Examples of site-specific projects include projects to control erosion or to revegetate a wide range of large-scale private and municipal projects.

Full Circle is proud that it produces quality products that provide many benefits to the region. In 2020, its work kept about 40,000 tons of organic materials out of the landfill; enough to fill a football field with yard waste four stories high. The greenhouse gases avoided by composting instead of sending those materials to a landfill were equivalent to removing more than 29,000 cars from the road. This was made possible by the sustainable community of suppliers and producers Full Circle has built, from programs to collect pine needles in Incline Village and South Lake Tahoe to increase fire safety; to commercial food waste programs in South Lake Tahoe and Truckee, California; and programs to compost organic materials in Carson City, at the University of Nevada, and many landscaping, construction and excavation companies in the area. They also received manure from the neighboring 1,500 wild Mustangs in Nevada's Saddle Horse and Burro Training Program. From these locally derived materials, Full Circle delivered 18,000,000 pounds of compost and mulches back into the community, improving plants and soils while conducting business in ways that are good for the planet.

Full Circle currently employs eight employees to run a 40-acre site. It gets additional labor from the neighboring Correctional Facility as a part of a rehabilitation program that helps offenders build skills that will smooth their re-entry into the workforce and society.

Daily operations require about $2 million in capital equipment, including Midwest Biosystems Aeromaster turners, custom wagons for applying water and compost tea, 5 large front-end loaders, a Morbark 950 Grinder, Rotochopper B66L grinders, a Morbark 837 Screening Plant, and a CEC 5 x 12 Double Deck Screen. They also have a 2,000 square feet of greenhouse space where they propagate plants, test products for quality control, and run a worm composting operation.

Regulations require a producer to make compost that does not contaminate crops, soil, or water with nutrients, heavy metals, or prohibited substances. Pathogens must be reduced below a threshold that could transmit disease. To meet these requirements, Full Circle uses two composting techniques: aerated windrow composting and aerated static pile composting. They compost year-round, using the same processes regardless of season – successfully producing even in sub-zero winter months. Full Circle primarily uses treated water, especially when adding water or compost tea to any finished product. To ensure full sanitation, untreated water may be used only during one of the approved composting processes. Full Circle regulates sodium and potassium levels -- which is a problem in many composts -- by limiting manure content in finished compost to less than 20 percent.

Aerobic windrows can produce compost in twelve weeks. Full Circle processes fifteen windrows at a time, each of which contains about 400 cubic yards. Regulations require compost piles to be turned at least five times and to reach 131 °F for 15 non-consecutive days. Full Circle exceeds regulations by turning each pile 24 times on average and maintaining windrow temperatures around 140 °F for five weeks. The number of times a windrow is turned is determined by moisture, CO_2 levels and temperature range.

Full Circle added aerated static pile composting because it produces large volumes of compost. Static piles are about 4,000 cubic yards each but require a longer processing time of 6-12 months. Regulations require aerated static piles to reach 131 °F for three consecutive days, but Full Circle maintains them at an average of 140 °F for 5 months.

That Full Circle succeeds is a testament to its savvy response to a highly competitive business environment. Incomes in the composting business are relatively low, only 5 to 15% of revenue. The challenge is even greater for Full Circle because the regulatory and business support for green businesses is not well developed in Northern Nevada. And just 25 miles away lies California, which is aggressively encouraging compost production and use.

Full Circle's strategy to compete in this challenging business environment emphasizes high product quality and offers its customers compost customized to a particular site and purpose. As a result, Full Circle's customers are willing to pay more for its compost because it produces good results.

Appendix C: Pyrolysis and Biochar

Biochar Production

Biochar is produced by quickly decomposing organic matter at high temperatures. This process, in which the organic material is heated without oxygen, is called pyrolysis. The lack of oxygen means that although the material does not combust, its component chemical compounds (i.e., cellulose, hemicellulose, and lignin) thermally decompose into three products – liquid bio-oil, syngas and solid biochar. The proportion of each will vary depending on the composition of the original biomass and process factors. Faster heating and higher temperatures produce a higher yield of bio-oil, while slower rates produce more solid product. The energy required to heat the system itself can be provided by burning the resulting syngas and bio-oil, leaving biochar as the only external product.

A pyrolysis unit can be a community asset, since it can be a source of clean alternative energy for heating and cooling needs and power and can also feed power back into the local grid. Mobile units have been developed which can be moved to areas where the biomass supplies may be only periodically plentiful.

Bio-oil as Byproduct

Bio-oil has a higher density than biomass feedstocks, so is more cost effective to transport. It is a dark, viscous liquid comprised of ketones, carboxylic acids, aldehydes, furans, sugars and water, in varying proportions depending on the originating feedstock and the process used. It is usually acidic and can be unstable and corrosive, requiring additions of catalysts or other changes in the processing conditions to make transport and storage less problematic.A dense complex mixture of oxygenated organic compounds, with fuel value of about 50-70% of that of petroleum-based fuels (because of its higher oxygenation).

Recent USDA research shows that in this model the higher operational costs are offset by the savings in transporting bio-oil, rather than the original waste biomass. The reduced cost of transport means that a distributed processing model is possible, in which multiple farm-scale pyrolyzers convert biomass to bio-oil, which is then refined in a central location. Alternatively, the bio-oil can be used as fuel directly in the pyrolyzer itself, reducing fuel and transport costs for the production of biochar. The Airburner PGFirebox (see below) creates its own fuel in this way.

Mobile Burning and Biochar Production

AirBurners make the Firebox, which is marketed as a pollution control device to eliminate wood waste quickly in an environmentally acceptable way. Although not a pyrolzer and therefore not designed specifically to produce biochar, it can be produced as a byproduct of processing. The ash residue collects in the bottom of the FireBox, and as a result some coals will be insulated by the ash and starved of oxygen, effectively creating biochar[#].

