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Evaluation of Air Quality and Climate Change Impacts from Specialized Biomass Processing Technologies under the California Vegetation Treatment Program

Prepared for:

**Board of Forestry and
Fire Protection**

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1   INTRODUCTION

Proponents of vegetation treatment projects using the CEQA streamlining provisions of the California Vegetation Treatment Program (CalVTP) and Program Environmental Impact Report (Program EIR) are proposing one or more specialized technologies in combination with or wholly in place of pile burning to process portions of biomass created by the treatments. Most proposals to date focus on portable equipment that can be brought to a treatment area for set up and operation during vegetation treatment to reduce distance and cost of biomass transport to the processing site.

This paper evaluates the potential for specialized biomass processing technologies to reduce emissions of greenhouse gas (GHG) and criteria air pollutant emissions, compared to the conventional biomass processing method of pile burning. Pile burning is among the biomass disposal methods included in the CalVTP and covered in the Program EIR, which was certified in December 2019.

In the Program EIR, Mitigation Measure GHG-2 was identified to reduce significant impacts from emissions of GHGs during pile burning. Also, pile burning is noted in the Program EIR as one of the most substantial sources of criteria air pollutant emissions, including particulates and fine particulates in smoke, among the covered treatment activities, as discussed in the Program EIR under Impact AQ-1. The specialized technologies provide an opportunity to reduce criteria air pollutants, as well as GHGs.

The analysis in this technical paper provides substantial evidence for project proponents to demonstrate that the specialized technologies addressed herein may be used in the CalVTP process for project approvals, because new significant environmental impacts or substantially more severe significant impacts would not occur beyond effects already covered in the Program EIR. The analysis also concludes that the GHG, criteria pollutant, and smoke/odor emissions from biomass processing by pile burning can be reduced by use of the specialized technologies. The information herein may be used in PSAs or addenda to the Program EIR to inform the analysis of specialized biomass processing technologies.

2   SUMMARY OF IMPACTS

2.1   AIR QUALITY

The use of any of the specialized biomass processing technologies described herein would reduce criteria air pollutant emissions compared to pile burning. Emissions from diesel engines used in additional haul trucks or equipment required for biomass processing would be minimal and temporary. Related to air quality, the use of these technologies would be environmentally advantageous compared to pile burning.

2.2   GREENHOUSE GAS EMISSIONS

The use of specialized biomass processing technologies described herein would reduce GHG emissions compared to pile burning. Emissions from diesel engines used in additional haul trucks or equipment required for biomass processing would be minimal and temporary. The degree of net GHG benefits to using these technologies compared to pile burning relates, in large part, to the end use of processed byproducts, such as biofuels and biochar. For instance, biofuels can directly replace and offset GHG emissions from non-renewable fossil fuels used in treatment activities. Solid byproducts, such as biochar and ash, can be applied as soil amendments that keep carbon stored in the soil for extended periods, rather than emitted into the atmosphere as carbon dioxide (CO_2). The use of these technologies would be environmentally advantageous compared to pile burning with GHG-offsetting end uses of byproducts.

