Bioenergy Solutions for Forest Fuels Reduction Activities for the Eastern Sierra

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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 TOML is located within the boundaries of the Inyo National Forest (INF), which is the most visited National Forest in California, with nearly four million visitors annually[1]. 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 wildfire occur in the area under unfavorable conditions. The region is now accelerating the pace and extent of wildfire reduction activities to align with new State Wildfire Task Force goals of increasing pace and scale of forest restoration across California to reduce, and hopefully eliminate potential adverse impacts to rural Sierra Nevada communities.

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 conditions of the Mammoth Region forests in many areas.

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

[1] "Interesting Inyo Facts: https://www.fs.usda.gov/detail/inyo/learning/history-culture/?cid=fsbdev3_003745#:~:text=With%20nearly%204%20million%20visits,California%2C%20America's%20most%20populous%20state

This report complements three other study reports concurrently prepared by TSS Consultants (TSS) – 1) "*Biomass Feedstock Supply Availability and Cost Analysis for the Mammoth Lakes Region*," (prepared for Cal Trout, October 2021); 2) "June Mountain Fuels Hazardous Forest Fuels Reduction Utilization and Removal Options" (prepared for Cal Trout, June 2022), and; 3) "Biomass Utilization Solutions for Forest Fuels Reduction Activities for the Eastern Sierra" (prepared for Cal Trout, September 2022). The June Mountain 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 second study 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 was prepared for site-specific biomass processing needs using the study analyses to determine the optimal approaches to achieve the best solution.

FEASIBILITY STUDY OBJECTIVES

This study incorporates technology evaluation, and preliminary siting review, for longer-term woody biomass utilization systems can be used for the planned Eastern Sierra fuels reduction projects below, and any additional projects promulgated in the future in the region.

- SCE Utility Line Improvements (unknown acreage) and utility "trimming" (~10,000 acres). Status: Ongoing vegetation management program. Most tree removal in Mammoth Region reported mostly complete. Area within 50 miles of Mammoth Lakes may still 1,000 trees removed for the foreseeable future[2];
- Eastern Sierra Climate and Communities Resilience Project (56,000 acres as of June 2022) Status: Planning and NEPA review stage – implementation anticipated 2025.

There will likely be additional funding to further increase the scale and pace of forest treatment in the Mammoth Region.

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

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 of the 56,000 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 Region, that would be most likely be electricity for export to the regional electrical distribution/transmission grid.