The US Forest Service has recently formulated a Cooperative Research and Development Agreement (CRADA) with AirBurners to develop a way to optimize biochar production in a FireBox while still efficiently eliminating large amounts of wood waste from the forest.

AirBurners (based in Palm City, Florida) report that existing customers are using their FireBoxes to produce biochar, creating a second income from their machines. They set out a five-step process for production:

1. Rake ash and coals out of the FireBox at the end of the workday.
2. Rake away the solids, separating unburned wood from the ashes.
3. Solid coals and wood chunks are doused with water.
4. The remaining material is sized using a simple ½" screen.
5. The biochar that passes through the screen is stored.

AirBurners report some of their customers making 10-15 cubic yards per day per machine. They quote a maximum price of $120 per cubic yard. The Firebox comes in a roll-off, cable-hoist, or hook-lift version, as well as the BurnBoss version, which was specifically designed to support the U.S. Forest Service in wildfire prevention. It is a self-contained, fully assembled above-ground Air Curtain Burner, powered by a small onboard diesel engine. The BurnBoss produces about 1-2 cubic yards of biochar per day.

AirBurners also make the PGFireBox, which has already been sold to some municipalities within California. It qualifies for landfill diversion credits, is transported on three flatbed trucks and generates power for itself as well as additional thermal and/or electric power. It does not require any preprocessing of materials, will consume 7 to 13 tons per hour, and produces about 10-15 cubic yards of biochar per day. The cost varies by power capacity (100kW, 500 kW, 1000kW) from $830,000 to $4,200,000 and it has the potential to revolutionize recycling, as a portable system converting forest waste into fuel, power and biochar.

Tigercat makes the Carbonator, which is also an air curtain burner, but a much bigger and more expensive piece of equipment, costing around $700,000 and processing about 15-20 tons an hour of forest material, compared to $55,000 for the BurnBoss which processes about 10-20 cubic yards an hour. All Power Labs is currently developing the Chartainer, out as beta test now. It is a combined Heat and Biochar pyrolyzer system, contained in a 20’ shipping container, which works totally off grid without a separate power source. The biochar produced is certified by the IBI, made from all woody biomass from 1/8” to 21/2” in diameter. These units are expected to cost around $200,000 and were deployed in a pilot project in Yosemite National Park in 2020. Biochar Solutions Inc. make a containerized biochar pyrolyzer system, the B-1000 which uses clean dry wood chip as input and produces 1-2 yards of char per hour, as well as 3-6 MMBTU thermal, and costs $400,000.

Soil Amendment and Carbon Sequestration

Biochar has been used as a soil amendment for thousands of years, likely originating in the Amazon where charcoal (biochar produced at lower temperatures and compressed) was added to the red clay soil, transforming it into black earth capable of retaining nutrients during the frequent rains.[#] Soil amendments should have no negative effect on the soil structure, soil fertility or the ecosystem as a whole[#], and biochar is currently being widely tested to assess its effect on soil quality and crop yield as well as its ability to remove heavy-metal pollutants[#] from the soil. Some studies show biochar increasing agricultural yields by up to 25%, while others consider that this improvement only applies in tropical climes. Soil health and amelioration involves many more factors than simple yield, and there is a wealth of new research currently underway.

Carbon is captured in the form of CO_2 by plants through photosynthesis, then it proceeds through the complex web of life to be released again by animal respiration back into the atmosphere and so on: this is the carbon cycle. This process is much quicker in warmer climates, hence the exponential acceleration of concentration of carbon dioxide in the atmosphere as the cooler regions warm. Attempts to slow this process encourage sequestration of carbon at various points in the cycle. Using biochar as a soil amendment takes carbon out of the cycle, returns it to the soil and stores it there for long periods, hundreds if not thousands of years.

If using the farm scale model, the biochar produced can be used locally on the farm[2] as a soil amender that sequesters carbon. Biochar is highly absorbent and increases the soil's ability to retain water and nutrients, preventing erosion. It increases the fertility of the soil, increases its water holding capacity, can rid soil of heavy metals and other pollutants, and captures in solid form the carbon previously absorbed by the organic material via photosynthesis, thus sequestering carbon when buried. It has been suggested that adding biochar to 10% of global cropland could sequester the equivalent of 29 billion tons of CO_2 roughly equal to global annual greenhouse gas emissions.[64]

Biochar as Animal Feed

A 2021 review summarizing the major studies to date of the use of biochar as a feed additive for ruminants, pigs, poultry and fish found improved growth, blood profiles, egg yield, ability to resist disease, and reduction of methane where relevant. Biochar is also highly absorbent, removing pollutants from the animals and their surrounding environments. The review concludes that exploration of the use of biochar in medical and human health may well be worthwhile. It seems highly probably that biochar could be a good substitute for prophylactic antibiotic use[#], as well as potentially purposes currently fulfilled by diatomaceous earth (DE[#]).[65] Although DE is priced about the same as biochar, it is a mined product with negative environmental impacts, while biochar is local, organic, a carbon sink and makes use of waste forest product.

Biochar is currently used as animal feed in many places globally, but not yet in the US. There are efforts to change that, but there are issues around standardization of product and interplay with other regulations. As an example, in organic husbandry, the composite is tested after the killing of the animal. Since biochar is so effective at absorbing toxins, it

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[64] https://e360.yale.edu/features/as_uses_of_biochar_expand_climate_benefits_still_uncertain

[65] Murtaza, G., Ditta, A., Ullah, N. et al. Biochar for the Management of Nutrient Impoverished and Metal Contaminated Soils: Preparation, Applications, and Prospects. J Soil Sci Plant Nutr 21, 2191–2213 (2021)

would be possible for an animal to test clean for organic certification even if it has not been managed organically throughout most of its life, but biochar included in its feed towards the end of life.