3   SUMMARY OF BIOMASS PROCESSING TECHNOLOGIES

3.1   DIRECT COMBUSTION – AIR CURTAIN BURNERS

Air curtain burners use direct combustion to process biomass. Combustion is an exothermic (heat-producing) reaction between oxygen and the hydrocarbon in biomass. The biomass is converted into heat, water, and CO_2. They are operated by depositing biomass in the firebox, an open top metal container, within which the biomass is set alight. The air curtain filter (i.e., fast-moving curtain of air) is drawn over the firebox while a blower circulates the air and smoke within the firebox, subjecting it to repeated cycles of burning in the flames. The blower creates a high temperature vortex inside the chamber to accelerate biomass combustion, more completely combust the material, and keep most pollutants from escaping the firebox into the atmosphere. The air curtain at the top of the firebox acts as a filter to reduce any particulate matter (PM) emissions from the resulting exhaust. This process is depicted in **Figure 1**; an example is shown in **Figure 2**.
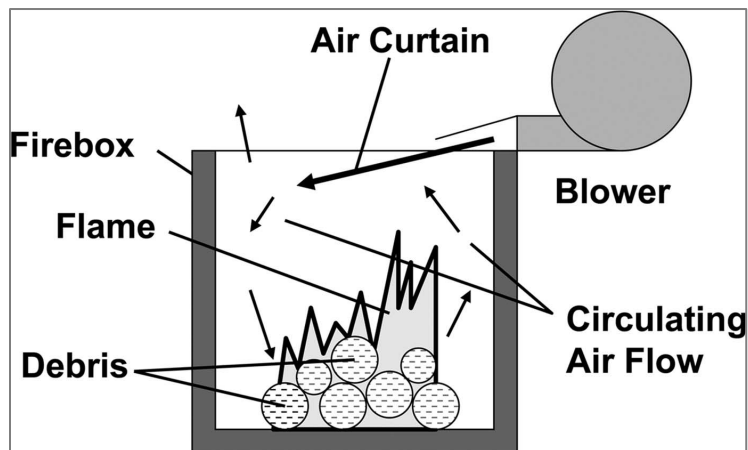
Source: Miller and Lemieux 2007

Figure 1   Schematic of air curtain destructor operation

Source: Air Burners 2022

Figure 2   Example of an Air Curtain Burner

3.2   PYROLYSIS/CARBONIZATION

Pyrolysis (or carbonization) can be performed in a variety of ways, from simple oxygen-depriving designs, such as an Oregon kiln, which can process up to several cubic yards at time, to modular and portable carbonation units, to more complex large-scale pyrolysis chamber systems in a fixed location that can process up hundreds of tons of biomass per day. Pyrolysis involves the conversion of biomass into hydrocarbon liquids, gases, or solids (or all three) in the absence of oxygen at temperatures ranging from (400–900 degrees C). Pyrolysis can be segmented into three process types: torrefaction, slow pyrolysis, and fast pyrolysis each with different temperatures, pressures, and reaction times.

Slow pyrolysis will produce gases and solid biochars while fast pyrolysis will produce liquids. Biochar is a charcoal-like material primarily consisting of carbon and ash and has been used as a soil amendment, increasing soil carbon content and health where applied. Biochar-amended soil retains carbon from the biomass for an extended period.

The product of fast pyrolysis, called bio-oil, is an energy-rich liquid recovered from condensable vapors and aerosols. Bio-oil consists of a mixture of oxygenated organic compounds including carbolic acids, alcohols, aldehydes, esters, saccharides, and other compounds. Pyrolysis can be a standalone process or a precursor process to gasification or other technologies where the gas or liquid product of pyrolysis is used as an intermediate feedstock in the production of more complex products downstream.

Pyrolysis can be performed in a variety of ways, from simple oxygen-depriving designs such as an Oregon kiln, which can process up to several cubic yards at time, to more complex large scale pyrolysis chamber systems processing up hundreds of tons of biomass per day. Oregon kilns are simply open top metal containers in the shape of an inverted truncated pyramid, which can often be transported by haul truck. Biomass is put into the Oregon kilns and either combusted at the top of the container or combusted as a whole with a loose metal cap covering the system. This results in a high-heat, low-oxygen environment for biomass underneath the flame curtain or cap at the top of the kiln, a pyrolysis method called flame carbonization. Without the need for chipping or transport of biomass, processing biomass in Oregon kilns is an economical onsite pyrolysis and biochar production method. These kilns come in various sizes from several cubic feet to up to 20 cubic yards. An example of an Oregon kiln is shown in **Figure 3**.

Source: Puettman et. al. 2020

Figure 3   Example of an Oregon Kiln

Torrefaction, a medium temperature pyrolysis method used in larger systems, is a more recent technique that has shown to produce a higher percentage of tars and carbonized wood products with high energy contents that can be used as fuel (e.g., pellets). For larger systems, biomass is heated in a controlled oxygen-free chamber using an external source of heat, such as external biomass combustion or even other fuel sources (e.g., natural gas, diesel, steam, solar). Larger systems can either be modular, portable, and located on-site in forest areas requiring some on-site ground preparation for short term activities,

processing up to 150 tons per day; or they can be located at stationary off-site industrial facilities where biomass would need to be delivered to those sites for processing (Taylor and Ashton 2019). Larger pyrolysis systems are shown in **Figure 4** and **Figure 5.**

