Biomass Utilization Solutions for Forest Fuels Reduction Activities for the Eastern Sierra

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California Trout

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This work was performed under contract to California Trout (Sierra regional office in Mammoth Lakes, CA) with funding from National Fish and Wildlife Foundation under the Pacific Southwest Fuels Management Partnership program. This partnership identifies and funds fuel management projects that reduce the risk of severe wildfire, protects ecological values of U.S. Forest Service restoration investments, and reduces the chance of damage to public and private improvements near U.S. Forest Service Lands. This work was performed under NFWF Agreement #70624 (4/15/2021 – 6/30/2022) entitled "Sierra Fuels Reduction Impact: Solving for Biomass Removal, Water and GHG Benefits". Technical memos describing biomass processing technologies, biomass availability and pricing, as well as GHG and water benefits from fuels reduction in the eastern Sierra were generated as part of this grant.

INTRODUCTION

The Mammoth Lakes region on the eastern side of the Sierra Nevada Mountain range in California has considerable forestlands. The forests in the region are currently experiencing significant forest health issues, along with overstocked forestlands encircling the Town of Mammoth Lakes (TOML). The town is home to over 8,000 year-round residents and can swell to over 100,000 visitors during times in both the winter and summer months. Concern has been in place for many years due to the potential catastrophic wildfire hazard which surrounds the TOML, and has the potential to cause serious damage and life-threatening conditions should a catastrophic wildfire occur in the area. The region is now accelerating the pace and extent of wildfire reduction activities to reduce, and hopefully eliminate potential catastrophe.

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Forest health in the region has been comprised by the continuing infestation of Mountain Pine beetle infestation, resulting in tree mortality across the landscape. Figure 1 shows the current look of the Mammoth Region forests in many areas.

Figure 1. Distressed and Dying Trees in the Mammoth Area (grey and orange conifers)

This report complements another report concurrently prepared by TSS Consultants (TSS) – "June Mountain Fuels Reduction: Utilization and Removal Options" (prepared for Cal Trout, June 2022). That study looked principally at the ongoing forest treatment activities at the June Mountain Ski Resort, located on June Mountain approximately eight air miles north of the TOML. It analyzed short-term solutions for the disposal or utilization of the forest slash and log produced in earlier forest treatment activities at the mountain.

The fuels reduction work on the mountain was conducted between 2019-2022 and resulted in whole logs being decked at the top of the mountain, and at mid-mountain, and were removed via transport to base or chipping during 2022. TSS was retained by California Trout (Cal Trout) to perform a feasibility study for short-term removal of biomass generated during fuels reduction at June Mountain. The TSS study includes technical, economic, and environmental analyses of short-term solutions that could have been employed at June Mountain. The results of the study are germane to the analysis below.

FEASIBILITY STUDY OBJECTIVES

This feasibility study is to present and analyze potential solutions based on the previous analysis of utilization options for waste woody biomass at June Mountain, and for ongoing and future forest treatments to reduce the overstocked and unhealthy conditions of the Mammoth region forestlands. Lessons learned and utilization options analyzed in these studies are transferrable to other planned forest treatment sites and woody biomass types. A decision tree is presented here for site-specific biomass processing needs using the above analyses to determine the optimal custom approach to achieve the best solution. In addition, and in coordination with other TSS bioenergy utilization analysis, longer-term solutions are also reviewed and included in this report.

This feasibility assessment and decision tree can be used for the planned Eastern Sierra fuels reduction projects below, and any additional projects promulgated in the future.

- Mammoth Lakes Basin (667 acres Lodgepole Pine) – This fuels reduction project is nearly complete. The forest thinnings were small-piled on over 550 acres, of which 340 acres have been burned as of summer 2022;
- Reds Meadow (2,139 acres) – Thinning activities are underway in the Reds Meadow project area. Disposition of thinnings is pile and burn. Status: The final piles are scheduled for burning in Winter 2022/2023;
- Three Creeks Jeffrey Pine Forest Health and Restoration Project (9,950 acres) Status: 8- 10-year implementation schedule;
- SCE Utility Line Improvements (unknown acreage) and utility "trimming" (~10,000

acres). Status: Ongoing vegetation management program. Most tree removal in Mammoth Lakes region reported mostly complete. Area within 50 miles of Mammoth Lakes may still 1,000 trees removed for the foreseeable future[1];

- Eastern Sierra Climate and Communities Resilience Project (56,000 acres as of June 2022) Status: Planning and NEPA review stage – implementation anticipated 2025.

EASTERN SIERRA FUELS REDUCTION AND UTILIZATION OF BIOMASS RECOVERED

Eastern Sierra Climate & Communities Resilience Project

Forest health management and hazardous fuels reduction activities are currently programmed to happen primarily under the Eastern Sierra Climate and Communities Project (ESCCRP). This multi-year project has the following stated goals:

1. Protect the TOML
2. Allow for safe and effective fire management
3. Promote community fire resilience
4. Restore ecosystem health and resilience
5. Utilize best available science
6. Create a fire-conscious community
7. Cultivate long-term, sustainable partnerships
8. Build local capacity

This project targeting 56,000 acres, roughly centered around the TOML (see Figures 2 and 3 below), is planning to conduct forest fuels treatment activities on approximately 44,000 acres over a 20-plus year period averaging 2,000 acres a year of treatment. This will result in a significant amount of woody biomass that must be disposed of, or utilized in, some manner. Objectives of the ESCCRP related to this study include:

- By 2025, have long-term biomass utilization technology in place and operational. (Goal #7);
- By 2030, create a defensible space buffer around the TOML. (Goal # 1, 2, and 3).

TSS believes that the longer-term biomass utilization will need to be some form of bioenergy technology that can create an economically and financially-viable product. In the case of the Mammoth Area, that would be most likely be electricity for export to the

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[1] "*Biomass Feedstock Supply Availability and Cost Analysis for the Mammoth Lakes Region*," prepared October 2021 by TSS Consultants for Cal Trout.

regional electrical distribution/transmission grid. There is, however, the need for short-term solutions until long-term solutions are potentially in-place. These short- and medium-term options are reviewed below.

Figure 2. The ESCCRP Area

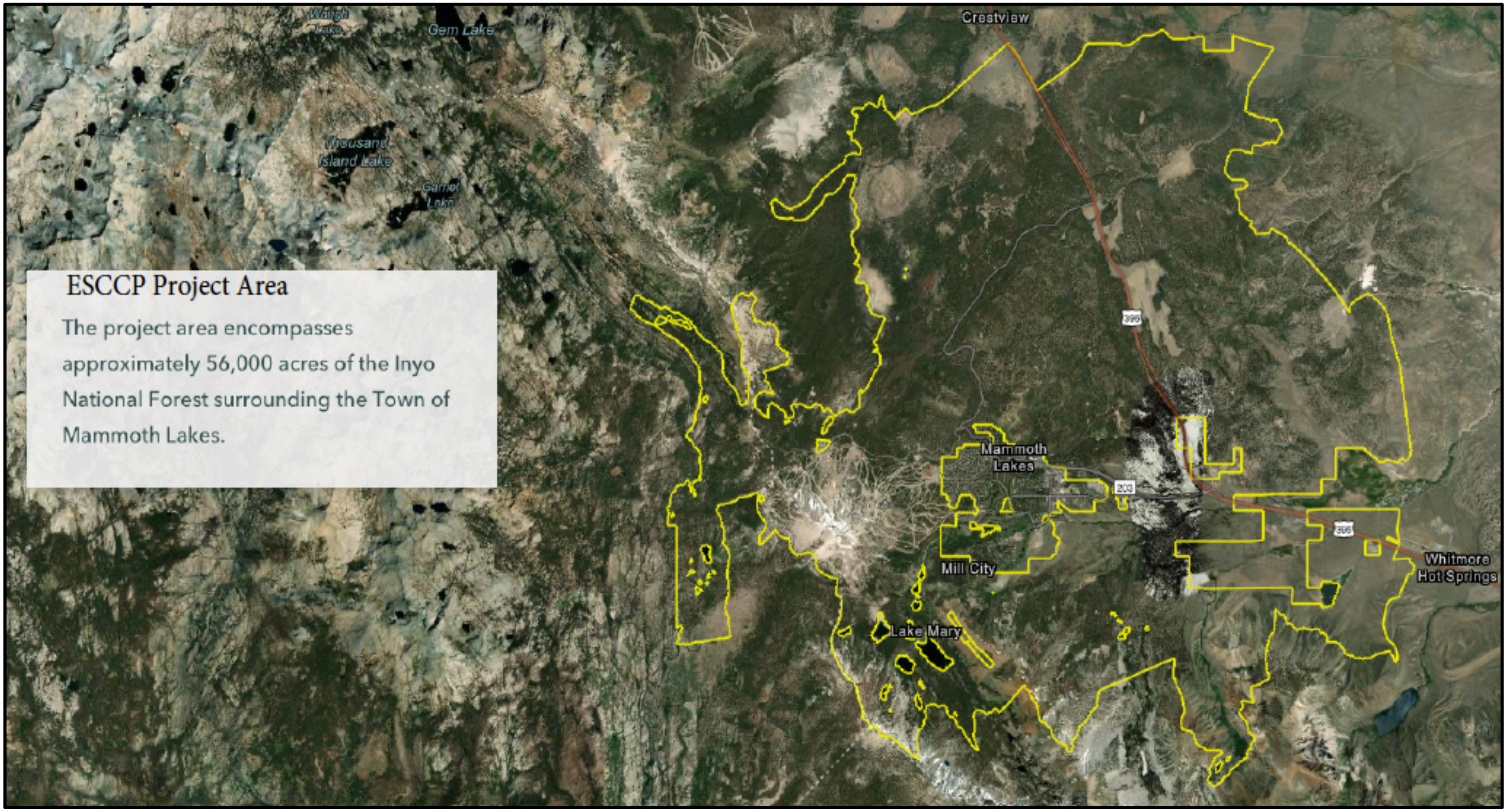
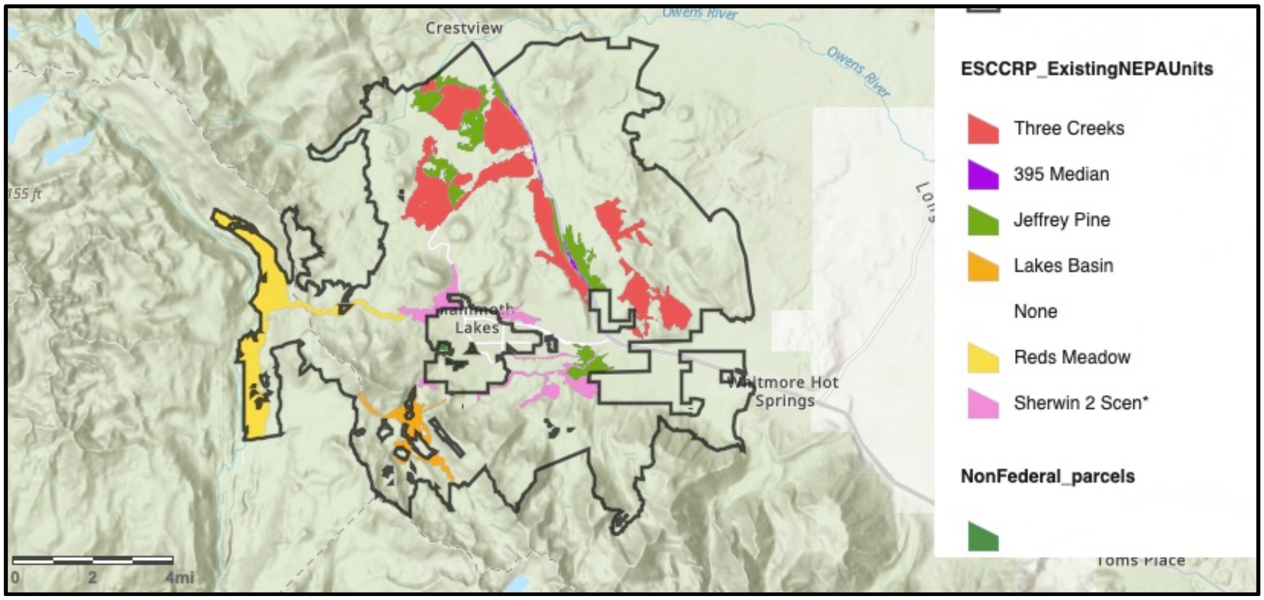


Figure 3. On-Going and Near-Term Forest Fuels Reduction Project Areas in the ESCCRP Footprint



Short- and Medium-Term Solutions

Fuel reduction activities for the ESCCRP are already occurring, such as in Reds Meadow (see Figure 3 above). The treatment on those forestlands is pile and burn. However, for those ESCCRP areas, such as the Three Creeks Unit, to be treated in the short-term between 2023 and 2025, there are potential alternative options as discussed below.