A 2014 survey in Switzerland found that biochar administration to herds of an average size of 150 cows provided improved vitality, improved udder health, minimization of hoof problems, decline in mortality, increase in milk protein, less odorous slurry, increased ammonium nitrogen and reduced nitrate and nitrite levels. The same study found that combining the biochar with sauerkraut brine was beneficial, since the brine adds acetylcholine, lactobacilli, enterococci, B-vitamins and vitamin C.

Human Food Grade Biochar

Until recently, only activated charcoal was used for human consumption. Biochar uses a similar production process, with an additional stage of activation in order to increase the surface area, and thus absorption ability, of the resulting charcoal. This is usually either by introducing steam, or by adding acids or hydroxides to the source wood. Since biochar is cheaper to produce (by a factor of 5-10), its use for the same purposes is being tested. Even if 2-3 times the volume would be required in order to be as effective as activated charcoal, that could still be cost effective, at the same time as making use of the forest waste product. There is some evidence to show that it can be used as a substitute for salt for select purposes, including fermentation.

Biochar Building Materials

The first building using biochar-based building material[#] was constructed in 2013 at the Ithaka Institute in Switzerland. The relevant key properties of biochar for building are its low thermal conductivity and ability to absorb water. It can be added to clay, cement and/or plaster to improve the insulation, regulate humidity, and absorb toxins and smells as well as electromagnetic radiation, preventing ‘electrosmog’. The buildings constructed using biochar-based insulation materials will be long term carbon sinks. Research continues into biochar building materials including panels, bricks, plasters and adhesives, as well as into the best avenue for deployment, likely pairing building industry partners with local biochar producers.

Activated Charcoal

Activation occurs by using acids or hydroxides or 900°C water steam. This increases the specific surface area from approximately 300 m^2/g to over 1000 m^2/g. Activated carbon usually costs between five and ten times the price of simple biochar. For most applications, it is possible to use two to three times the amount of biochar to achieve the same result as activated carbon. This applies to animal husbandry as well as to sewage treatment. Activated carbon is often imported from places without sufficient regulation and control, so use of biochar made from local raw materials, with controlled production, may well be a cost-effective way to replace imported activated carbon.

Palmdale Water District in Southern California uses activated carbon as an alternative to reverse osmosis filtration. They contract with Calgon Carbon, a company based in Pittsburgh, PA. After use, the activated carbon is recycled through thermal reactivation at their plant in Gila Bend, Arizona. Reverse osmosis wastes large quantities of water (using four times as much water as is produced) and removes all minerals. In some systems, remineralization is an additional step after RO filtering. In contrast, activated carbon keeps minerals and other nutrients in the water, and does not waste water.

Market Potential of Biochar

In discussing potential use of waste products from forest management, biochar can be considered in combination with composting, as well as seen as a separate product option. The ideal organic waste for biochar production is different to that for compost, since ideally biochar is produced from drier materials with high lignin content, such as field residues or woody biomass.

The production of biochar is a much more expensive process than that for compost and it may well be the case that use of biochar is not a cost-effective way to remediate soil, unless it is in particularly poor condition. From 2013, the University of Nevada carried out a test project, in the production and use of biochar, and partnered with the Eureka County Department of Natural Resources to assess the potential production and use of biochar.

Their findings suggest that there is potential to develop and use biochar in agricultural systems and forest and rangeland management and restoration, although serious concerns remain regarding the economic return from applications and the long-term impacts of soils amended with biochar. However, there have not yet been larger scale, longer term studies of the value of biochar, which are needed to justify the relatively high production costs of the material. This information may come from China, where larger scale studies are being carried out using biochar to reduce the levels of cadmium in rice paddy soils. In the meantime, until real data is available, farmers will be unlikely to buy biochar at a cost in the region of twenty times that of compost or other fertilization, unless there is other market enhancement through carbon credits.

The 2020 Nevada Forest, Range & Watershed Action Plan produced by the Nevada Division of Forestry and the Nevada Department of Conservation & Natural Resources acknowledged that "although potential commercial forest product uses have been identified by biomass utilization working groups, such as power cogeneration feedstocks, biochar, and mass timber building materials, significant markets have not emerged in the western Nevada region".

A survey and analysis of the US biochar industry, received responses at a 45% rate and found two trends – a "growth in sales supported by a general optimism in the strength of the marketplace" and the desire for more information, support and in particular biochar-related research. Biochar producers noted that research publications assist their sales. The same survey reported a request for certification of biochar for animal feed, and for policy to recognize biochar as carbon negative, and to give financial credit accordingly.

As can be seen in the short survey of equipment above, some energy generators produce biochar as a secondary product, and some mobile pyrolyzers are marketed naming this biochar as a sellable product. Finding a valuable use for the waste from power and heat facilities is an important advantage, and yet this produces a lower cost product which may affect the ability of smaller scale quality producers to compete in a biochar market. This is a further reason for small-scale producers to aim for specific differentiation and customization of their product, and for workable standards in the industry.

Biochar Variability and Stability

Specific biochar properties will depend on the origination feedstock and the process parameters (temperature, speed, time). It is therefore not possible to make particular claims about the effects of biochar on soil and the time frame for which they will continue. In spite of the variability, it remains the case that there is a value – in carbon sequestration as well as soil amendment, even if the exact particular improvements cannot be specified.