Figure 2. The ESCCRP Area

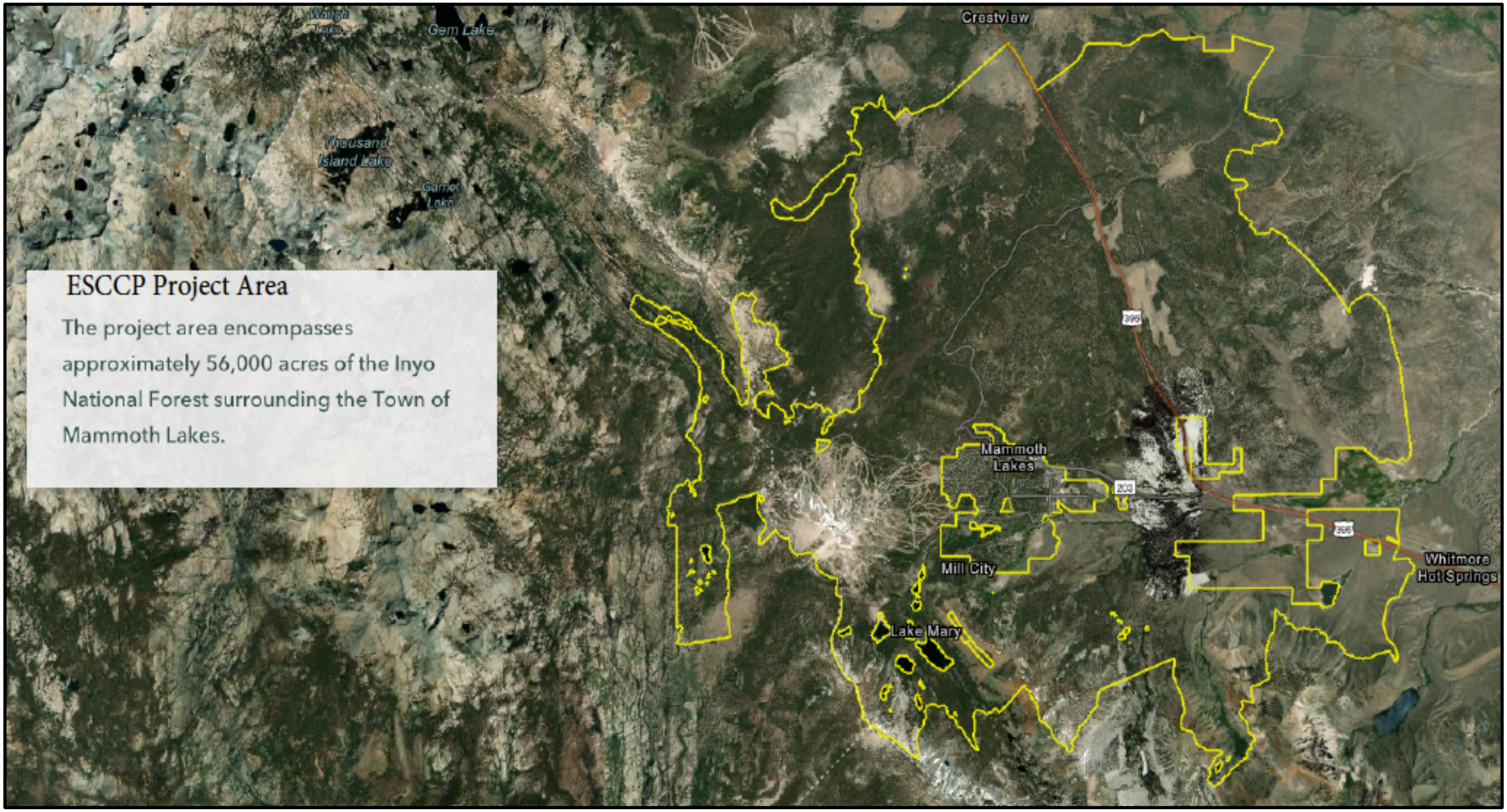
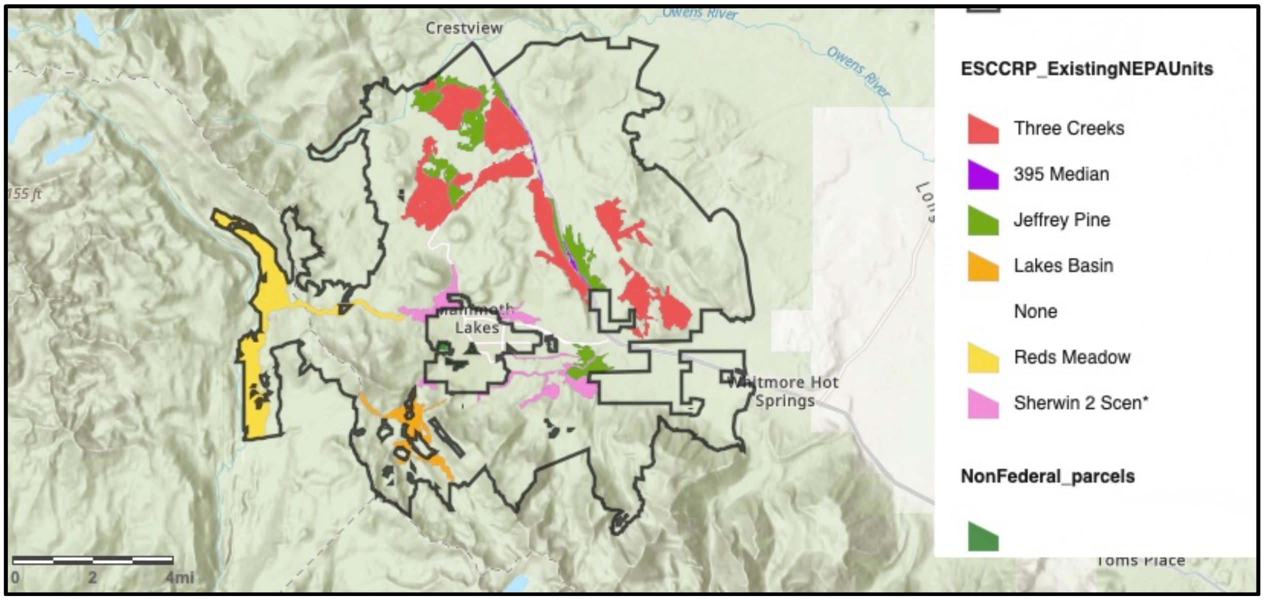