- Burn piles in fuels reduction area;
- Chip and spread in fuels reduction area;
- Air curtain burner;
- Consolidate and leave logs in treatment areas for firewood collection by community;
- Remove logs from treatment sites to processing facility for commercial firewood production;
- Remove logs to utilization markets;
- Remove logs from treatment sites to log storage for future use as bioenergy facility feedstock;
- Underground log storage for carbon sequestration;
- Mobile pyrolysis.

Table 1. Short- and Medium-Term Utilization

Removal and Utilization Alternatives	Ease of Implementa-tion	Duration	Relative Costs to other Alternatives	Logistical and Environmental Considerations	Notes
Burn piles	Easy	Dependent on fire season	Low	Burn piles cause unacceptable visual, odor, and potential impacts to local residents. Burn piles can also "escape" and cause wildfires.	Pile and burn is currently being used in the Red Meadows unit to dispose of the waste biomass.
Chip and spread onsite	Easy	Could be short	Low	Compliance observations and random measurements are required to ensure no chip layers were to exceed 4 inches.	Chip and spread should be limited to between two and four inches on the forest floor, where approved by the land manager.
Air curtain burner	Medium to difficult	Dependent on burn season	Medium to high	Can be considered a form of pile and burn. However, particulate matter emissions (which creates visible smoke) are substantially reduced to generally less than 10% of an open pile burn. Can also "escape" and cause wildfires	Air curtain burner can be difficult to place in certain areas of the forest where thinning activities might. It is better to temporarily site an air curtain burner in an open and relatively flat areas near the forest reduction activities.
Consolidate and leave logs in treatment areas for firewood processing and collecting by community	Easy to medium			Potential inadvertent impacts by members of the public cutting firewood in the forest setting.	It has been estimated that up to 30% of the woody biomass could be regionally used as firewood.
Remove logs from treatment sites to processing facility for commercial firewood production	Easy	30 to 60 days	Low to medium	Logs and limbs could be placed at landings accessible to trucks to move the logs to processing facilities such as GC Forest Products facility in Mammoth Lakes	See previous note above.
Log removal to utilization markets.	Medium	60 to 90 days-plus for construction	Medium	New or improved road access not analyzed. No new road building or maintenance in inventoried roadless areas. NEPA documentation would also be likely needed, causing further delay.	Logs would need to be placed near existing roads accessible to logging trucks. Biomass pricing dependent on accessibility and distance from facility.

Removal and Utilization Alternatives	Ease of Implementa-tion	Duration	Relative Costs to other Alternatives	Logistical and Environmental Considerations	Notes
Remove logs from treatment sites to log storage for future use as bioenergy facility feedstock.	Medium	6 months plus	Medium	A suitable site, with ample space for one to three years of log storage	
Underground Log Storage for Carbon Sequestration	Medium to difficult	6 to 12 months	Medium to high	Underground log storage is similar to a landfill and will require long-term monitoring.	The sequestration of carbon via this method can be monetized if the storage is of a permanent nature. Long-term monitoring for GHG emissions will be required. Permitting for this alternative will be difficult in California, but would be much easier in nearby Nevada.
Mobile pyrolysis	Medium to difficult	May be dependent on burn season	Medium to high	Not analyzed. This technology could be used at the bottom of the hill for removed logs.	Mobile pyrolysis for forest waste biomass is still an emerging commercial technology.

Chip and Spread on Mountain

The thinning of forests to reduce hazardous fuels and trees that have succumbed to insect infestation can result in significant amounts of woody biomass that must be dealt with. Mechanized treatment for this reduction activities is a common treatment option.

Mechanical treatment of hazardous fuels means reducing the amount of vegetation which has built up to dangerous levels, or changing the arrangement of these fuels in the environment.

Mechanical treatments can benefit ecosystems and people by:

- Reducing the probability of catastrophic fires;
- Helping maintain and restore healthy and resilient ecosystems;
- Protecting human communities.

Examples of mechanical treatment include the thinning of dense stands of trees, or other fuel treatments that make an area better able to withstand fire, such as shown in Figure 4. In that example location, when the intense wildfire spread through the overstocked forest on the left, it laid down and essentially stopped burning as it was about to enter the thinned forest stand.

Figure 4. Example of Fire Mitigation by Thinning

Such treatments as piling brush, pruning lower branches of trees, or creating fuel breaks to encourage the right kind of fire. Tools that are used to carry out the mechanical treatment of hazardous fuels range from hand tools such as chainsaws and rakes, to large machines like bulldozers and wood chippers.

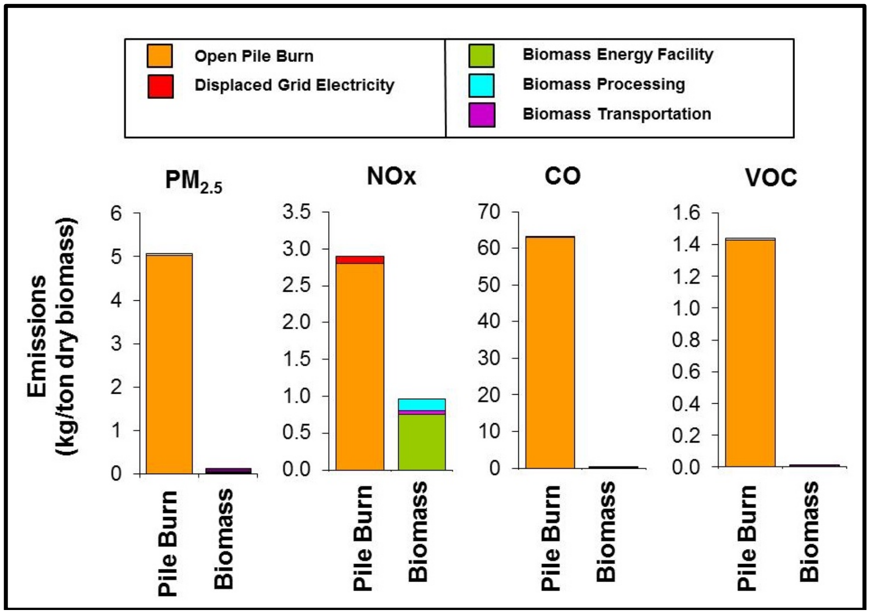
Open Burning

Open burning (in piles or broadcast burning) near the site of generation is the usual method of disposal for a significant quantity of the excess woody waste biomass throughout much of the western United States. The cost to collect, process, and transport biomass waste is often higher than its value for fuel or wood products because of the distance of the forest treatment activity location from the end user (e.g., mill, biomass energy facility), lack of infrastructure, and/or economics of bio- mass energy compared with fossil fuel generation. This limits the feasibility of using biomass waste for energy production although such use has significant environmental benefits.

Open pile burning of biomass waste can adversely impact regional air quality and human health through release of various air pollutants – including fine particulate matter (PM2.5), carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs), air toxics (including polycyclic aromatic hydrocarbons and aldehydes), and greenhouse gases of carbon dioxide (CO2), and short lived climate pollutants of methane and black carbon. Air districts, with regulatory authority over open pile burning, issue burn permits to mitigate smoke impacts when meteorological conditions allow for favorable smoke dispersion; however smoke and its impacts cannot be eliminated.

The environmental benefits of air curtain incinerators) and in the emissions-controlled environment of a biomass power plant are compelling. Significant analysis of emissions from a biomass power plant versus open pile burning has been conducted over the years. Figure 5 graphically illustrates the reduction of the major air pollutants created by the combustion of wood in open piles versus a controlled power plant environment. As can also be seen in Figure 5, the chipping, and transport, of forest-sourced biomass is a relatively small factor in the over emissions of a biomass power plant and related activities.

Figure 5. Open Pile Burning v. Controlled Emissions in Bioenergy Facility



Graphic courtesy of Placer County Air Pollution Control District

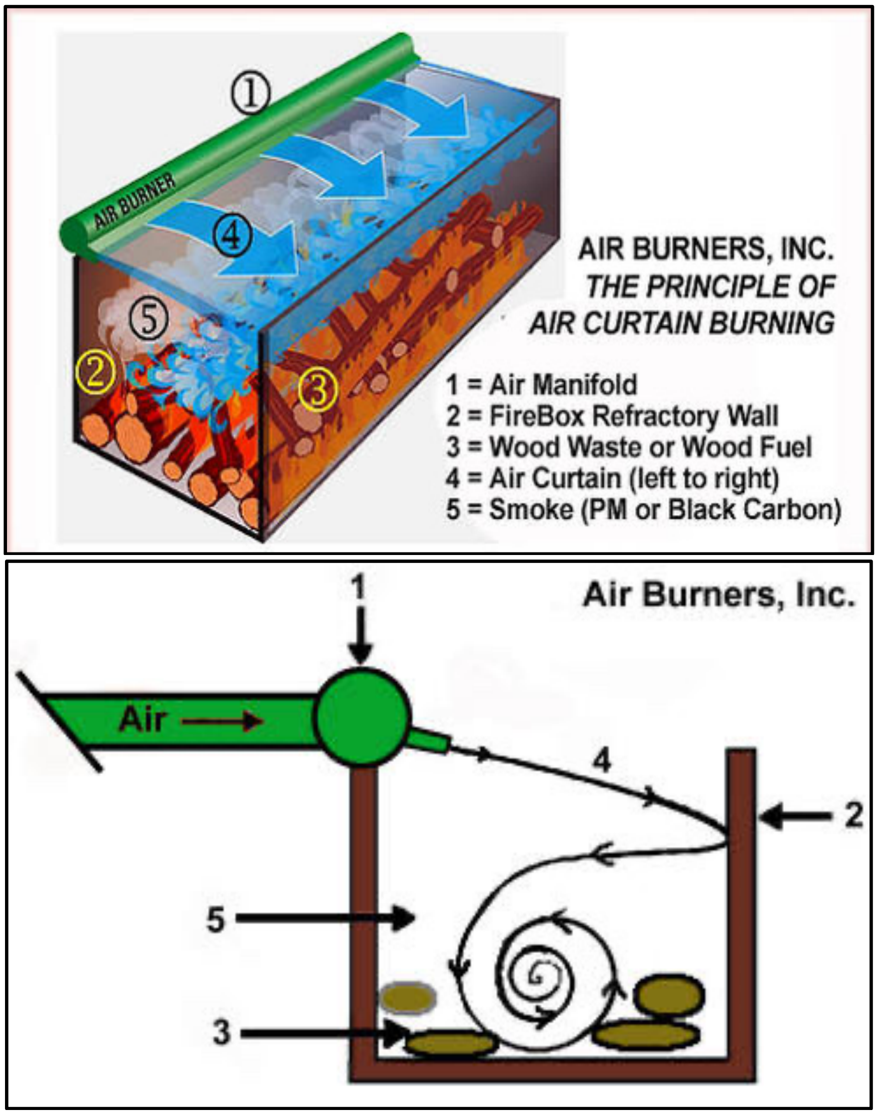
Air Curtain Burners

An alternative technology to dispose of forest residues is to use an Air Curtain Burner (ACB), such as the ones designed by Air Burners Inc., Palm City, FL, USA (also called as Air Curtain Destructor or Incinerator). ACBs are divided into two main types, stationary (positioned at the centralized landing area) and mobile applications (half-ton pick-up truck with trailer-mounted firebox system). These machines were developed in compliance with US Environmental Protection Agency's 40 Code of Federal Regulations Part 60 that determines allowable emissions from biomass burning. Figure 6 displays an ACB from Air Burners, Inc.