In order to assess how long the effects may remain, various stability test methods have been derived and an (international) Expert Panel convened by the International Biochar Initiative has developed the Biochar Carbon Stability Test Method, by assessing (in terms of cost, repeatability and availability) 27 existing methods. The final agreed upon Stability Test Method "uses the ratio of hydrogen to organic carbon (H/C_{org}) – as measured using standard analytical techniques – to estimate the fraction of biochar carbon that will persist in soil for 100 years."[#] The Panel considers their current methodology to be conservative,

likely underestimating the amount of stable charcoal in biochar by limiting to 100 years with a view to improving the accuracy using the rapidly evolving relevant science. As can be seen from the emerging standardization, there are multiple parameters to compare, which means that any standardization is very technical, and it is difficult to produce a scheme that is useful for both producers and consumers. From the consumer perspective, again because of the multiple parameters, it may be difficult to translate the data into meaningful information, especially if compared to simpler parameters, for example NPK values in fertilizers.

Biochar and Climate Change Mitigation

In the 2020 Nevada Forest, Range and Watershed Action Plan, "sequestering atmospheric carbon in environmental sinks through strategic land management" is considered an opportunity to mitigate climate change, and biochar is included as a "productive purpose" for the harvesting of carbon.

The Action Plan includes biochar in the strategy section of "Opportunities for Agency and Cooperators to Mitigate Climate Change", where Strategy 8-1-14 calls for the harvest and utilization of forest and rangeland biomass products for items or practices that short carbon, with biochar named as an example. Performance would be measured by total tons of carbon removed and stored. The Action Plan proposes the creation of a carbon market as well as incentives for participation in programs that support carbon sequestration such as forest management, while recommending inventories of the emissions from ecological processes and the capacity of carbon sinks.

Carbon Credits for Biochar

A 2010 issues paper commissioned by the Climate Action Reserve[#] concluded that biochar incorporation projects lead to net greenhouse gas benefits, and that soil incorporation may lead to higher yields, as well as potentially reducing soil erosion. Despite the issues of biochar product variability, the paper concludes that the "GHG accounting and verification is relatively straightforward, and the generation of verifiable carbon credits is feasible." The paper called for the following three research needs:

- Rapid, accurate and robust techniques to be developed to test the fraction of resistant matter in biochar, for certification scheme.
- A set of generalized coefficients to predict the effect of microclimate and soil type on biochar decomposition.
- The establishment of a limit on the amount of biochar that can be incorporated, expressed as tons per acre.

The American Carbon Registry (ACR), a non-profit enterprise of Winrock International, decided not to accept the Methodology for Biochar Projects[#] developed by the Climate Trust, The Prasino Group, the International Biochar Initiative and Carbon Consulting, following a peer review process that concluded there was not sufficient evidence of the stability of solid carbon sequestration in fields treated with biochar using $H:C_{org}$ ratio correlations as cited in the International Biochar Initiative's Standard Test Method for Estimating Biochar Carbon Stability (BC+100). Following the 2018 Special Report of the IPCC, renewed attention has focused on sequestration of carbon, and biochar was

included in the short list of Negative Emission Technologies that the IPCC recommended as potentially significant. Biochar has been included in a voluntary carbon marketplace in Finland[#] since 2019, and since 2020 in CarbonFuture[#], another voluntary marketplace, which calls itself "the most advanced biochar carbon sink platform" and offers certified sinks based on biochar applications in Europe and California.

Pacific Biochar, a company based in Santa Rosa, California and Hawaii, was certified in November 2020 for the sale of carbon credits, having worked for about a decade on the methodology for calculation of carbon sequestration, as well as an accurate method for assessing the stability of a sample of biochar. They work with the CarbonFuture voluntary carbon credit platform. Shortly afterward, another California biochar company, Carbo-Culture registered with Puro, an alternative credit platform.

Pacific Biochar enumerates these requirements for registration with a carbon credit platform:

- Lab reports to confirm that the biochar is safe for use, and with known permanence
- A third-party Life Cycle Analysis including detailed accounting of:
- Feedstock characteristics and sourcing
- Emissions associated with feedstock procurement, transportation and processing
- Emissions association with biochar production
- Energy consumption and energy generation balances of production
- Post-pyrolysis processing emissions, transportation, and packaging
- Ongoing confirmation of sequestration

Both Carbon Future and Puro are blockchain based platforms for carbon credits.

Both the US and International Biochar Standards Initiatives are crucial in the further development of carbon credit schemes, as is the long-term commitment of farmers and consumers to the use of biochar to reduce forest waste, sequester carbon and mitigate climate change.

Appendix D: Loyalton Biomass Plant – Past, Present, & Future Potential

Like many biomass power plants in California, the Loyalton plant was built in conjunction with an existing sawmill. It was sized to utilize the waste stream produced from that mill and to supply its power, with only a small amount of excess power, if any, sold to third parties.

The mill closed in 2009 and while the power plant remained, it has run intermittently since then. Finding sufficient wood supply as well as a power purchase agreement (PPA) of a sufficient price to allow for the profitable operation of the plant has been an ongoing challenge for the series of owners who have owned and managed the plant over the last decade.

In late 2019, the plant was purchased by Sierra Valley Enterprises, LLC, an entity led by CTL Forest Management, Inc., a logging and trucking firm based in Placerville, CA. CTL is the largest logging operator in the Tahoe Basin, with 80% of its business in that region. Having an established logging operator as a partner in the plant should strengthen the plant's ability to successfully source material for operations. SVE has been working to restart the plant but still requires significant additional capital to fund deferred maintenance and manage working capital to successfully run the plant. They are targeting running the plant at 15 megawatts and believe they could find a reasonably attractive Power Purchase Agreement (PPA) for that amount of power to a California utility.

As of September 2022, future plans for Loyalton remain somewhat uncertain. A commodity scale sawmill has now set up operations, with an operating potential of 100,000 board feet of material per day. That capacity is yet to be reached. There is currently no official word on what is happening to their waste streams.