Figure 3. On-Going and Near-Term Forest Fuels Reduction Project Areas in the ESCCRP Footprint



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. TSS has also recently completed a study on the short- and medium-term solutions for utilization of biomass from ongoing and near-term forest treatment projects[3].

LONGER-TERM SOLUTIONS FOR BIOMASS UTILIZATION

Ultimately, for the long-term (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 Region 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-

[3] *"Biomass Utilization Solutions for Forest Fuels Reduction Activities for the Eastern Sierra", prepared* June 2022 by TSS Consultants for Cal Trout.

12-081[4] and 15-09-004[5] 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 Region, 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 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 Region.

Biomass to Electricity

Direct combustion

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 4 and 5 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 6 and 7 below).

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

Figure 4. Biomass Direct Combustion Schematic

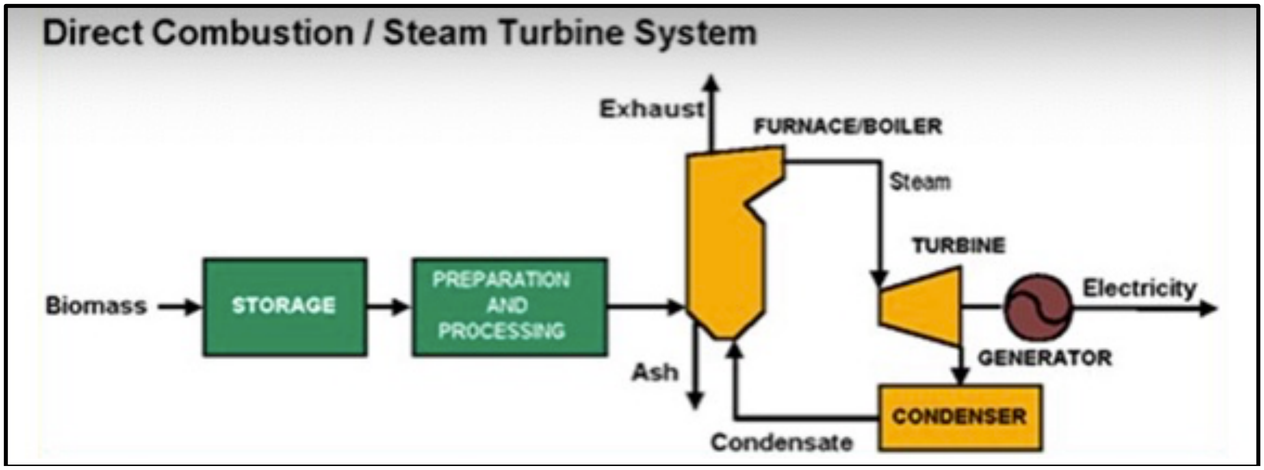

Figure 5. Biomass Direct Combustion Power Plant

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

Figure 6. Biomass Direct Combustion with ORC Electricity Generation Schematic

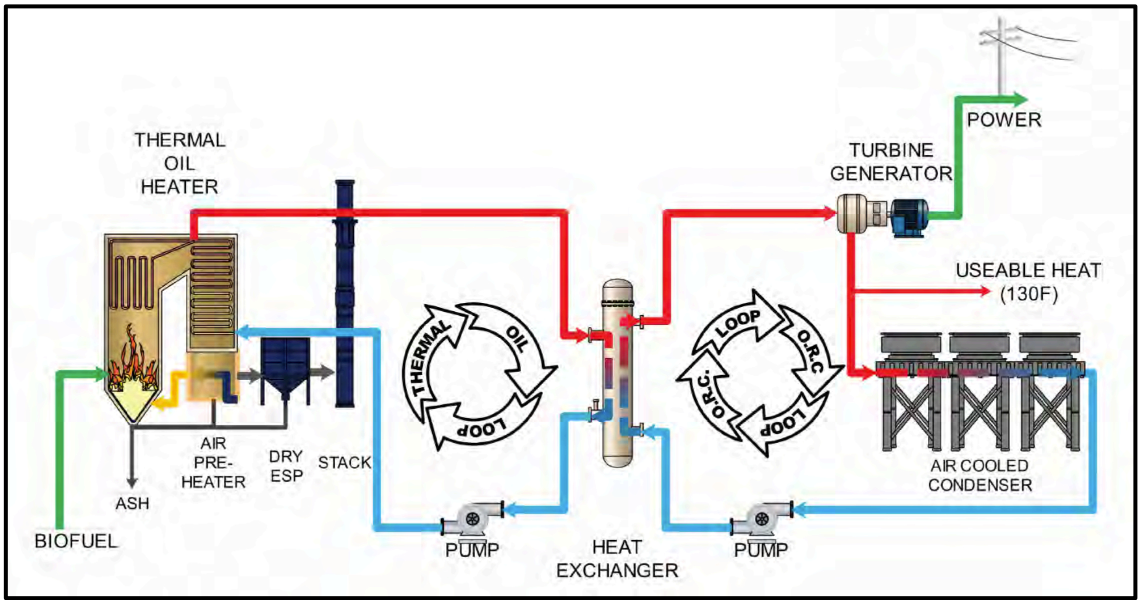

Figure 7. Biomass Direct Combustion with ORC Electricity Generation