Figure 6. Air Curtain Burner

ACBs are used to dispose of woody residues from forest thinning and tree mortality, waste wood and landscape wastes, and woody debris from natural disasters. Details on how the ACBs efficiently burn woody materials are shown in Figure 7. These machines operate by blocking various air pollutant emissions including greenhouse gases and particulate matter by using a high velocity (1600–2000 revolution per minute) of airflow from the air blower part which is referred to as "air curtain". Past studies show that ACBs can reduce CO and PM emissions by 80% or more compared to open pile burning and reduce smoke opacity. In addition, it also minimizes escaping embers, soil damage, and burn scars by creating an air curtain across the fire box opening.

Figure 7. Principles of Air Curtain Burning



Permitting, as required from the local air district (Great Basin Unified Air Pollution Control District), as well as U.S. Environmental Protection Agency rules, may limit the throughput of wood waste in an ACB, as well as when it can operate[2]. As it is a burning operation it may likely have to conform to no-burn days and periods in the year.

Consolidate Logs for Firewood and Wood Products Utilization

Logs and larger limbs generated by forest management activities can be utilized for various forms of wood products such as firewood, lumber, and other manufactured wood products. However, apart from firewood which can used locally, transport to wood products facilities is more difficult to the lack of such local and regional facilities. The nearest wood products facilities are north of Lake Tahoe and in the Reno area which would likely make woody biomass transport uneconomical.

To be utilized as firewood or transported out of the forests to wood products facilities, logs and large limbs should be consolidated into areas where are more easily accessed. A forwarder, such as the one shown in Figure 8, is a forestry vehicle that carries felled logs from the stump to a roadside landing. Unlike a skidder, a forwarder carries logs clear of the ground, which can reduce soil impacts but tends to limit the size of the logs it can move. Forwarders are typically employed together with harvesters in cut-to-length logging operations.

Figure 8. Forwarder Able to Move On- and Off-Road

Once logs are accessible to road vehicles, they can potentially be transported to off-site to wood product facilities for further processing, or made available to the local community for firewood (see Figure 9).

[2] An air curtain burner will require a permit from the GBUAPCD per communication with District Staff.

Figure 9. Disposition of Logs

Log Storage for Later Utilization

This option is being considered for short-term utilization as a source of feedstock for a potential bioenergy facility to be sited and operated in the Mammoth Area (see Longer Term Solutions for Biomass Utilization below).

Estimated Temporary Storage Area

To determine how much space might be needed to store one to three years of forest treatment activities in the Mammoth area, TSS conducted the following analysis.

As Inyo Forest Service staff[3] forecasted, using recent stand exam data, biomass removal volume is 15.8 BDT per acre. Further estimating that up to 30% of the biomass removed likely will be used for firewood, with the remainder available for alternative utilization of some type, it has been calculated that approximately 11 BDT per acre is potentially available. Staff working on the ESCCRP project[4] confirmed plans to treat 2,000 acres per year as the ESCCRP is implemented across target forestlands. This amounts to approximately 22,000 BDT of forest biomass per year over a 20-year project timeline. Not all forest biomass will be available, as topography and road systems may limit accessibility. However, most of the ESCCRP treatment area is accessible and relatively flat. TSS

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[3] Stephen Calkin, Forester, Inyo National Forest.
[4] Janet Hatfield, ESCCRP Project Manager, Whitebark Institute.

estimates that 90% of the forest biomass will be recoverable, yielding 19,800 BDT/year as practically available[5].

In determining the amount of storage might be needed for predicted amount of forest fuels treatment in the Mammoth area per current and future plans of the ESCCRP it is assumed that approximately 2,000 acres per year would be treated, with a resultant 19,800 BDT available per year, or 33,000 green tons (GT) at average 40% moisture content per year as described above. Further assumptions include:

- Log amounts would vary from zero to 11 BDT per acre – assume average of 5.5 BDT per treatment acre, or with average 40% moisture, 9.2 green tons (GT). The BDT is calculated via the following formula: 1 minus 40% moisture x green tons ((1-0.40)*9.2);
- At 9.2 GT per acre – 16,560 GT per year as logs
- Log dimension would average 15 inches diameter, and cut on site to 16-foot lengths;
- A log truck could transport approximately 120 logs at 24 GT per load;
- Decking height of logs would not exceed 14 feet (the reach of a standard log loader), and 15' fire lanes in the storage area per the Fire Marshal;
- An acre of storage would hold approximately 480 GT, the equivalent of 20 log truck loads.

Using the above assumptions, the acreage needed to store an annual number of logs is estimated at nearly 35 acres (16,560 GT divided by 480 GT/acre).

Interviews with southern Sierra Nevada contractors that manage forest fuels reduction operations confirmed that costs range from $35 to $45/BDT loaded onto the truck at the landing. Assuming a 10-mile one-way transport[6] from the forest to a biomass utilization facility near Mammoth Lakes, the delivered cost will range from approximately $46 to $56/BDT (see TSS, Biomass Feedstock Supply Availability and Cost Assessment, 2021). Note that this cost estimate does not include cost offsets such as transportation cost incentives provided by USFS service contracts or grant funding, nor is this cost technology utilization dependent.

Log storage should occur on sites that have already been disturbed by other land use activities such as surface mining, and should be in relatively close proximity to Mammoth Lakes for transportation cost reasons and for future use at a bioenergy facility. Figures 10 and 11 display potential storage sites. The airport site shows the most promise as a site with enough space. Discussions with the U.S. Forest Service are ongoing regarding that site.

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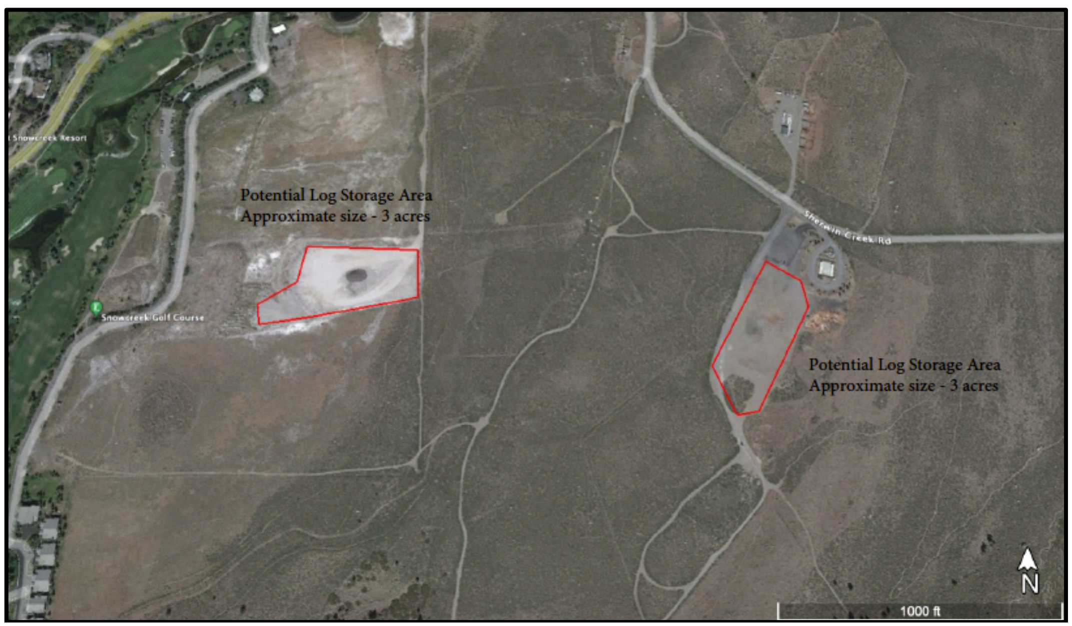
[5] "*Biomass Feedstock Supply Availability and Cost Analysis for the Mammoth Lakes Region*," prepared October 2021 by TSS Consultants for Cal Trout.

[6] Chip transport costs average $110 per hour with a total roundtrip cost of $165 per delivery (1.5 hours). At 15 BDT per load, the haul cost is $11/BDT for the 20-mile roundtrip transport.

Figure 10. Potential Log Storage Area near Mammoth Airport

Figure 11. Potential Log Storage Areas south of Town of Mammoth Lakes



Log Storage Underground for Carbon Sequestration

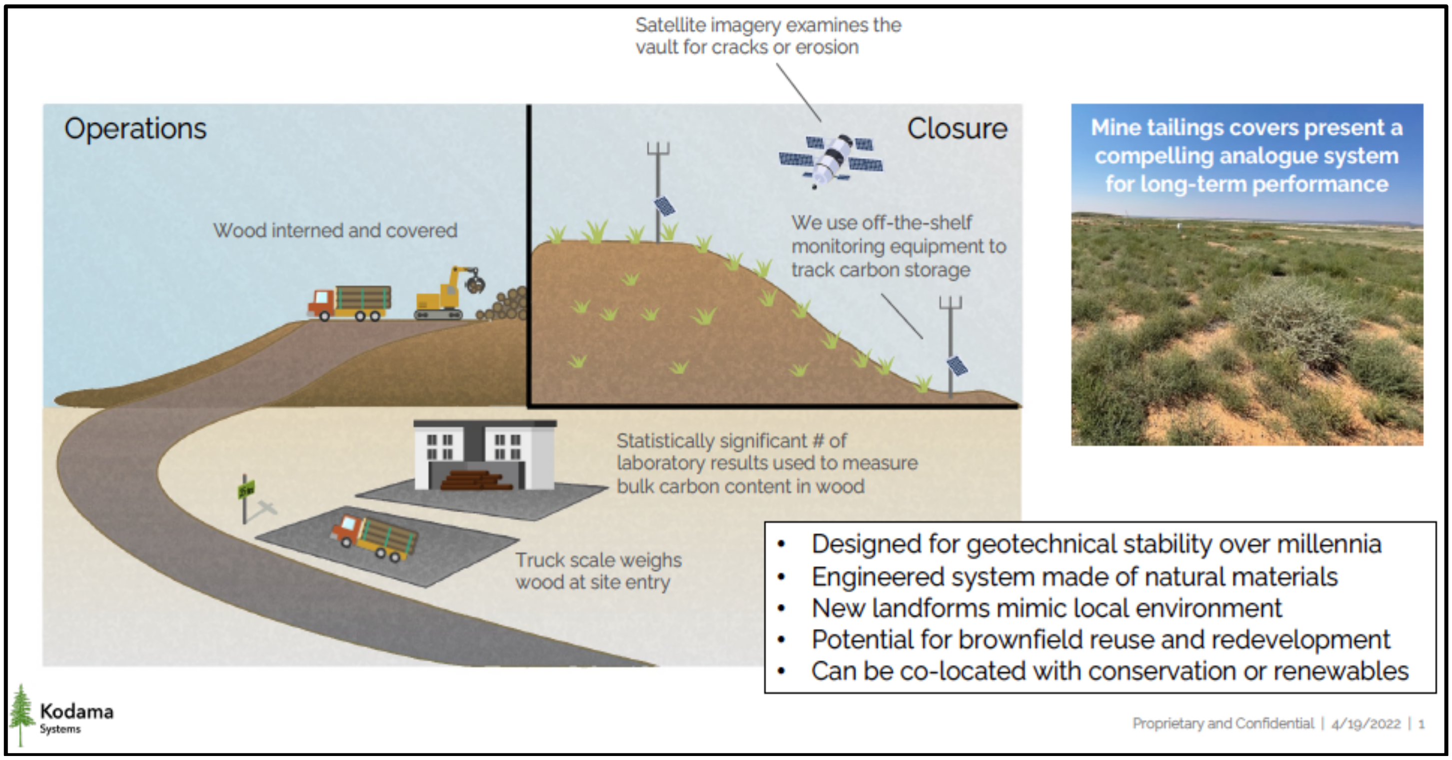
Forest thinning activities involving the removal of logs and larger limbs could involve the "burial" of such materials for the sequestration of carbon, and the monetization of that sequestration via carbon credit markets. Also known as wood vaulting, this alternative handling method of forest biomass buries woody biomass in specially engineered underground enclosures to ensure anaerobic environments, preventing the decay of the wood, and significantly minimizing, or eliminating the generation and release of carbon to the atmosphere.