The Wood Utilization Campus Concept

The idea of creating a wood utilization campus has been, for many years, central to the efforts to revitalize the plant and the surrounding town. The ideal wood utilization campus would incorporate into a central site several businesses that utilize timber and biomass

for higher value products, allowing economies of scale and shared resources to bring the cost of that material in at competitive prices. Any successful campus must have some type of biomass energy facility at its core, as it is inevitable that the other uses would generate wood waste streams (chips, sawdust etc.) that need to be disposed of and can create a long-term low-cost feedstock for the facility. As a result, the idea of a campus has been investigated at several sites like Loyalton, where an existing power plant can act as an anchor tenant around which the added value businesses can be located. Combined, such a campus can have a very positive economic impact on rural communities by creating a network of sustainable businesses that offer compelling and well-paid employment while also driving demand for material that would underlie sustainable forest management in the surrounding region.

If a PPA can be attained at such plants, such a project may be viable, though longer-term, biomass electricity production faces a challenging market, one where wind and solar, combined with increasingly competitively priced battery storage, are offering a much lower priced renewable electricity source. Longer term, other more economically attractive uses for the biomass chip and sawdust stream must be identified, such as certain building materials, soil additives, biofuels, or bioplastics production.

As discussed above, the essential infrastructure to support related businesses is already in place and the campus is zoned appropriately. A wood utilization campus could offer attractively priced power to tenants from the captive power plant, has ample potable water and attractive water rights for larger volumes if needed, and sewage-wastewater treatment as well.

Current Status

SVE is seeking to build out complementary businesses as part of the development of a broader wood utilization campus. Over the summer of 2021, a small-diameter wood mill was established on the site and began operations. This operation utilizes timber and, as described above, could complement the operation of a biomass plant by producing low-cost wood chips/waste that would be utilized by the plant. Yet, unfortunately, because the powerplant is not operational, this waste stream is a challenge to manage.

The wood utilization campus model has been much discussed around the state over the last few years, but, to date, this approach has been difficult to implement in California. Finding the right combination of businesses with management teams to manage them and capital to fund them is challenging, as there are many moving pieces and often the business propositions are early stage and unproven. Also, as discussed above a traditional biomass electricity plant, unless it can find an attractive PPA, will be challenged to run profitably as other renewable power options drive power prices down. Finally, another other large asset that a wood utilization campus like Loyalton has, once its biomass energy plant is operational, is a large waste heat stream. To date, finding complementary businesses that can utilize what is a large amount of heat has been difficult.

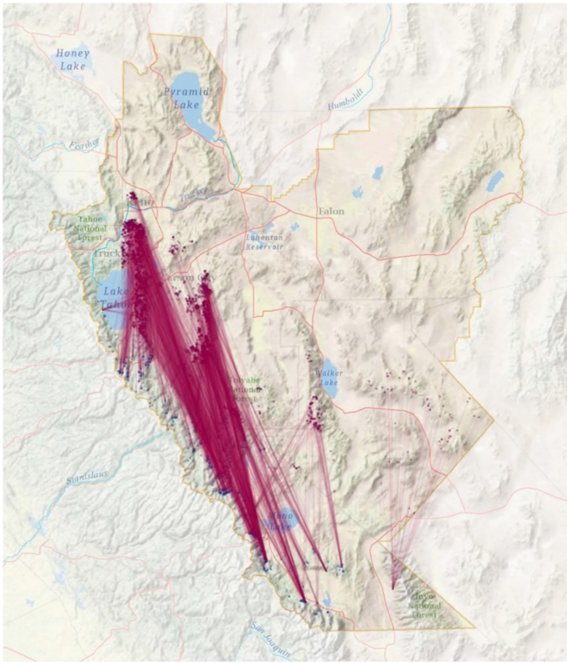
Appendix E: Forest Species Missing Value Imputation Process

Forest structure data from LEMMA was limited to California, and characteristics for the Nevada forest needed to be determined using a process known as missing value imputation. The first step in this process involved finding a series of representative forest and climatic data that exists across state lines in which to base the imputation mapping process. The following representative data were used to match Nevada forest units with California units:

1. Geographic Area
    a. Proximity in latitude or
    b. A defined regional area known to be similar in both states
2. Elevation
3. Water Availability
    a. Potential Evapotranspiration or
    b. Aridity Index
4. Forest Structure Characteristics:
    a. Quadratic Mean Diameter or
    b. Canopy Cover

Imputation was accomplished using a K-nearest neighbor (kNN) process and utilized an R-based script from the 'imputation' library (Hastie T, Tibshirani R, Narasimhan B, Chu G (2021). Imputation for microarray data. R package version 1.66.0). In order to map like forest units between California and Nevada, a crosswalk was established between Calveg and GAP data in Nevada. Imputation was accomplished by first matching units from the crosswalk, then determining specific climatic and forest structure correlations for each particular vegetative grouping. The Nevada unit that best matched a California unit was then assigned all relevant LEMMA data categories; scaling outputs based on unit size. The maps that follow show where California and Nevada units were matched. The blue dots on the maps represent the California source (or anchor) units, and the red lines and dots represent the Nevada target unit that was imputed.