Three megawatt biomass power plant in Williams, CA

Biomass electric power systems typically use one dry ton per megawatt-hour of electricity production, or approximately 8,000 BDT annually to produce one megawatt annually[6]. However, this approximation is only typical of woody biomass combustion steam turbine systems but is useful as an indicative estimate of fuel use and storage requirements. The actual amount per megawatt-year 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, 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

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.

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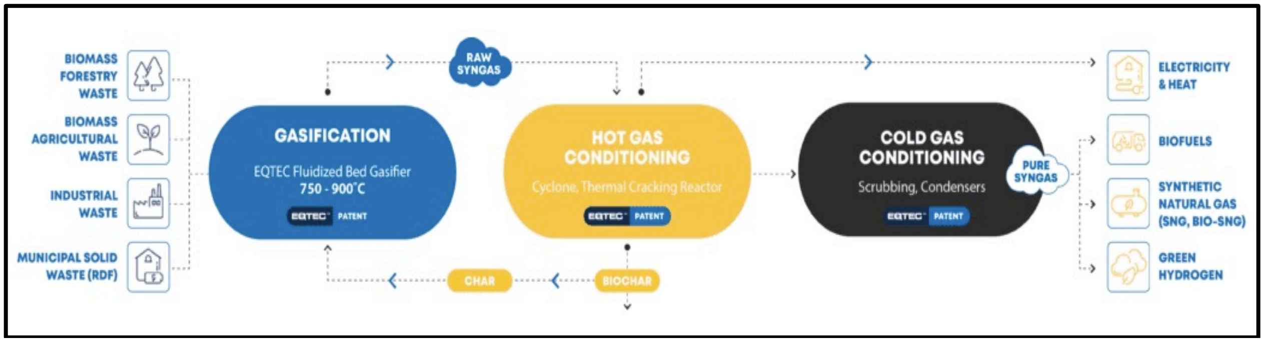
[6] One megawatt annually means the same as a megawatt-year, which the measure of electric capacity from a one (1) MW source available in one year.

Figure 8. 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 9. 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

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 30,000 BDT, approximately 3,000 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. To be fiscally conservative, $150 to $250 per ton should be considered in any financial analysis.[7] With 3,000 tons of biochar, this could result in $450K to $750K per year in additional revenues. In addition, putting this on the carbon sequestration credits market could add up to currently an addition $300K to $450K.