Most pieces of the wood vault technology already exist, but need to be fashioned together for efficient storage of the woody biomass. This technology could be implemented to be highly durable, the carbon storage verifiable, at lower potential cost that other carbon sequestration methods.

To reduce, and potentially eliminate wood decay underground, the optimal location for wood vaulting is arid desert, and desert-like environments, such as the region east of Mammoth Lakes in California, and over the state border into Nevada. Siting of such a facility, whether it be an initial demonstration or commercial, will have challenges both with permitting, and potential societal challenges. Such a facility may be construed by some as landfill and would require permitting in California by the Department of Resources Recycling and Recovery (CalRecycle), the Regional Water Quality Control Board, and possibly the local air quality management district. Plus, depending on land ownership where the facility is located, if on private property would require land use permitting, and on government-managed property approvals by the land management agencies (i.e., U.S. Forest Service, U.S. Bureau of Land Management, etc.). However, it believed that permitting in Nevada on privately-held land would be easier and more streamlined.

Figure 12 below graphically illustrates a wood vault facility and the monitoring systems to any air emissions release.

Figure 12. Wood Vaulting Process



Mobile Pyrolysis

Wood pyrolysis has been historically used to produce charcoal or tar for a variety of applications, including improving soil productivity by introducing the carbon from the biomass. Woody biomass pyrolysis the process of heating a biomass feedstock in the absence of oxygen and condensing the resultant vapors.

Figure 13 simplistically displays the pyrolysis process. The principal products created by pyrolysis are bio-oil[7], biochar[8], and syngas[9]. Of the three products, biochar may be useful for restoring or revitalizing degraded forest soils and help with carbon sequestration, nutrient leaching losses, and reducing greenhouse gas emissions. Bio-oil and syngas are not products used in forest health management due to their properties.

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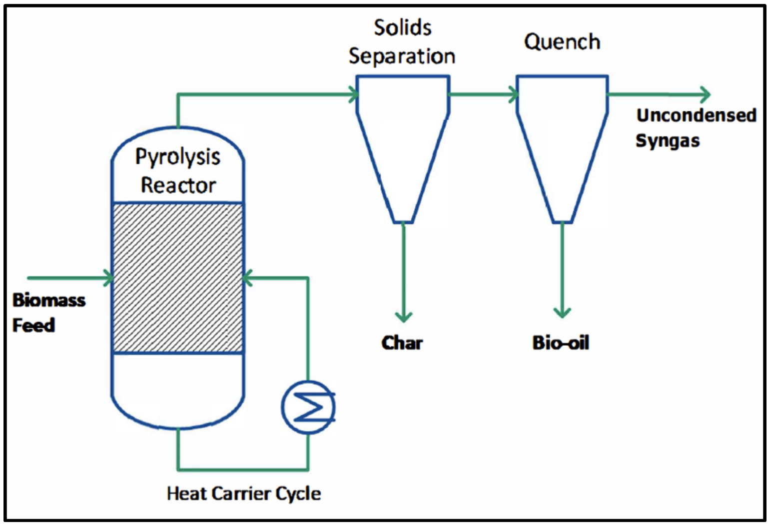
[7]Also known as pyrolysis oil, it is a liquid emulsion of oxygenated organic compounds, polymers, and water which can be burned directly as a petroleum substitute, or potentially upgraded in a refinery to be a hydrocarbon fungible fuel.

[8] Biochar is a carbon-rich organic material, an organic amendment, and a by-product derived from biomass by pyrolysis under elevated temperature and low- to no-oxygen conditions.

[9] Syngas, also called a synthesis gas, is a mix of molecules containing hydrogen, methane, carbon monoxide, carbon dioxide, water vapors, as well as other hydrocarbons and condensable compounds.

Figure 13. Woody Biomass Pyrolysis and Products



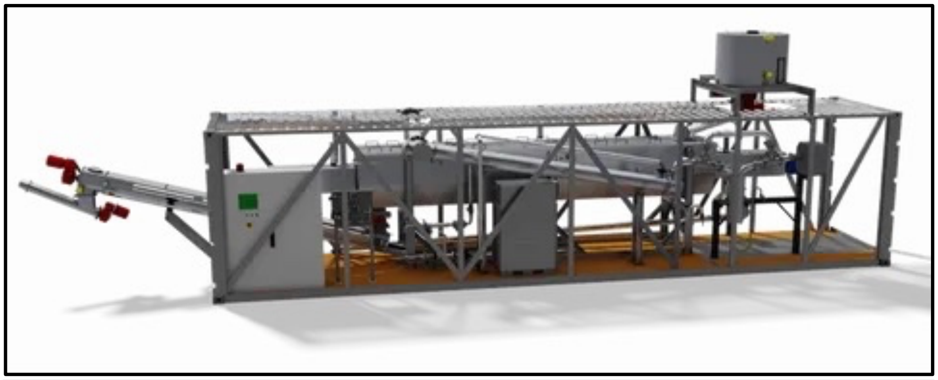
Pyrolysis of woody biomass can be performed at different temperatures and residence times in the reactor vessel which create the different products and in different ratios obtainable by pyrolysis. For biochar production Table 2 below displays the potential per unit of woody biomass, as well as bio-oil and syngas production.

Table 2. Pyrolysis Products per Different Temperatures and Residence Time

Type of Pyrolysis	Temperature and Residence Time	Biochar	Bio-oil	Syngas
Fast	950 F – 1 second	12%	75%	13%
Intermediate	950 F – 10 to 30 seconds	25%	50%	25%
Slow (torrefaction)	550 F - ~30 minutes	80% (more like a charcoal)	0%	20%
Slow (carbonization)	750 F – can be days	35%	30%	35%
Gasification	1400 to 1700 F	10%	<5%	85%

The pyrolysis process can be scaled to be portable units that can be brought to the forest. However, there will forest treatment units where portable unit may not be able to access. Such units are currently available and a truck mounted unit is shown in Figure 14. This is a very robust and commercial system, which in the cost range of $2 to $3MM. Smaller trailer mounted units can cost $250 to $500K and up depending on throughput

Figure 14. Heavy Duty Truck Trailer Mounted Mobile Pyrolysis Unit



The drawback to the use of a mobile pyrolysis unit is the disposition of the non-biochar products, bio-oil and syngas, particularly in remote forest settings such as the Eastern Sierras. Bio-oil would have to be exported to a location where it could be utilized and currently those options are nearly non-existent in California and Nevada. Syngas, which cannot be containerized, would have to be used at the site, which would not occur in a forest setting or it needs to be flared. Flaring, the combustion of the syngas with a resulting flame, would also likely not be allowed in the forest setting. However, the syngas can be recycled as fuel for heating the pyrolysis unit itself, and the waste heat from this combustion to dry the higher moisture forest wood waste.

In addition to the pyrolysis unit, the forest treatment still requires the equipment and processes for getting the targeted forest woody biomass down and converted into chips as feedstock into the unit.

Town of Mammoth Lakes Bioenergy Initiative

The Town of Mammoth Lakes (TOML) has been looking into bioenergy options for their waste diversion needs, as well as use of waste woody biomass. The TOML received a U.S. Forest Service Wood Innovation Grant to look at utilization options to assist the Town and region in dealing with the woody biomass from forest treatments planned for the region, as well to process locally generated municipal solid waste (MSW) such urban greenwaste, food and other organic wastes, wood debris, generated in the Town area. The waste materials, that are not recyclable, would have historically been landfilled at the Benton

Crossing Landfill. However, this landfill is scheduled to be closed by the end of 2022 and alternative landfills are located some distance away, making transport of the waste expensive and that cost is on the top of the landfill's tipping (disposal) fee.

Through its Wood Innovation Grant funding, the TOML issued a Request for Proposal (RFP) in July 2020, using a public-private partnership to select a bioenergy project developer and technology, which was to lead to a Design, Build, Operate (DBO) agreement. Through the RFP process, the TOML selected Earthcare, LLC (Evansville, IN). The agreement between Earthcare and TOML was approved in November 2020, and was for the design, planning, location, financial viability, and permitting process review for the bioenergy project to produce both electricity and biochar. To meet the Town's waste management needs, with the closure of the Benton Crossing Landfill, and the pending construction and operation of a proposed Materials Recovery Facility to process municipal solid waste (MSW) collected in the TOML, this bioenergy facility is proposed to accept greenwaste and other organics for utilization as feedstock. The proposed bioenergy project is to also design to utilize woody biomass from the forest treatments planned in the region by the ESCCRP and federal land management agencies over the next two decades. As any bioenergy project in the Mammoth Region will by necessity of having available biomass feedstock will be relatively small scale. Based on the 2021 biomass resource assessment prepared by TSS, any facility could not exceed 2.5 to 3 MW of produced electricity (see Longer-Term Solutions for Biomass Utilization below). And, as the TOML reported in their Final Report (dated December 10, 2021) financial viability is directly linked to the cost of delivery of biomass to a bioenergy facility.

The TOML is continuing to move forward, currently looking at siting options for an Earthcare facility. The Earthcare is also considered in the bioenergy technology/developer evaluations in Tables 3, 4, and 5 in the next section.

Longer-Term Solutions for Biomass Utilization

Ultimately, for the long-term (up to 20 years) disposition of woody biomass from forest treatment activities are those to be undertaken by the ESCCRP. As bioenergy can be inherently higher priced than other electricity generation technologies, a bioenergy facility in the Mammoth area for generating electricity would have to take advantage of California's Bioenergy Market Adjusting Tariff (BioMAT). BioMAT is a renewable energy feed-in tariff established by the California Public Utilities Commission (CPUC) Decisions 14-12-081[10] and 15-09-004[11] to implement California Senate Bill 1122. BioMAT allows for long term power purchase agreements (up to 20 years) to purchase wholesale power from small bioenergy projects up to 3 MW at premium prices. A BioMAT facility in the Mammoth area,

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[10] https://www.pge.com/includes/docs/pdfs/b2b/wholesaleelectricsuppliersolicitation/BioMAT/SB1122_D-14-12-081.pdf
[11] https://www.pge.com/includes/docs/pdfs/b2b/wholesaleelectricsuppliersolicitation/BioMAT/SB1122_D-15-09-004.pdf

using woody biomass from forest treatments could realize up to nearly 20 cents a kilowatt hour.

However, the CPUC decisions also placed limits on how much forest-source bioenergy megawattage could be contracted per each of the three major Investor-Owned Utilities (Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric). Southern California Edison (SCE) only received an allotment of 2.5 MW of forest wood-sourced BioMAT power (also known as BioMAT Category 3). However, this should not be an issue as 2 to 2.5 MW is about all the forest treatment over the next 20-year horizon could likely support.

Bioenergy Technologies

As mentioned above there is predicted to be enough woody biomass available over 20 years to support a BioMAT power plant. Below is a discussion of the principal types of biomass to electricity as well as several potential vendor of small scale technologies that could be interested in establishing a facility in the Mammoth area.

Biomass to Electricity

Production of electricity from biomass combustion has been widely commercialized worldwide for many decades and is the most common form of woody biomass to electricity systems. Direct combustion systems feed biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create high pressure steam. This steam drives a turbine generator to make electricity (see Figures 15 and 16 below). Biomass direct combustion can also produce heat which can then be used to heat a working fluid in an Organic Rankine Cycle (ORC) turbine generator system. Such ORC systems use air cooling systems to condense the working fluid from the vapor phase back to the liquid phase in a closed loop system, thus eliminating the need for continuous water supply (for steam) and process wastewater requiring disposal (see Figures 17 and 18 below).