Quaking Aspen



CA Source Units: **Total:** 16,507
Linked to NV: 880 (5% utilized)
Total Acreage: 5,195

NV Target Units: **Linked to CA:** 3,290
Total Acreage: 1,007

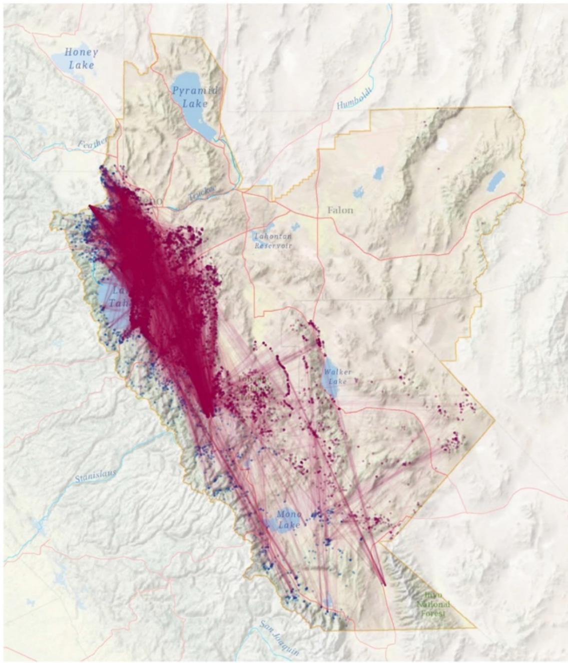
Riparian Hardwoods

CA Source Units: **Total:** 3,630
Linked to NV: 229 (6% utilized)
Total Acreage: 1,843

NV Target Units: **Linked to CA:** 1,981
Total Acreage: 947

Figure A-3. Quaking Aspen and Riparian Hardwood Imputations

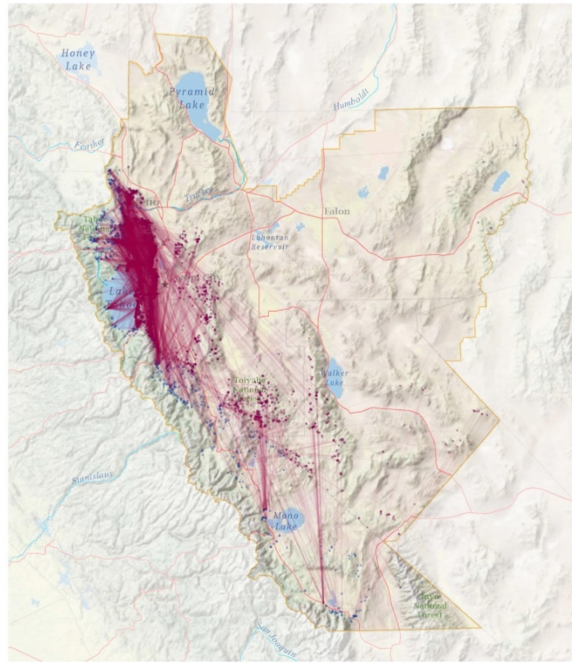
Jeffrey Pine



CA Source Units: **Total:** 56,692
Linked to NV: 2,698 (5% utilized)
Total Acreage: 19,416

NV Target Units: **Linked to CA:** 13,264
Total Acreage: 5,660

Eastside Pine



CA Source Units: **Total:** 19,645
Linked to NV: 1,233 (6% utilized)
Total Acreage: 13,523

NV Target Units: **Linked to CA:** 4,655
Total Acreage: 1,362

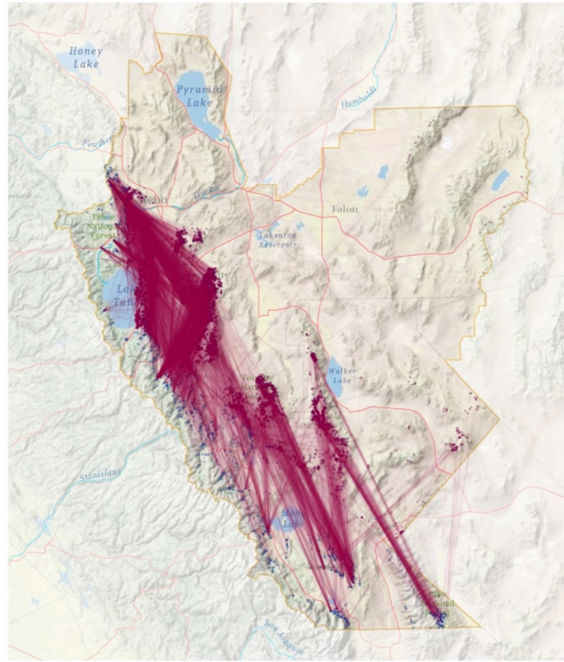
Figure A-4. Jeffrey Pine and Eastside Pine Imputations

Limber Pine

CA Source Units: **Total:** 3,215
Linked to NV: 170 (5% utilized)
Total Acreage: 712

NV Target Units: **Linked to CA:** 518
Total Acreage: 209

Hardwoods (Primarily Mountain Mahogany)



CA Source Units: **Total:** 23,639
Linked to NV: 1,660 (7% utilized)
Total Acreage: 7,012

NV Target Units: **Linked to CA:** 14,638
Total Acreage: 3,806

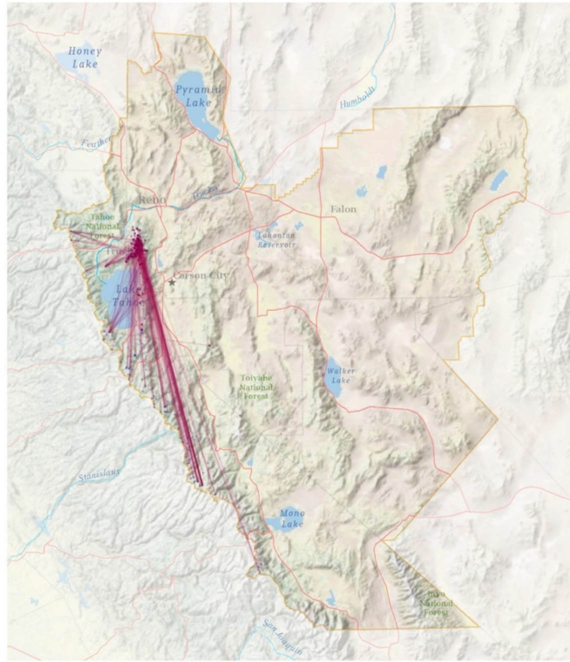
Figure A-5. Limber Pine and Hardwood Imputations