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 feedstock supply availability analysis and 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.

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 (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).

[7] 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. Two companies were included that could produce wood fuel pellets.

- 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 (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 (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[8]. 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 17 direct combustion and gasification/pyrolysis technology vendors/developers, along with two pellet companies. TSS requested data and information on the attributes of their respective technologies as indicated in the bulleted list above. Twelve of those contacted supplied sufficient information and data 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 Region in 2021[9].

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

TSS has also considered the potential to store some biomass, principally in the form of logs, from near-term forest treatments in the region, for ultimate use in a future bioenergy system. In a previous report prepared for Cal Trout[10], TSS discussed the potential to store logs at an existing surface aggregate mining operation just north of the Mammoth Airport. It was calculated that at least one year supply of woody biomass (as logs from forest treatment activities) for a 2.5 MW bioenergy facility of woody biomass (as logs) could be stored at that site. Discussions with the U.S. Forest Service are ongoing regarding that site.

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

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[8] 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.

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

[10] *"Biomass Utilization Solutions for Forest Fuels Reduction Activities for the Eastern Sierra", prepared* June 2022 by TSS Consultants for Cal Trout.

contacted 17 bioenergy companies known to meet this TRL metric. Eleven 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.ariescleanenergy. Contact: Gary Darling, baraka.poulin@ariesenergy.com
- Biogas-Energy – www.biogas-energy.com. Contact: Brian Gannon, bgannon@biogas-energy.com
- Brad Thompson Company -www.bradco.com. Contact Paul Sicurezza, pauls@bradco.com
- Char Technologies – www.Chartechnologies.com. Contact: Andrew Friedenthal, afriedenthal@chartechnologies.com
- Earthcare - https://www.earthcarellc.com. Contact: Michael McGolden, mikemcgolden@gmail.com.
- Engemann Energy – 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@sierraengery.com
- Wellons – Wellons.com. Contact: Rob Broberg, Rob.Broberg@wellons.com
- West Biofuels – www.westbiofuels. Contact: Matt Summers, matt.summer@westbiofuels.com

Table 1. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[11]	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 Joseph Renergy Gary Darling	*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

[11] 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 1. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[11]	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	*Gasification*; Bubbling Fluidized Bed/close-coupled or Reciprocating Grate Stocker. Either can be set up to produce bio-char.	Electricity (8-9) Liquid/Gaseous fuels (7)	Urban wood, Ag wood, and Forest wood. Have ongoing and proposed projects using agriculture waste.
Char Technologies	www.Chartechnologies.com Andrew Friedenthal afriedenthal@chartechnologies.com	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 1. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[11]	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 1. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[11]	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 product yield of 1,000-1200 kwh per bone dry ton of biomass. 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 1. Biomass Utilization Technology Companies

Company	Website & Contact Information	Technology Product(s)	Technology Maturity[11]	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 2. Cost Estimates

Company	Estimated Cost of Production[12]	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.	$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.
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

[12] 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 2. Cost Estimates

Company	Estimated Cost of Production[12]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
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.	$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	Assuming no cost for feedstock, $4.42/MMBTUs	$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.
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.

Table 2. Cost Estimates

Company	Estimated Cost of Production[12]	Capital Cost Estimate	Operation and Maintenance	Marketable Byproduct(s)
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.
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 3. 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 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 3. 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 3. 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 3. 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.

Preliminary Recommendations for Bioenergy Systems

A small-scale bioenergy system is the declared longer-term goal for the Mammoth Region, if one can be built and operated economically in the Mammoth Region, which the potential appears to exist. The primary metrics to be met for bioenergy option are long term, and sustainable, availability of forest-sourced feedstock, i.e., 20 years, and at a cost that allows financial feasibility. Tables 4 and 5 contains this information as determined previously in the resource assessment report prepared by TSS[13].