Figure 15. Biomass Direct Combustion Schematic

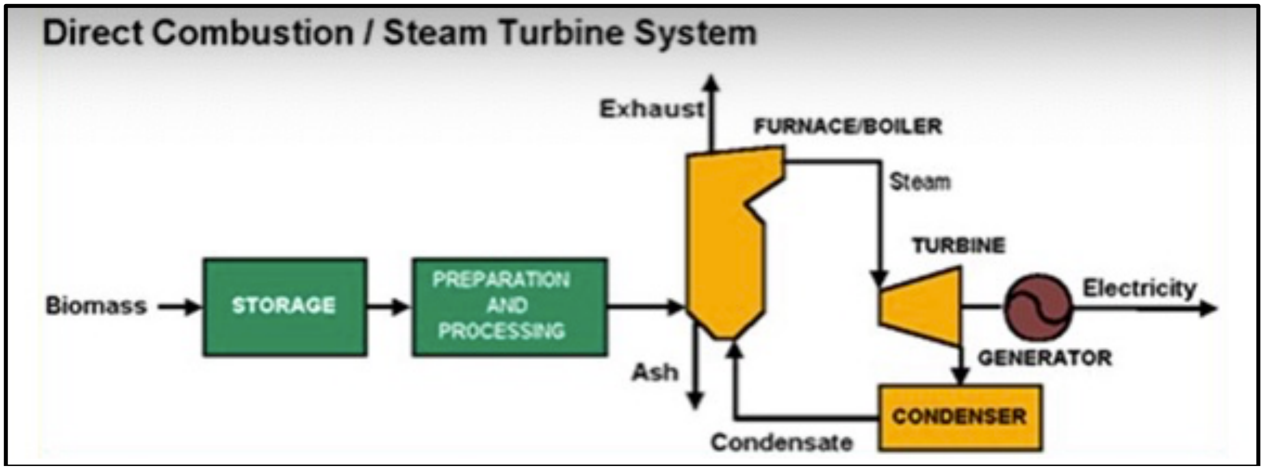


Figure 16. Biomass Direct Combustion Power Plant

Small Direct Combustion Biomass Plant in Carson City, NV (currently offline)

Figure 17. Biomass Direct Combustion with ORC Electricity Generation Schematic

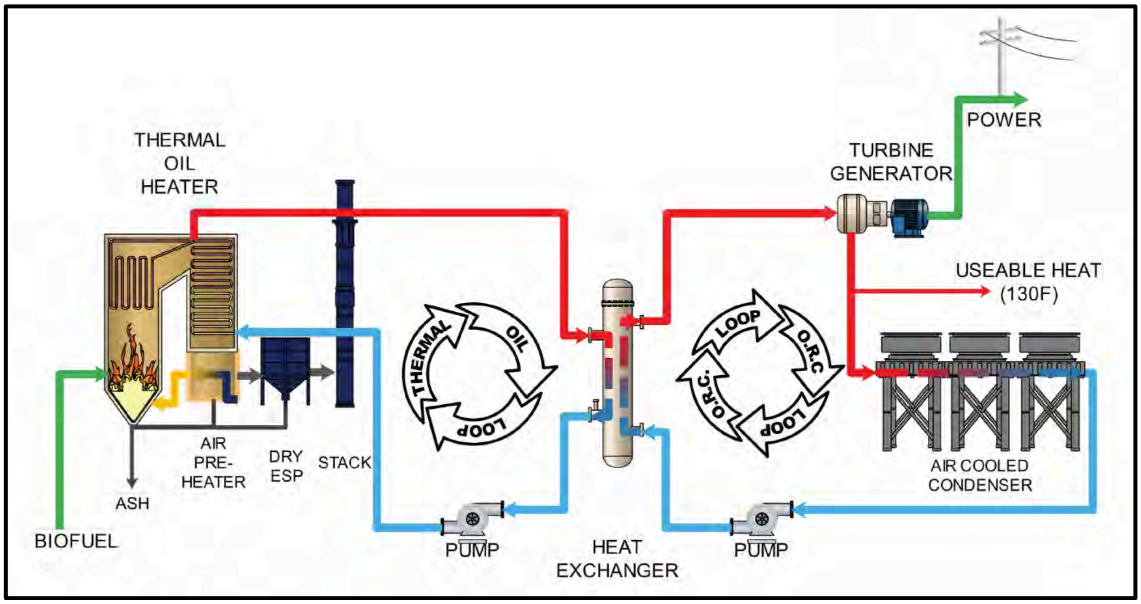


Figure 18. Biomass Direct Combustion with ORC Electricity Generation

Three-megawatt biomass power plant in Williams, CA

Biomass electric power systems typically use one dry ton per megawatt-hour of electricity production (approximately 8,000 BDT per megawatt-year). This approximation is typical of woody biomass systems and is useful as an indicative estimate of fuel use and storage requirements but the actual value will vary with system efficiency.

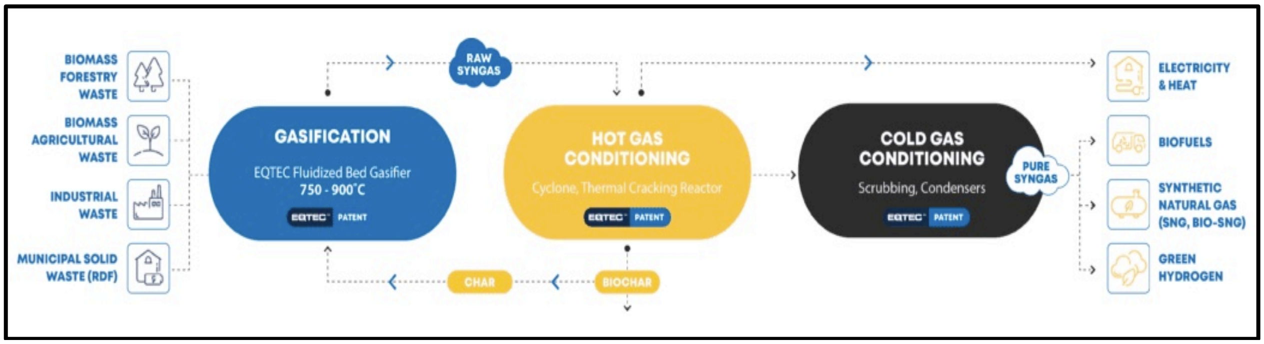
Most wood chips produced from forest-sourced biomass will have a moisture content of 40% to 55%, wet basis, which means that a ton of green fuel will contain 800 to 1,100 pounds of water. This water will reduce the recoverable energy content of the fuel, and reduce the efficiency of the boiler, as the water must be evaporated in the first stages of combustion.

A significant consideration with forest-sourced woody biomass-fired plants are storage, handling, and pre-processing of the fuel. This is the case with both small, grate-fired plants and large suspension-fired plants. Drying the biomass before combusting improves the overall process efficiency, but may not be economically viable in many cases. Storage must be provided for the fuel whether chipped or in whole log form, particularly in the winter months, when biomass may not be sourced due to inclement weather conditions.

Exhaust systems are used to vent combustion by-products to the environment. Emission controls might include a cyclone or multi-cyclone, a baghouse, or an electrostatic precipitator. The primary function of this equipment is particulate matter control. Cyclones and multi-cyclones can be used as pre-collectors to remove larger particles upstream of a baghouse (fabric filter) or electrostatic precipitator. Reduction in particulate can be as high as 99%+. In addition, emission controls for unburned hydrocarbons, oxides of nitrogen, and sulfur are generally required per state and federal air quality regulations

Gasification technology is also used to convert biomass fuels into energy. Biomass gasification systems are similar to combustion systems, except that the quantity of air is limited or totally absent to produce a fuel gas (a.k.a. producer gas) with a usable heating value in contrast to combustion, in which the off gas does not have a usable heating value. This producer gas is subjected to gas clean-up to remove contaminants and compounds that foul the electrical generation system. Once cleaned and conditioned, this syngas provides the ability to power many different kinds of gas-based prime movers, such as internal combustion engines, Stirling engines, thermoelectric generators, fuel cells, and micro-turbines to produce electricity. And, as it is gas that is actually combusted or used chemically in the prime mover, emissions can be substantially less than the combustion of the solid wood fuel. A simple schematic of the gasification process is shown in Figure 19 below. It should be noted that woody biomass gasification can also be utilized to produce biofuels, biomethane (a.k.a. renewable natural gas) and green hydrogen.

Figure 19. Biomass Gasification



A 2MW biomass to gasification facility was previously proposed in the Lake Tahoe area between Truckee and Tahoe City through the Placer County Biomass Program. Although it is not in a BioMAT eligible area of California, it is currently being reconsidered as one of the solutions to biomass utilization in the Lake Tahoe Basin due to increased forest treatments. This facility was fully permitted to be constructed and operated. Figure 20 is a graphic rendition of the proposed facility.

Figure 20. Cabin Creek Biomass Gasification Facility Rendering

Gasification of woody biomass also results in a marketable byproduct in addition to electricity – biochar. Biochar is the lightweight black residue, made of carbon and ashes, remaining after the gasification of biomass. Biochar is defined by the International Biochar Initiative as "the solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment".

Biochar is beneficial to sequester carbon (reduces GHG emissions) and it can also improve soil moisture retention. Biochar has been also demonstrated to improve soil health and enhance agricultural productivity when applied in combination with composting. There are numerous other potential uses for biochar including (but not limited to):

- Use as a soil conditioner;
    - Carbon fertilizer
    - Compensatory fertilizer for trace elements
    - Compost
    - Water retention

- Use in the building sector;
    - Insulation
    - Air decontamination

- Decontamination;
    - Soil additive for soil remediation (for use in particular on former mine-works, military bases and landfill sites)
    - Soil substrates (highly adsorbing, plantable soil substrates for use in cleaning waste water; in particular urban waste water contaminated by heavy metals)
    - A barrier preventing pesticides seeping into surface water (sides of field and ponds can be equipped with 30-50 cm deep barriers made of biochar for filtering out pesticides)
    - Treating pond and lake water (biochar is good for adsorbing pesticides and fertilizers, as well as for improving water aeration)

- Biogas production;
    - Biomass additive to increase biogas production

- Treatment of waste water;
    - Activated carbon filter
    - Pre-rinsing additive
    - Soil substrate for organic plant beds

- Treatment of drinking water.
    - Micro-filtration

With some equipment modifications and loss of electrical generation efficiency biochar can also be produced in biomass direct combustion units as well. Biomass One, in Medford, Oregon produces biochar for sale.

Biochar production is generally calculated at 10% (plus/minus 2%) of the input volume of woody biomass. Thus, if a biomass power plant utilizes 160,000 BDT, approximately 16,000 tons of biochar could be available for sale. Existing biochar markets are in the $500 to $1,000+ per ton range, however as more and more biochar is being produced by the increasing number of biochar processors in the United States, this price is likely to go down. Thus, $150 to $250 per ton, which could result in additional revenues of $2.4MM to $4MM per year, should be considered in any financial analysis.[12]

Candidate Technology Attributes

TSS conducted this bioenergy technology review to seek out commercially-available conversion technologies utilizing small log and/or wood fiber feedstocks at a scale and technology type consistent with Task 2 feedstock supply availability analysis and 3 candidate site review findings. A Conversion Technology Review matrix was utilized to consider key variables such as:

- U.S. Department of Energy Technology Readiness Level – TRL must be seven or higher;
- Proven ability to utilize locally available feedstocks (small logs and wood fiber);
- Technical support available once technology is deployed;
- Economic and environmental viability and commercialization potential

These key variables are principal to the following candidate technology attributes. The information gathered and evaluated are included in three separate tables identified below.

Company Information (see Table 3)

- Contact Information – Company name, website, contact person with email address are provided.
- Technology Product – Technologies selected were of the gasification and pyrolysis type. Some technology vendors indicated that they could produce both electricity or liquid or gaseous transportation fuels, such as renewable diesel, jet fuel, biomethane (as renewable natural gas) and hydrogen (as a renewable transportation fuel). Five of the 12 technologies indicated they could produce biofuels and electricity, while the other five would produce only electricity. One of the technology companies offered two separate systems (gasification to electricity, and pyrolysis to bio-oil).

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[12] Personal communication with Tom Miles, Executive Director, U.S. Biochar Initiative, Former Chair of the International Biochar Initiative.

The yield of electricity and/or biofuels is included in this section. One technology is for the clean burning of wood waste as a disposal option (air curtain burner).

- Technology Maturity – Technology maturity identification was based on the U.S. Department of Energy technology readiness assessment protocols, which were adapted from proven NASA and Department of Defense technology assessment models. A numeric value was given to each company technology, which correspond to the level of technology maturity the respective technology is believed to have achieved. Technology maturity or technology readiness levels (TRLs) run from 1 to 9 with 9 being the most ready or mature. Technologies less than 7 were not considered for this report. The TRL matrix is attached in Appendix A.
- Experience with Woody Biomass Feedstocks and Project Locations – Candidates were queried on their past experience(s) with urban-, agricultural-, and forest-sourced woody biomass. Additional information about past and current projects is also included.