Lodgepole Pine

CA Source Units: **Total:** 10,256
Linked to NV: 127 (1% utilized)
Total Acreage: 1,973

NV Target Units: **Linked to CA:** 327
Total Acreage: 78

Mountain Hemlock

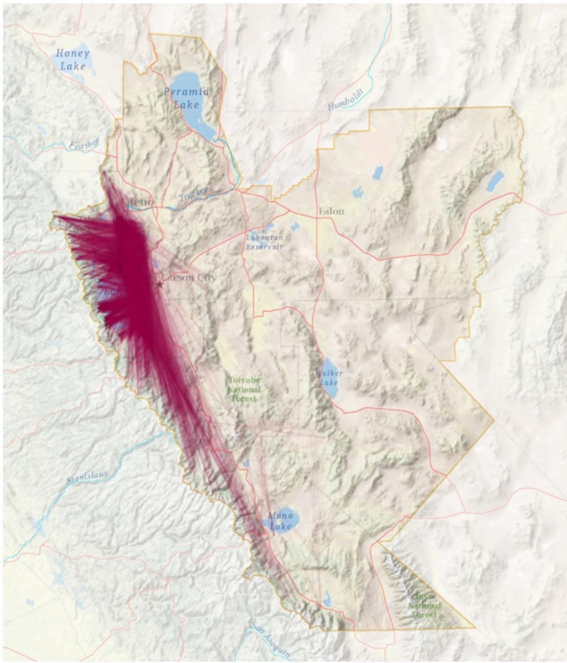


CA Source Units: **Total:** 2,891
Linked to NV: 75 (3% utilized)
Total Acreage: 453

NV Target Units: **Linked to CA:** 338
Total Acreage: 68

Figure A-6. Lodgepole Pine and Mountain Hemlock Imputations

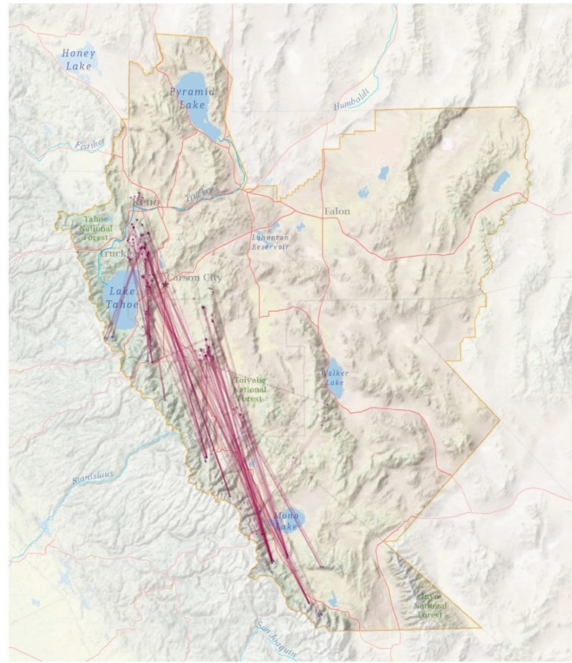
Mixed Conifer - Fir



CA Source Units: **Total:** 92,992
Linked to NV: 7,070 (8% utilized)
Total Acreage: 29,953

NV Target Units: **Linked to CA:** 29,335
Total Acreage: 6,329

Western White Pine

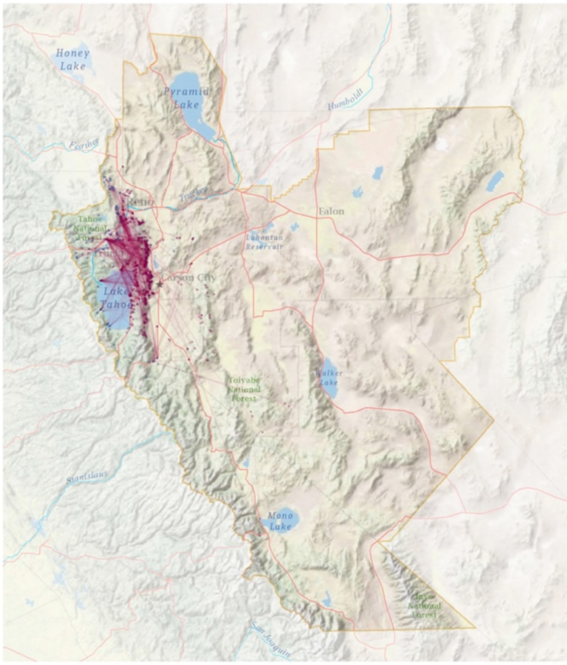


CA Source Units: **Total:** 791
Linked to NV: 47 (6% utilized)
Total Acreage: 78

NV Target Units: **Linked to CA:** 167
Total Acreage: 54

Figure A-7. Mixed Conifer and Western White Pine Imputations

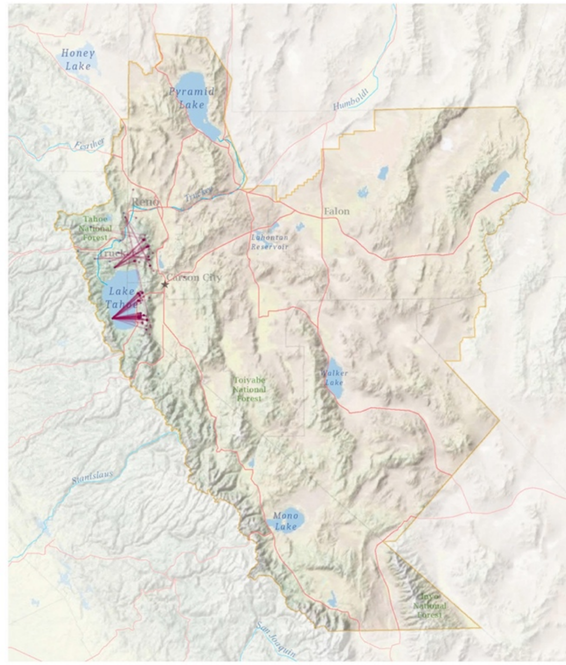
Ponderosa Pine



CA Source Units: **Total:** 1,069
Linked to NV: 155 (14% utilized)
Total Acreage: 148