Table 4. Feedstock Supply Potentially and Practically Available

	Timber Harvest Residuals (BDT/Yr)	Forest Fuels Reduction (BDT/Yr)	Forest Products Manufacturing Residuals (BDT/Yr)	Urban Wood (BDT/Yr)	Powerline Corridor Maintenance (BDT/Yr)	Totals (BDT/Yr)
Potentially Available	1,961	28,000	360	1,864	350	32,535
Practically Available	1,765	25,800	360	1,678	245	**29,848**

Table 5. Biomass Fuel Current Delivered Pricing by Fuel Type

Feedstock Type	Low Range ($/BDT)	High Range ($/BDT)	Average Delivered Price to Mammoth Lakes ($/BDT)
Timber Harvest Residuals	$50.00	$55.00	$52.50
Forest Fuels Reduction	$46.00	$56.00	**$51.00**
Forest Products Manufacturing Residuals	$10.00	$20.00	$15.00
Urban Wood	$10.00	$20.00	$15.00
Powerline Corridor Maintenance	$5.00	$10.00	$7.50

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[14]. 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

[13] . "*Biomass Feedstock Supply Availability and Cost Analysis for the Mammoth Lakes Region*," prepared October 2021 by TSS Consultants for Cal Trout.
[14] The California Public Utilities Commission only allocated 2.5 MW of forest-sourced biomass to electricity to Southern California Edison which they must buy.

such as LADWP) forest treatment programs. And, a 2.5 MW facility could be large enough to meet financial feasibility, even with the feedstock cost around $50+/-.

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
- EQTEC
- West Biofuels
- Earthcare

It should be noted here, that TSS did not numerically score and rank the above listed technologies. It was not the intent of this evaluation to pick a "winner", but rather to obtain a list of technologies/developers that have the potential, and experience, to build and operate an appropriate bioenergy system in the Mammoth Region.

The first four 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 very 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. The Aries Clean Energy and West Biofuels bioenergy facilities both generate their electricity via an Organic Rankine Cycle (ORC) system (which is preferred by the potential bioenergy facility host site – see review of sites section below). The other two technologies could be adapted to use ORC, instead of steam cycle (Engemann) and internal combustion engine generator system (EQTEC). These four technologies also meet the Technology Readiness Level of 8 (see Appendix A) as being fully commercialized bioenergy systems (with some modification for Engemann and EQTEC).

The fifth bullet above refers to the technology that the Town of Mammoth Lakes has been conducting feasibility work on to convert both woody biomass from the various forest treatment projects in the Mammoth Region and the organic component of the Town's municipal solid waste – both woody and non-woody organic waste. Collaboration with the Town should continue as the Earthcare system reportedly can convert non-woody organic waste to biochar and electricity, which has the potential so solve a more complex problem of municipal solid waste disposal given the looming closure of the current County landfill closure at Benton crossing.

There is also the potential that a woody biomass bioenergy facility could include a collocated anaerobic digestion system for non-woody organic wastes, such as food wastes and wastewater sludges from the local wastewater treatment plant. This could also supplement the electricity to be produced by the woody biomass power plant, and add value to the overall project. However, evaluation of potential anaerobic digestion systems for such a venture were not part of this bioenergy technology evaluation.

REVIEW OF SITES FOR BIOENERGY UTILIZATION

As a follow-up to the short-term biomass utilization in Mammoth Region, some type of long-term solution is called for as the forest fuels activities are expected to last 15 to 20 years. Long-term solutions are likely to be some type of bioenergy development that can be economically viable in the region. Bioenergy projects could be woody biomass to electricity, transportation fuels, and biochar, and can be a combination of technology. However, whatever the preferred solution is, in the short-term, a site must be selected and working with the land owner(s) must begin. To select a site, TSS conducted a high-level review of sites. These candidate sites were selected in discussion with various stakeholders in the Mammoth Region.

The candidates site selected were:

- Lee Vining Substation
- Pumice Valley Landfill and Transfer Station
- Rush Creek Powerhouse June Lake
- GC Forest Products, Mammoth Lakes Industrial Park
- Casa Diablo Substation
- Airport Industrial Park
- Tom's Place

Although Benton Crossing, site of another Mono County landfill was suggested as a candidate site it was removed from further consideration as this facility is about to undergo closure, with an engineered cap. This engineer cap will negate the ability to build any industrial structures on the closed landfill, as well as being not suitable for biomass storage.