Cost Estimates (see Table 4)

- Estimated Cost of Production – Where available, the cost of producing the electricity and/or biofuels was requested of the companies.
- Capital Cost Estimate – The capital cost per MW was requested.
- Operation and Maintenance Cost Estimate – The annual cost of operating and maintaining the candidate facility was requested. When candidates replied it was a percentage of the capital costs.
- Marketable Byproducts – Marketable byproducts, in addition to electricity or biofuels (principal products), were considered important as such byproducts could have a significant beneficial effect on revenue generation. This would be particularly important where electricity prices are low.

Operating and Site Parameters (see Table 5)

- Operating Requirements – Emphasis here is placed on number of employees needed to operate the facilities (if in the 3 to 5 MW range) per shift.
- System Efficiency and Parasitic Loads – The relative overall efficiency and parasitic load (internal use of power) was addressed.
- Site Requirements – Focus here is the amount of land needed for a 3 to 5 MW facility (or 40,000 BDT for biofuels). It should be noted that all facility sites would require some access to electricity, particularly while the facility is not producing its own electricity.
- Environmental Considerations – All facilities will have some air pollutant emissions of some kind. Experience, however, indicates that the air emissions are generally very low with gasification systems (whether to electricity or biofuels). All candidates realized that Best Available Control Technology (BACT) would be

needed[13]. Water supply and wastewater discharge needs were also considered, along with any significant solid waste disposal.

- Involvement in Projects – Candidates were queried as to their respective roles in the design, construction, operation, and ownership of facilities using their technologies.

TSS contacted 15 direct combustion and gasification/pyrolysis technology vendors/developers, along with one air curtain burner vendor. TSS requested data and information on the attributes of their respective technologies as indicated in the bulleted list above. Ten of those contacted supplied sufficient information and data to be considered for inclusion in this report. TSS evaluated the information received from the responding candidate technologies and with TSS's extensive experience in the bioenergy sector, TSS has prepared a technology evaluation matrix. TSS has also included explanatory text regarding the matrix information and findings, as well as the parameters and attributes (listed above) used for the matrix.

TSS used a benchmark regarding the technical availability of woody biomass of 2.5 MW, or approximately 27,000 to 30,000 Bone Dry Tons (BDT). This is based on the resource assessment work conducted for the Mammoth Area in 2021.

Where appropriate, TSS also considered other factors offered by candidate technology companies during various communications (emails, conference calls, and video meetings) for information and data acquisition.

Responding Technology Companies

TSS used its standard information procurement protocol, and required that the bioenergy technologies should be commercial, or at least near commercial, with a U.S. Department of Energy Technology Readiness Level or 7 or higher. As previously mentioned, TSS contacted 15 bioenergy companies known to meet this TRL metric. Ten of them responded with some, or all, of the information requested. These companies were:

- Air Burners, Inc. – www.airburner.com. Contact:Brian O'Connor, boconnor@airburner.com
- Aries Clean Energy – www.ariescleantech.com. Contact: Gary Darling, gary@darlingh2o.com
- Brad Thompson Company – www.bradco.com Contact: Paul Sicurezza, pauls@bradco.com
- Char Technologies – www.Chartechnologies.com Contact: Andrew Friedenthal, afriedenthal@chartechnologies.com

[13] BACT means any emission control equipment or technique which the division determines to be available for maximum reduction of emissions. This determination shall consider the energy, environmental, and economic impacts on the source

- Earthcare - https://www.earthcarellc.com. Contact:Michael McGolden, mikemcgolden@gmail.com
- Engemann Energy – www.engemanenergy.com. Contact: Andrew Grant, agrant@biomasspc.com
- EQTEC – www.Eqtec.com. Contact: Jeffery Vander Linden, jvanderlinden@eqtec.com
- Sierra Energy – www.sierraenergy.com. Contact: Michael Kleist, mkleist@sierraenergy.com
- Wellons Inc – www.Wellons.com. Contact: Rob Broberg, Rob.Broberg@wellons.com
- West Biofuels – www.westbiofuels. Contact: Matt Summers, matt.summer@westbiofuels.com

Table 3. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[14]	Experience with Woody Biomass/Project Locations
Air Burners	www.airburners.com Brian O'Connor boconnor@airburner.com 772-220-7303	Biomass burner which uses a small diesel fueled engine to safely burn biomass leaving only carbon ash and biochar. Reduces particulate matter emissions by 80 to 90% over open pile burning.	TRL: 9	Will burn most any type of biomass including forest and agriculture biomass. No chipping or grinding required. Will take whole logs as long as they fit in firebox.
Aries Clean Energy	www.ariescleanenergy.com Gary Darling gary@darlingh2o.com	*Electricity only* Gasification process with Organic Rankine Cycle engine/genset used to make electricity. Did not state how many BDT needed per MW (assume rule of thumb – 1.5 BDT per MW hour for ORC generators, with 1 BDT producing 0.67 MW).	TRL: 7 to 9 Aries has existing commercial unit but continues to conduct engineering work to improve overall systems.	Yes, with urban, agricultural, and forest wood. Operating projects in TN and FL. Projects in various stages of development in CA.
Bio-Gas Energy (gasification)	www.biogas-energy.com Brian Gannon bgannon@biogas-energy.com	*Electricity Only* Small modular gasification systems plumbed together. Vendor reports 1.8 MWh of electricity generated per BDT of wood.	TRL: 9 Using commercially available 70 kW gasification system (with IC engine)	Yes, with urban, agricultural, and forest wood. 1.75 MW facility in development

[14] Technology maturity based on the U.S. Department of Energy Technology Readiness Level (TRL) guidance. The TRLs are defined in Table 1 of the guidance document. This table is located in Appendix A, and full guidance document can be found at: https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04-admchg1/@@images/file

Table 3. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[14]	Experience with Woody Biomass/Project Locations
Bio-Gas Energy (pyrolysis)	www.biogas-energy.com Brian Gannon bgannon@ biogas-energy.com	*Biofuel Only* Currently only has 10 ton per day feed rate unit producing bio-oil (a precursor to fungible transportation fuels, or can be used as fuel oil substitute). Hoping to expand up to 200 ton/day feed rate. Conversion rate is up to 75% by mass.	TRL: 7	Yes, with ag and forest wood. Demonstration project in Northern California being funded by the CA Energy Commission (10 ton/day unit)
Brad Thompson Company	www.bradtco.com Paul Sicurezza pauls@bradtco.com 360-635-7005	*Electricity Only* Bubbling Fluidized Bed/close-coupled or Reciprocating Grate Stoker. Either can be set up to produce bio-char.	Electricity (8-9)	Urban wood, Ag wood, and Forest wood. Have ongoing and proposed projects using agriculture waste.
Char Technologies	www.Chartechnologies.com Andrew Friedenthal afriedenthal@chartechnologies.c2om	High Temperature Pyrolysis & WGS/Methanation to produce Renewable Natural Gas (RNG) and Biochar	TRL of 8-9. Will have TRL 9 project in Europe by end of summer	Experience with urban wood, Agriculture wood, and forest wood. At Kirkland Lake, 72K tons per year of wood waste into RNG; at St. Felicien, 36K tons per year of wood waste into Syngas & Biochar; at Obispo Hitachi Zosen Inova, 18K tons per year of digestate into Green Hydrogen & Biochar.

Table 3. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[14]	Experience with Woody Biomass/Project Locations
Earthcare	www.earthcare.com Mike McGolden mikemcgolden@gmail.com	Earthcare uses gasification to produce heat, steam, and electricity as well as biochar.	TRL: 7-8	Unknown, but technology being considered by Town of Mammoth Lakes to use forest biomass and possibly other organic wastes. Technology is being used at facilities in Russia, and Earthcare systems are reportedly under construction in Pennsylvania.
Engemann Energy	www.engemanenergy.com Andrew Grant agrant@biomasspc.com 330-607-4648	Direct combustion, steam cycle power plant. Technology uses commercially available components.	TRL: 9	Numerous facilities in South America. Currently about to begin construction of 5 MW facility in Northern California.
EQTEC	www.Eqtec.com Jeffery Vander Linden jvanderlinden@eqtec.com	Gasification of biomass to create hydrogen, biochar, Renewable Natural Gas(RNG), Heat and Electricity.	TRL: 8	50,000 ton/year plant in Spain operating 7,500-8,000 hours per year since 2010. Produces 5.9 Mw electricity and heat. Plant in North Fork CA producing 2 Mw electricity and heat using forest wood. Operational in 2002. Numerous plants in Europe.

Table 3. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[14]	Experience with Woody Biomass/Project Locations
Sierra Energy	www.sierraenergy.com Michael Kleist mkleist@ sierraenergy.com	*Electricity* Current modular design of 1 MW units. Conversion is about 1 BDT per MW. *Biofuels* Can produce diesel as liquid fuel, and hydrogen as gaseous fuel. Sierra Energy reportedly can produce hydrogen as gaseous fuel, creating about 50 kg of hydrogen per BDT.	TRL: 5 to 7. Demonstration plant constructed and undergoing commissioning, producing both electricity and biofuels	Yes, with urban, agricultural, and forest wood. 25 tons a day demonstration facility currently located in Central CA. Construction and demonstration funded in part by CA Energy Commission, and U.S. Department of Defense
Wellons	www.wellons.com Rob Broberg Rob.Broberg@wellons.com	*Electricity and Process Steam* Direct burn with a conversion yield of 0.8 BDT to 1 BDT per MW. System efficiency of about 50% for straight condensing system. Much higher efficiency if waste heat is recovered and utilized.	TRL for electricity: 9	Yes, with urban, agricultural, and forest wood. 350 energy systems around the world operational. Currently one system under construction and eight systems proposed each with a high probability of success.

Table 3. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[14]	Experience with Woody Biomass/Project Locations
West Biofuels	www.westbiofuels.com Matt Summers matt.summers@westbiofuels.com	*Electricity* Direct combustion process with Organic Rankine Cycle engine/genset used to make electricity from 500 kw to 5 MW, 1.25 BDT per MW	TRL for electricity: 7 to 8. Demonstration unit at West Biofuels research and development facility in Woodland, CA	Yes, with urban, agricultural, and forest wood. Currently developing 3 MW electricity project in Northern CA using forest sourced wood. Partially funded by the CA Energy Commission ($5MM). Also developing 3 MW facility using rice hulls in Northern CA. For biofuels, just completed a CA Energy Commission (CEC) funded ($1MM) R&D mixed alcohol synthesis project, CEC funded ($1MM) RNG R&D project, and are actively working on a bio-oil to jet fuel project with NREL ($3M CEC funded)
West Biofuels Direct Burn - Electricity	www.westbiofuels.com Matt Summers matt.summers@westbiofuels.com	*Electricity-Direct Burn* Uses a direct combustion thermal oil heater which drives an Organic Rankine Cycle engine/genset.	TRL 8 – 9 for electricity. Off the shelf technology primarily used.	Several similar systems operating world-wide. West Biofuels is operating a 3 MW unit in California, and developing additional project sites.

Table 4. Cost Estimates

Company	Estimated Cost of Production[15]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
Air Burners	No production of electricity. Front loader needed for loading the system and water tank truck (or trailer) need for fire escape prevention/suppression	Controlled combustion unit – no electricity production $250K to $300K.	Assume 3 to 5 % of total capital per year.	Can be used to make biochar. Approximately 10% of weight of woody biomass throughput.
Aries Clean Energy	Dependent on cost of feedstock and tipping fee received. At $50 BDT for feedstock, this could be as high as $0.17 kWh. Using 20% urban wood waste (maximum for a Category 3 BioMAT) could lower that to $0.16 kWh	$6 M to $7 M per MW.	3.8 % of capital cost on an annual basis.	Biochar production is ~10% of feedstock. Expected price is $200 to $300/ton.