NV Target Units: **Linked to CA:** 707
Total Acreage: 140

Ponderosa Pine - White Fir

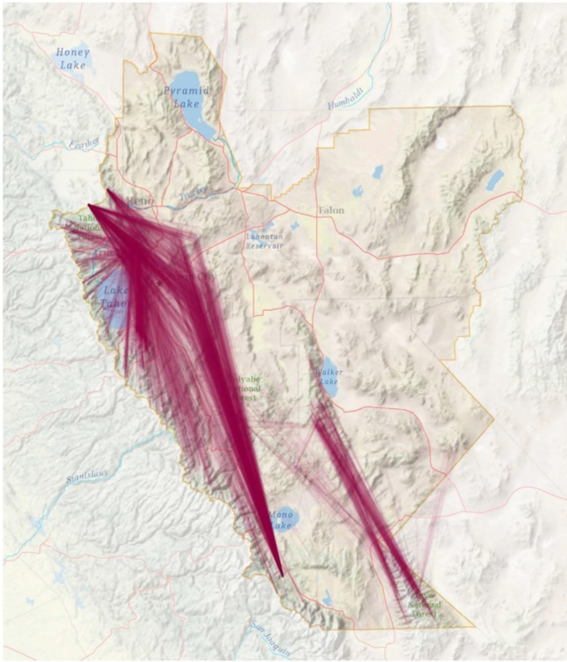


CA Source Units: **Total:** 107
Linked to NV: 12 (11% utilized)
Total Acreage: 31

NV Target Units: **Linked to CA:** 124
Total Acreage: 23

Figure A-8. Ponderosa Pine and Ponderosa Pine - White Fir Imputations

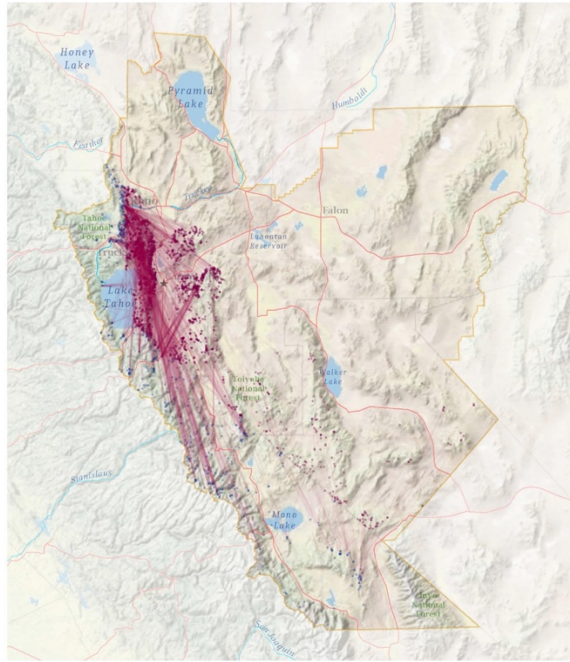
Subalpine Conifer



CA Source Units: **Total:** 92,001
Linked to NV: 2,867 (3% utilized)
Total Acreage: 37,063

NV Target Units: **Linked to CA:** 15,565
Total Acreage: 4,652

Other Mixed Conifer Forest

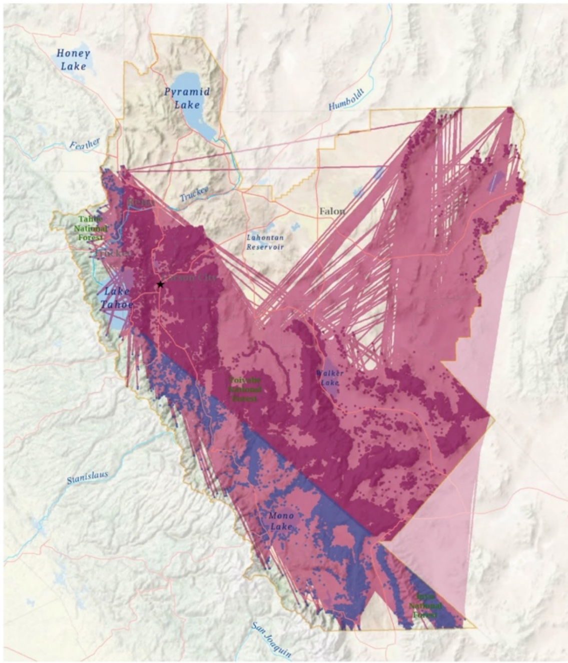


CA Source Units: **Total:** 6,324
Linked to NV: 562 (9% utilized)
Total Acreage: 1,226

NV Target Units: **Linked to CA:** 2,791
Total Acreage: 1,047

Figure A-9. Subalpine Conifer and Other Mixed Conifer Imputations

Pinyon - Juniper



CA Source Units: **Total:** 90,257
Linked to NV: 24,390 (27% utilized)
Total Acreage: 48,471

NV Target Units: **Linked to CA:** 200,616
Total Acreage: 104,118

Figure A-10. Pinyon – Juniper Imputations