Figure10 below shows the approximate location of these sites.

Figure 10. Candidate Sites for Long-Term Biomass Utilization

Lee Vining Substation

Located on the southern edge of Lee Vining, adjacent to intersection of U.S. Highway 395 and California Highway 120. Close to a perennial stream with very little flat land. High visibility site, located not far from Mono Lake viewshed. A recent housing development was unsuccessful in this immediate vicinity due to viewshed issues. It is also nearly 35 miles from the center of the ESCCRP projects area.

Figure 11. Lee Vining Substation Area

Pumice Valley Landfill and Transfer Station

Located on relatively remote 40-acre parcel approximately two miles east of U.S. 395 on Highway 120, Mono County manages a landfill and transfer station. Currently open one day/week the site has a commercial weigh scale and may be open full time once Benton Crossing Landfill closes.[15] This site is under long term lease from the Los Angeles Department of Water and Power (LADWP), who retains the water rights. This site has potential due its location and currently used as a landfill with available room for a bioenergy facility. However, it is not near an electrical substation and a significant (and expensive) distribution line for generated electricity would need to be installed. Plus, it is approximately 30 miles from the center of the ESCCRP projects area.

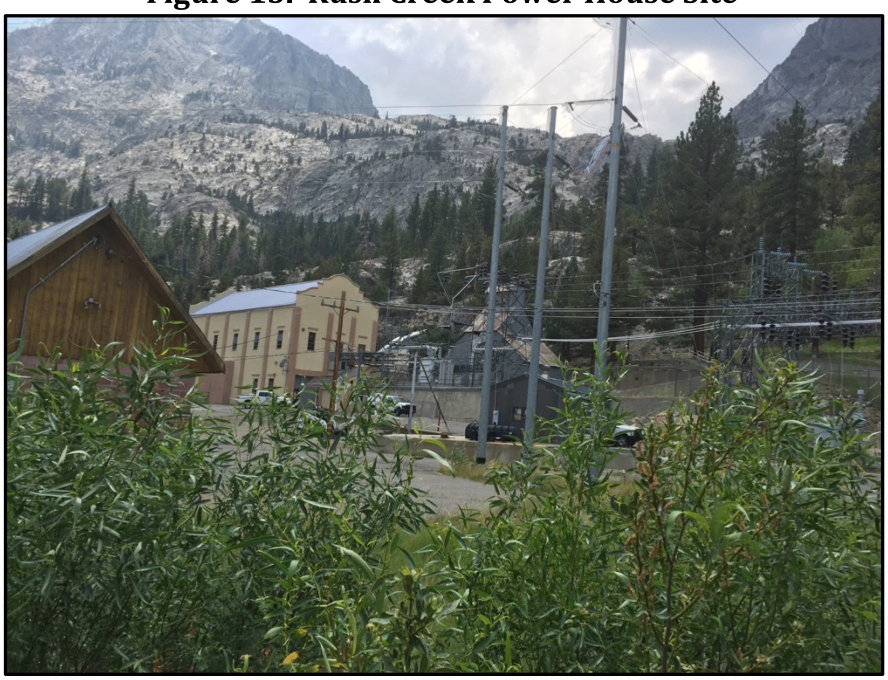
[15] Per discussions with Justin Nalder, Superintendent, Solid Waste Dept, Mono County.

Figure 12. Pumice Valley Facility Area

Rush Creek Power House

Located along the scenic June Lake Loop, this site is immediately adjacent to Rush Creek. The Loop Road serves a variety of resorts that appear to operate year-round (fishing in the summer, skiing in the winter). Several campgrounds (USFS and private) also along the Loop Road. Topography at this site is not conducive to a bioenergy facility with a chip/log storage area. Also, due to the high recreation use, this road system is not conducive to heavy duty truck traffic.

Figure 13. Rush Creek Power House Site



GC Products Mammoth Industrial Park

Located on approximately one acre within a heavily developed industrial park. GCFP operates a firewood processor onsite and stores firewood (packaged and in bulk) and logs. This site is extremely limited in available area, and was removed from further consideration for a bioenergy facility with chip and log storage.