Source: Taylor and Ashton 2019

Figure 4   Example of an In-Woods Modular Pyrolysis System
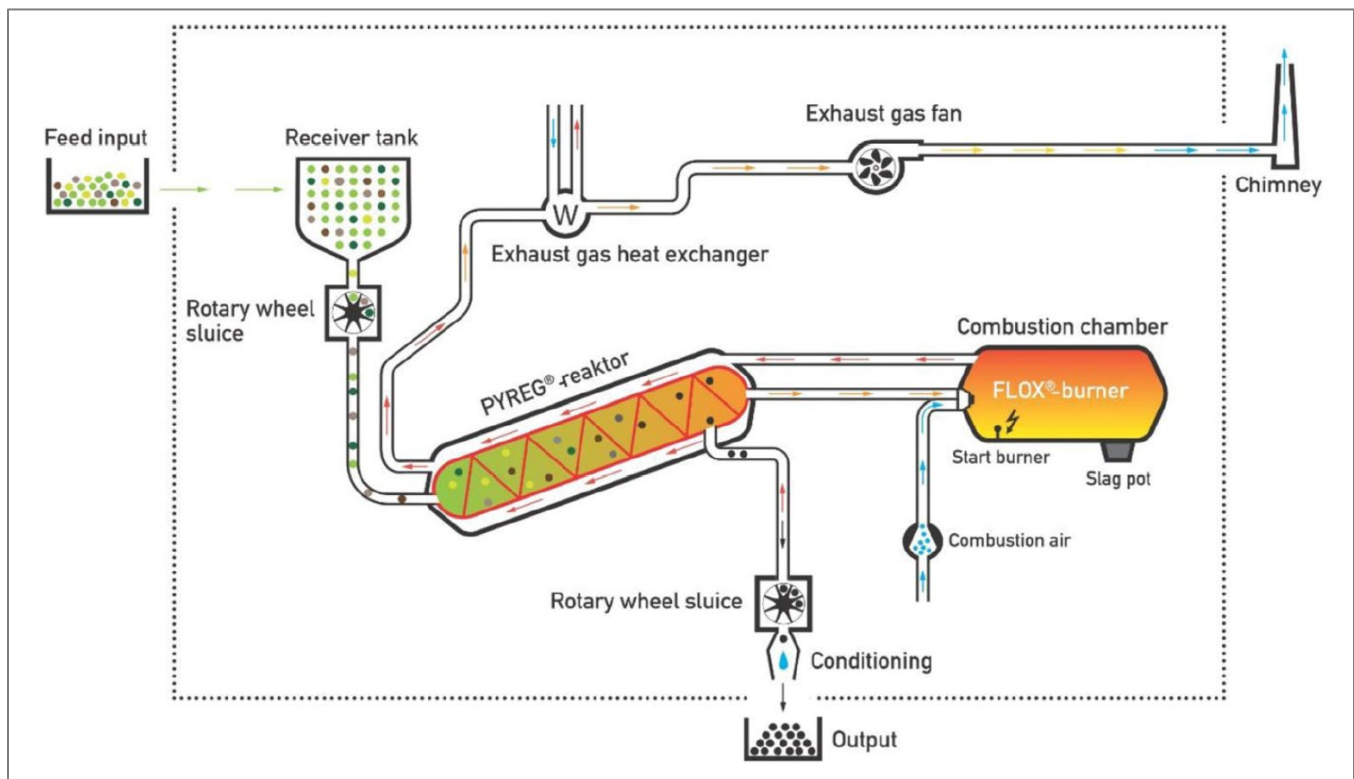
Source: Sormo et. al. 2020

Figure 5   Example of a Medium-Scale Waste Timber Pyrolysis Unit Process Flow Diagram

3.3   GASIFICATION

Gasification is defined as a high-temperature conversion of carbonaceous materials (biomass) into a combustible gas mixture under reducing conditions. Through gasification, a heterogeneous solid material (biomass) can be converted into gaseous fuels intermediate (producer gas and syngas) that can be used for heating, industrial processes, electricity generation, and liquid fuel production.