[15] As stated by many of the respondents, there are many variables associated with the capital costs and operations and maintenance costs of a facility. With the exceptions of a few outliers, TSS would consider all of the reported information to be functionally the same from a technology evaluation perspective and generally aligning with established industry rules of thumb. TSS would not recommend using Table 2 information about estimated cost of production, capital cost estimate, or operations and maintenance as a final means to differentiate technologies

Table 4. Cost Estimates

Company	Estimated Cost of Production[15]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
Bio-Gas Energy (gasification)	Size dependent	Would not state. Project dependent.	2.0 % of capital cost on an annual basis.	Not stated. However, gasification usually leads to some amount of biochar production for byproduct sale, unless the biochar is recycled back into the system for additional energy production.
Bio-Gas Energy (pyrolysis)	Size dependent	Would not state. Project dependent.	2.0 % of capital cost on an annual basis.	Biochar production – amount not yet vetted. Technology vendor claims expected price is $1,000/ton
Brad Thompson Company	Depends heavily on fuel and interest costs, if fuel cost is $0 then electricity cost is $0.08 to $0.12 per kWh. If fuel cost is $50 per BDT, then electricity cost $0.13 to $0.17 per kWh.	$650-$700 per BDT biomass fuel, but depends on initial biomass moisture and type and condition of fuel.	$0.04/kWh although equipment dependent. Annual two-week outage typical.	Biochar which is fuel and technology dependent. Also driven by economics and electrical efficiency requirements. Price is dependent on biochar quality and the target market.
CHAR Technologies	Not provided for electricity	$448 per BDT of biomass throughput.	Station load of 350 kW, 5% of capital cost (without labor cost).	Biochar, produced from 26 percent of BDT of biomass input.
Earthcare	Not Provided.	$15.5M for 1.25 MW of electricity and 5,000 tons of biochar annually	$820K annual for gasifier O&M. $250K annual for biomass dryer and ORC system.	Biochar and electricity. Biochar priced for sale at $500/ton.

Table 4. Cost Estimates

Company	Estimated Cost of Production[15]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
Engemann Energy	Not Provided.	$20M to $25M for 5 MW plant.	Not Provided.	Electricity and biochar (Amount produced – tailored to meet local demand).
EQTEC	Not Provided.	$7M to $8M per MW.	Not Provided.	High quality biochar.
Sierra Energy	Not Provided.	$5.5M to $6.5M per MW.	3.5% of capital cost on an annual basis.	Due to high operating temperature in the Sierra Energy gasifier, biochar is not produced as a byproduct.
Wellons	Estimated cost of electricity production is $.095 to $0.125/kWh at a fuel cost of $0 per BDT. . If fuel cost is $50 per BDT, then electricity cost $0.145 to $0.175 per kWh	Depending on scale and design of system will range from $3.5 M per MW to over $8M per MW.	Depending on system design, $0.012 to $0.03 per kWh.	None stated.
West Biofuels Gasification – Electricity	$0.11 to $0.12 per kWh. Both California projects to receive $0.197 (forest wood) and $0.189 (ag biomass) under California Bioenergy Market Adjusting Tariff.	$5M to $6M per MW.	4 to 5% of capital costs on an annual basis.	Biochar production is 15 to 30% (can be adjusted to maximize biochar production). Technology developer claims expected bulk price per ton is $250 to $500.

Table 4. Cost Estimates

Company	Estimated Cost of Production[15]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
West Biofuels Direct Burn - Electricity	\$0.11 to \$0.12 per kWh. Both California projects to receive \$0.197 (forest wood) and \$0.189 (ag biomass) under California Bioenergy Market Adjusting Tariff.	\$5M to \$6M per MW.	3 to 5% of capital costs on an annual basis.	Can be configured to produce biochar <10% of feedstock weight input.

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Table 5. Operating and Site Parameters

Company	Operating Requirements	System Efficiency & Parasitic Load	Site Requirements	Environmental Considerations	Interest in Project
Air Burners	1 shift needs 1 front loader operator to load system, and a spotter for potential fire escape and assistance in operations.	N/A. Diesel fuel needed for air curtain blower.	Level area with storage area available to storage woody biomass to be consumed by system. Should be a cleared area away from vegetation	BAAQMD allows for the use of air curtain burners under their Rule 5 – Open Burning requirements.	Firm is basically equipment builder and vendor only.
Aries Clean Energy	1 power plant operator per shift. 1 machinery operator (in fuel yard) per shift plus management and admin staff. Cost is location dependent.	Gasifier 80%. ORC – 25%. Overall efficiency is relatively low at 20%. Parasitic load – 10%.	Power plant – 1 acre. Feedstock and byproduct storage – 2 acres.	Emissions control by BACT. Some wastewater. Minimal water supply needed. No solid waste generated.	Design – Yes. Design and Build – Yes. Design, build, operate, own - Yes.
Bio-Gas Energy (gasification)	1 power plant operator per shift. 1 machinery operator (in fuel yard) per shift plus management and admin staff. Cost is location dependent.	Overall efficiency 30%. Parasitic load – 5%.	Not well defined. Assume 1 acre for power plant and 2 -acre for feedstock storage.	Engine emissions. No water needed or wastewater discharge. Ash is only residue.	Design – No. Design and Build – Yes. Design, build, operate, own – Yes.

Table 5. Operating and Site Parameters

Company	Operating Requirements	System Efficiency & Parasitic Load	Site Requirements	Environmental Considerations	Interest in Project
Bio-Gas Energy (pyrolysis)	1 operator per shift. 1 machinery operator (in fuel yard) per shift plus management and admin staff. Cost is location dependent.	N/A	Containerized system. Size for 200 ton a day unit not specified.	Low NOx burner. No water needed and no wastewater discharge. No solid waste.	Design – No. Design and Build – Yes. Design, build, operate, own – Yes.
Brad Thompson Company	3-5 Operators per shift. System operator; Mechanical and Electrical laborer.	12,000-16,000 Btu/kWh. Electricity parasitic load of 10%.	Power plant, 1-2 acres; Feedstock and feedstock storage area 2-3 acres.	Air emissions from exhaust stack and dust from the fuel yard. Water requirement depends on power cycle. Steam cycle with evaporative cooling – 75 GPM; Hybrid system – 35 GPM; dry system – 0 GPM.	Design – No. Design & build - Yes. Design, build, operate, and own – Yes.
Earthcare	1-2 operators	Not Provided	Power and biochar plant 1-2 acres and feedstock storage area 2 to 3 acres	Not provided, but given size of electricity production using pyrolysis, air emissions should be a significant impact.	Will develop, build, own and operate. And, enter into development partnerships.

Table 5. Operating and Site Parameters

Company	Operating Requirements	System Efficiency & Parasitic Load	Site Requirements	Environmental Considerations	Interest in Project
Engemann Energy	1-2 operators with automated remote support.	25-30% for 100% condensing steam turbine. 1,000-1,200 Kilowatt hours produced per BDT.	Not Provided.	Not provided. But probably air emissions from direct combustion and water requirements for condensing steam turbine.	Will develop, build, own and operate. (tax credits can be used by Engemann partners).
EQTEC	2 to 3 staff per day/evening shifts. 2 staff per night shift.	Not provided.	Power plant 1 to 2 acres, plus feedstock storage (2 to 5 acres depending on location).	Not provided, but given size of electricity production using gasification, air emissions should be a significant impact.	Will develop, build, own and operate. And, enter into development partnerships.
Sierra Energy	2 operators per shift. 1 machinery operator (in fuel yard) per shift, plus management and admin staff.	Gasifier 80%. ORC – 25% Overall efficiency is 20%. Parasitic load – 7.5%.	Station – 1 acre for 3 to 5 MW. Feedstock storage dependent on forest conditions – assume 1 acre per MW.	Engine and flare emissions to be controlled by BACT. No water supply needed and minimal wastewater discharge. No solid waste generated	Design – No. Design and Build – Yes. Design, build, operate, own – Possible.
Wellons	Personnel needed dependent on size of facility. Minimum number is 2 operators per shift, with 1 machinery.	Not provided.	Up to 20 acres for system sized at 20 MW (includes feedstock storage area).	Direct combustion unit will need NOx and particulate matter Best Available Control Technology.	Yes.

Table 5. Operating and Site Parameters

Company	Operating Requirements	System Efficiency & Parasitic Load	Site Requirements	Environmental Considerations	Interest in Project
West Biofuels Gasification – Electricity	2 operators per shift. 1 machinery operator (in fuel yard) per shift, plus management and admin staff.	Gasifier 70-80% (depends on desired biochar production) ORC – 25%. Overall efficiency is 16-20%. Parasitic load – 10%.	Station – 0.5 to 1 acre. Feedstock storage dependent on forest conditions – assume up to 3 acres for 2.5 MW plant.	System uses gasification syngas in oil heater, and an emergency flare. No water needed and no wastewater discharge. No solid waste.	Design – Yes. Design and Build – Yes. Design, build, operate, own – No.
West Biofuels Direct Burn - Electricity	2 operators per shift. 1 machinery operator (in fuel yard) per shift, plus management and admin staff.	Direct combustion unit 70%. ORC – 25%. Overall efficiency – 15 – 20%. Parasitic load – 10 – 12%.	Station – 0.5 to 1 acre. Feedstock storage dependent on forest conditions – assume up to 3 acres for 2.5 MW plant.	Direct combustion emissions controlled by Selective Non-Catalytic Reduction (for NOx). PM control via multiclones and bag house. Can meet ODEQ air emissions criteria.	Design – Yes. Design and Build – Yes. Design, build, operate, own – No.

CONCLUSION AND RECOMMENDATION

There are numerous short and medium-term solutions for the waste wood that will be utilized in the Mammoth area due to the significant increase in pace and scale of wildfire fuels reduction activities, particularly by the ESRRCP. There is up to 30,000 BDT of forest biomass to be utilized from various areas surrounding the Town of Mammoth Lakes. The fuels treatment areas have environmental, access, and topographic constraints, in addition to economic constraints inherent to the Mammoth region of being relatively remote. Thus, one single solution did not emerge from this analysis due these various constraints. The evaluation of short and medium-term utilization solutions above demonstrate that more than one type of utilization will be needed. The decision tree presented below is more of a decision guidance tree, spelling out the nine utilization methods and techniques that could be employed in the Mammoth region. In the decision guidance tree, the is identification of what type of treatment areas and felled/thinned forest materials from that area would be more suitable for the identified technology (to the right of the Yes boxes). This can be used to potentially compile a combination of technologies and utilization methods for the short- and medium term regarding the various forest treatments planned for next few years in the region.

When addressing the short- and medium utilization (and disposal) options, it must be kept in mind that the longer- term goal is a bioenergy system, if one can be built and operated economically in the Mammoth Region, which the potential exists. Two primary metrics to be met for that option are long term, and sustainable, availability of forest-sourced feedstock, i.e., 20 years, and at a cost that allows financial feasibility. Plus, only the BioMAT program, as discussed above, can give the necessary sales price for the electricity produced (nearly $0.20 per kilowatt hour). However, the BioMAT program also has constraints in that only a 2.5 MW biomass to electricity facility can obtain a power purchase agreement in the Mammoth region[16]. The upside is that there appears to be just enough woody biomass feedstock to be produced annually for the next 15 to 20 years in current ESCCRP and others (i.e., federal land management agencies, and large land owners such as LADWP) forest treatment programs. And, a 2.5 MW facility could be large enough to meet financial feasibility.