Figure 14. GC Products Facility Yard

Casa Diablo Substation and ORMAT Geothermal Facility

The Casa Diablo Substation and ORMAT Geothermal Facility is located immediately northeast of the intersection of Highway 395 and State Route 203, near the center of the ESCCRP forest treatment sites. It is the site of 4 geothermal power plants owned and operated by ORMAT. As recently as the Summer of 2022, another 30 MW of geothermal-based electric power has come on line, with a now a current total of 60 MW at the site.

The facilities are on both Federal managed lands and private land under the control of ORMAT. It is reported that 2.5 acres may be available and suitable for a bioenergy facility[16]. This amount of land would allow for a bioenergy facility with some storage for chips and logs.

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[16] Personal Communication with Dan Holler, Town of Mammoth Lakes Manager, October 10, 2022.

Discussions with the geothermal facility operators also indicated that the substation could easily handle an additional 2.5 MW of electricity for export to the Southern California Edison grid[17].

Figure 15. SCE Substation at Casa Diablo

Airport Industrial Park

This is a designated industrial park located across from Mammoth Airport along 395, approximately 7 miles from the Town of Mammoth Lakes. All infrastructure is in place. Although there are numerous vacant parcels none are large enough to site a bioenergy facility with an adequate feedstock storage yard. In addition, a bioenergy facility would be highly visible from US 395, and that highway corridor is a designated California Scenic Highway.

[17] Personal Communication with Avi Lessner, ORMAT Casa Diablo, August 12, 2021.

Figure 16. Airport Industrial Park

Tom's Place Substation Area

Located about 13 miles south of Mammoth Lakes, just west of Hwy 395, at junction of Crowley Lake Road and Rock Creek Road. The substation is relatively small and located on Inyo National Forest managed. It is Adjacent to water treatment plant and Inyo NF Guard Station. Trucks may have challenges crossing Hwy 395 (there is no overpass). Similar to the Airport Industrial Park site, a bioenergy facility would be highly visible from US 395, and that highway corridor is a designated California Scenic Highway.

Figure 17. Tom's Place Substation

Preliminary Recommendation for Site Location

Using the metrics needed to site and operate a 2.5+/- MW of adequate land, relatively flat topography, access to nearby electrical substation, and considering potential visual impact to the region's important viewsheds, the Casa Diablo site is considered the best site currently available. Discussions have been held by TSS and the Town of Mammoth Lakes with ORMAT representatives and ORMAT has expressed an interest in hosting a small bioenergy facility on their site, and most likely on the private lands that encompass their overall site.

Figure 18 below shows the 4 principal parcels the ORMAT Casa Diablo geothermal power plant complex is located on, with Table 6 displaying the parcel owners.

Figure 18. Land Ownership at Casa Diablo Site

Table 6. Land Ownership at Casa Diablo Site

Parcel	**Assessor Parcel Number**	**Land Owner**
1	037-050-002-000	Magma Energy Incorporated
2	037-050-005-000	Magma Energy Incorporated
3	037-050-014-000	Inyo National Forest
4	037-050-015-000	Inyo National Forest

The aerial photo above is a few years old and does not display ORMAT's Casa Diablo IV 30 MW power plant that came online in Summer 2022. That facility encompasses a large portion of Parcel 3.

As mentioned above, ORMAT has expressed an interest in hosting a bioenergy facility on their property if project conditions were appropriate. One of those conditions expressed is that if electricity generation utilizes an Organic Rankine Cycle system that that ORC system should be one manufactured by ORMAT. ORMAT is one of the largest suppliers of small and medium ORC systems in the world with systems operating in over 30 countries. ORMAT is moving into the bioenergy sector as well, and would like to see their ORC system used for bioenergy development at Casa Diablo.

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 beensuccessfully 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 and actual waste. 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 experiment tal 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. Supporting information includes the results 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. 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 ordetailed 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 orpaper 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. SupportingInformation includes published research or other references that identify the principles that underlie the technology.