Numerous longer-term bioenergy solutions were evaluated in Tables 3, 4, and 5 above. Since electricity appears to be the principal product that could be sold to support a bioenergy facility, the technologies that could be sized to 2.5 MW and be economically feasible include:

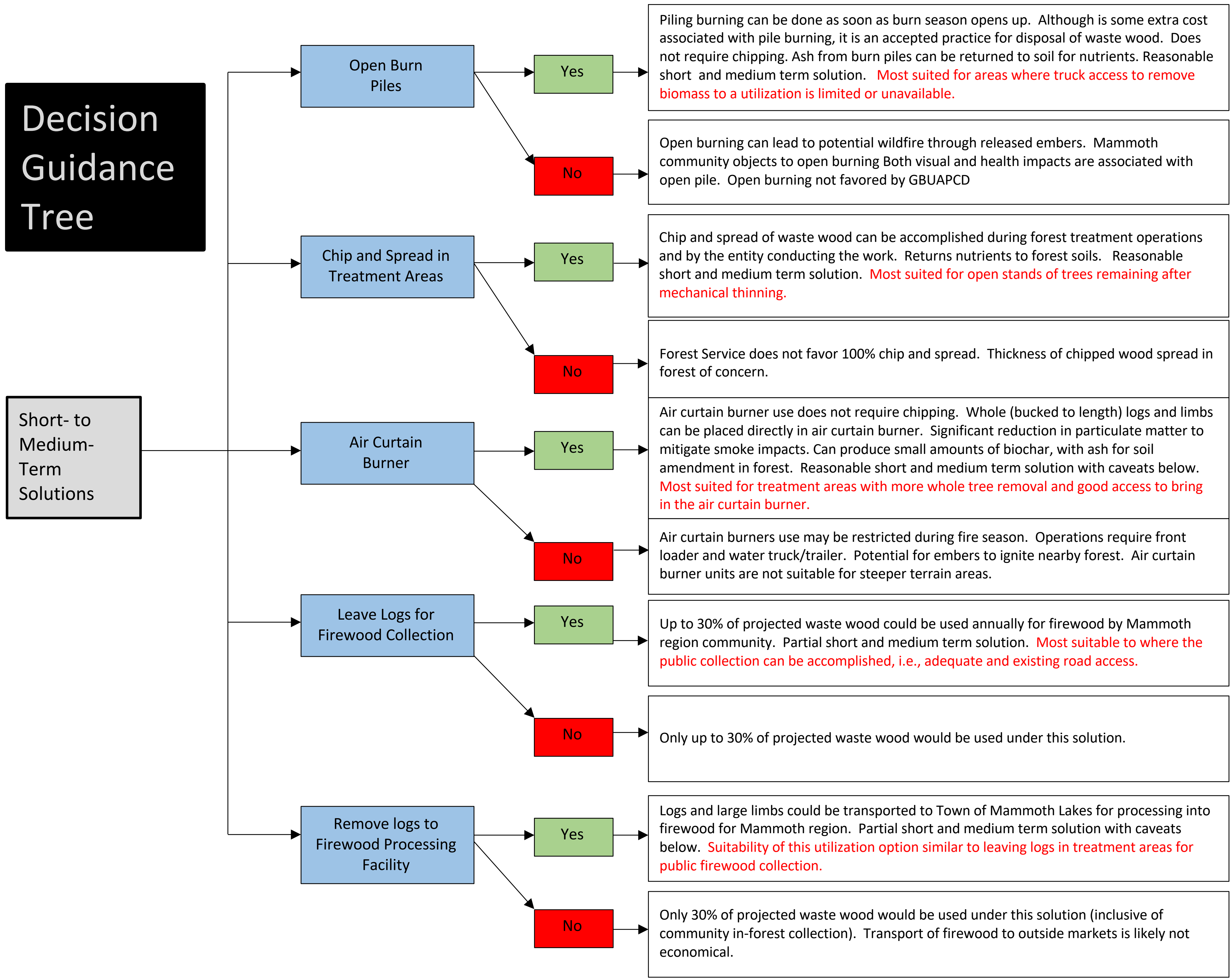
- Aries Clean Energy
- Engemann

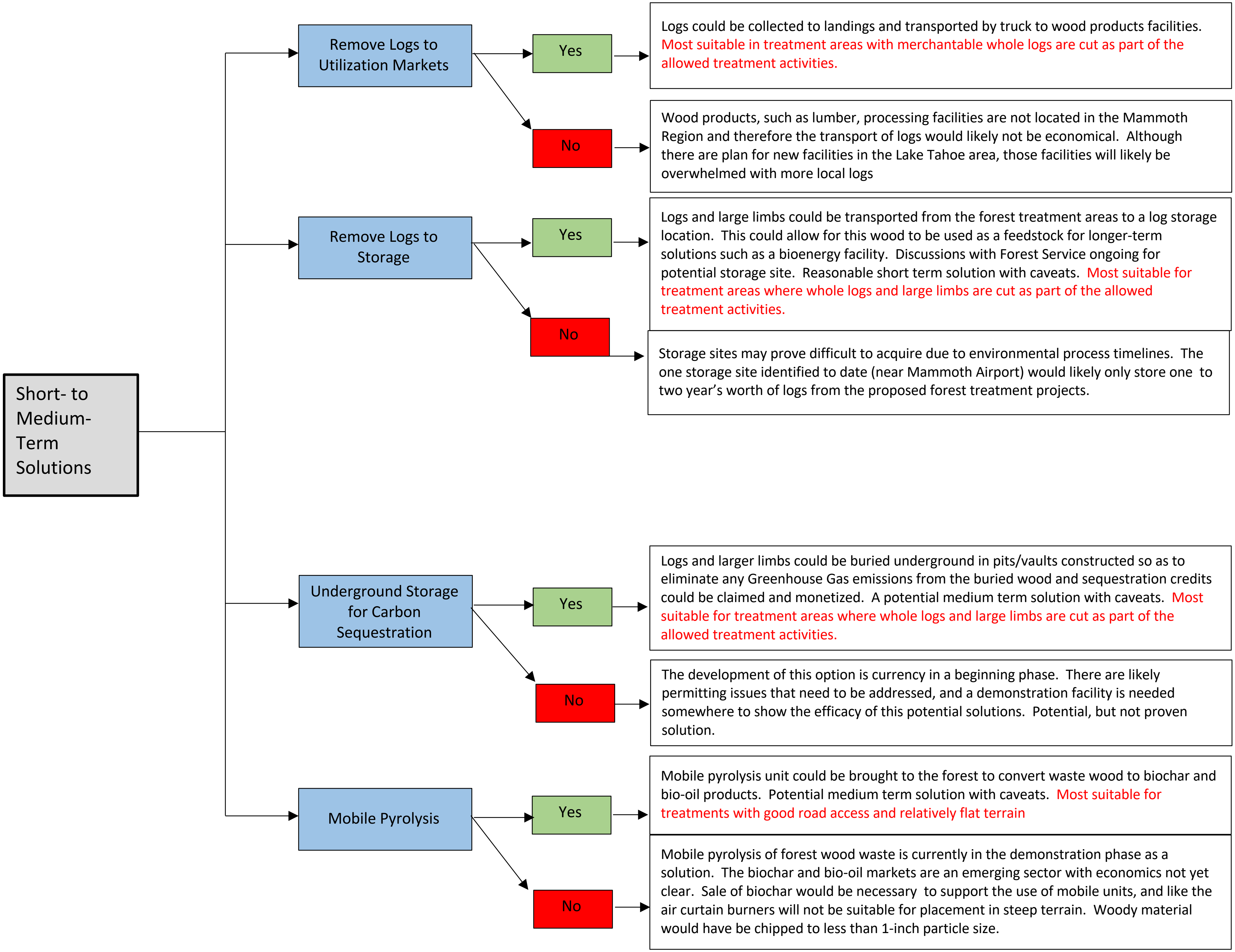
[16] The California Public Utilities Commission only allocated 2.5 MW of forest-sourced biomass to electricity to Southern California Edison which they must buy.

- EQTEC
- West Biofuels

All four of these companies are currently developing, constructing, or operating 2 to 3 MW power plants in California (in PG&E territory) which have received a BioMAT power purchase agreement. All four are also interested in the possibility of developing a BioMAT facility in the Mammoth region. It is recommended to continue dialogue with one or more of these companies on the concept of BioMAT facility in the Mammoth Region.

DECISION GUIDANCE TREE


Decision Guidance Tree
Short- to Medium-Term Solutions
Open Burn Piles
Yes
Piling burning can be done as soon as burn season opens up. Although is some extra cost associated with pile burning, it is an accepted practice for disposal of waste wood. Does not require chipping. Ash from burn piles can be returned to soil for nutrients. Reasonable short and medium term solution. Most suited for areas where truck access to remove biomass to a utilization is limited or unavailable.
No
Open burning can lead to potential wildfire through released embers. Mammoth community objects to open burning Both visual and health impacts are associated with open pile. Open burning not favored by GBUAPCD
Chip and Spread in Treatment Areas
Yes
Chip and spread of waste wood can be accomplished during forest treatment operations and by the entity conducting the work. Returns nutrients to forest soils. Reasonable short and medium term solution. Most suited for open stands of trees remaining after mechanical thinning.
No
Forest Service does not favor 100% chip and spread. Thickness of chipped wood spread in forest of concern.
Air Curtain Burner
Yes
Air curtain burner use does not require chipping. Whole (bucked to length) logs and limbs can be placed directly in air curtain burner. Significant reduction in particulate matter to mitigate smoke impacts. Can produce small amounts of biochar, with ash for soil amendment in forest. Reasonable short and medium term solution with caveats below. Most suited for treatment areas with more whole tree removal and good access to bring in the air curtain burner.
No
Air curtain burners use may be restricted during fire season. Operations require front loader and water truck/trailer. Potential for embers to ignite nearby forest. Air curtain burner units are not suitable for steeper terrain areas.
Leave Logs for Firewood Collection
Yes
Up to 30% of projected waste wood could be used annually for firewood by Mammoth region community. Partial short and medium term solution. Most suitable to where the public collection can be accomplished, i.e., adequate and existing road access.
No
Only up to 30% of projected waste wood would be used under this solution.
Remove logs to Firewood Processing Facility
Yes
Logs and large limbs could be transported to Town of Mammoth Lakes for processing into firewood for Mammoth region. Partial short and medium term solution with caveats below. Suitability of this utilization option similar to leaving logs in treatment areas for public firewood collection.
No
Only 30% of projected waste wood would be used under this solution (inclusive of community in-forest collection). Transport of firewood to outside markets is likely not economical.


Short- to Medium-Term Solutions
Remove Logs to Utilization Markets
Yes
Logs could be collected to landings and transported by truck to wood products facilities. Most suitable in treatment areas with merchantable whole logs are cut as part of the allowed treatment activities.
No
Wood products, such as lumber, processing facilities are not located in the Mammoth Region and therefore the transport of logs would likely not be economical. Although there are plan for new facilities in the Lake Tahoe area, those facilities will likely be overwhelmed with more local logs
Remove Logs to Storage
Yes
Logs and large limbs could be transported from the forest treatment areas to a log storage location. This could allow for this wood to be used as a feedstock for longer-term solutions such as a bioenergy facility. Discussions with Forest Service ongoing for potential storage site. Reasonable short term solution with caveats. Most suitable for treatment areas where whole logs and large limbs are cut as part of the allowed treatment activities.
No
Storage sites may prove difficult to acquire due to environmental process timelines. The one storage site identified to date (near Mammoth Airport) would likely only store one to two year's worth of logs from the proposed forest treatment projects.
Underground Storage for Carbon Sequestration
Yes
Logs and larger limbs could be buried underground in pits/vaults constructed so as to eliminate any Greenhouse Gas emissions from the buried wood and sequestration credits could be claimed and monetized. A potential medium term solution with caveats. Most suitable for treatment areas where whole logs and large limbs are cut as part of the allowed treatment activities.
No
The development of this option is currency in a beginning phase. There are likely permitting issues that need to be addressed, and a demonstration facility is needed somewhere to show the efficacy of this potential solutions. Potential, but not proven solution.
Mobile Pyrolysis
Yes
Mobile pyrolysis unit could be brought to the forest to convert waste wood to biochar and bio-oil products. Potential medium term solution with caveats. Most suitable for treatments with good road access and relatively flat terrain
No
Mobile pyrolysis of forest wood waste is currently in the demonstration phase as a solution. The biochar and bio-oil markets are an emerging sector with economics not yet clear. Sale of biochar would be necessary to support the use of mobile units, and like the air curtain burners will not be suitable for placement in steep terrain. Woody material would have be chipped to less than 1-inch particle size.

Appendix A
Technology Readiness Levels

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected mission conditions.	The technology is in its final form and operated under the full range of operating mission conditions. Examples include using the actual system with the full range of wastes in hot operations.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An Operational Readiness Review (ORR) has been successfully completed prior to the start of hot testing.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning[1]. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering scale prototypical system with a range of simulants.[1] Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.
Technology Development	**TRL 5**	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants[1] and actual waste[2] . Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small-scale tests on actual waste[2]. Supporting information includes theresults of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants.[1] Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
Basic Technology Research	**TRL 2**	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
	TRL 1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.