▶ **Producer gas** – a low heating value gas mixture of CO_2, H_2, CO, CH_4, N produced from gasification feedstocks in air.

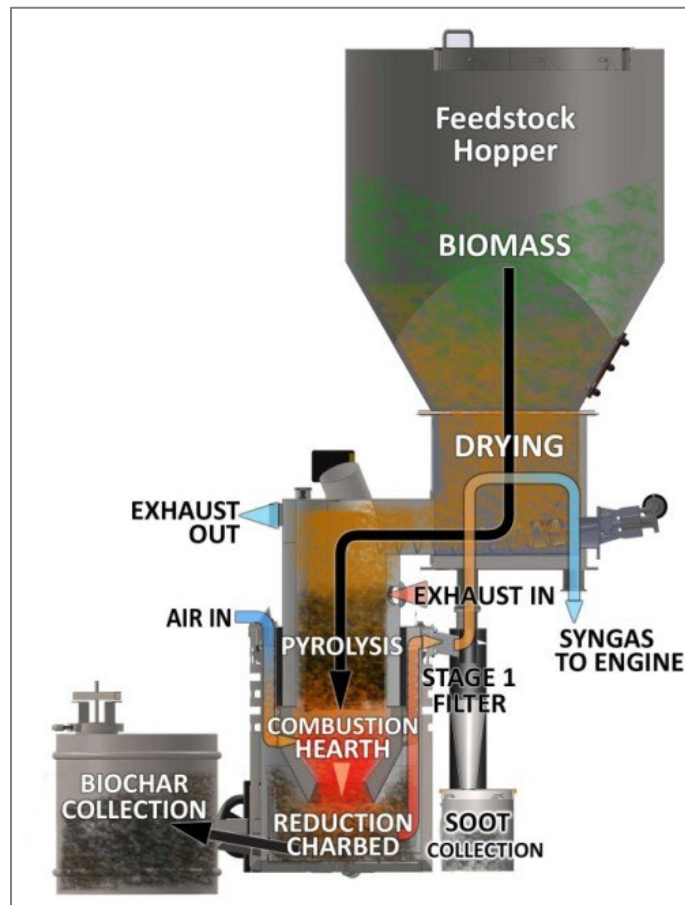▶ **Synthesis gas** (syngas) – a gas mixture of predominantly CO and H_2 produced from biomass feedstocks in oxygen and steam followed by gas separation to remove CO_2. This H_2 rich mixture was developed for the synthesis of fuels and chemicals.

As generally shown in the example process flow diagram in **Figure 6**, gasification of biomass has four key steps:

Source: Eco Energy International 2017

Figure 6   Example of a Gasifier Process Flow Diagram

▶ **Heating and Drying** – to reduce the moisture content from 10-50 percent to bone dry. The analysis of the energy to heat and dry the feedstock is balanced against the chemical makeup of the products produced that are affected by the moisture. Higher moisture will result in higher CO_2 and H_2O in the final mixture, while lower moisture results in higher CO, H_2, and CH_4.

▶ **Pyrolysis** – is the rapid thermal decomposition of biomass in the absence of oxygen. Starting at 300–500 degrees C, the process is accompanied by the release of volatiles, including producer water, which is a chemical compound produced from the reaction of the elements within the biomass, not the moisture, and permanent gases (CO, CO_2, H_2), which are gases that do not condense when cooling. Pyrolysis converts about 70-90 percent of biomass to vapors and gases, which is double the proportion converted in coal.

▶ **Gas Solid Reaction**s – after pyrolysis, chemical reactions continue to occur between char and the surrounding gas, typically when carbon and O2, CO_2, H_2O, and H_2 react to form CO, 2CO, H_2+CO, and CH_4.

▶ **Gas Phase Reactions** – the volatiles released in pyrolysis continue to react in gas phase reactions where CO reacts with H_2O to form H_2 + CO and CH_4 + H_2O.

The catalyst required for gasification typically consists of air, oxygen, steam, or a mixture of those three. The key benefits of using biomass as an energy source include the fact that the components, when released, do not constitute a net carbon contribution back into the atmosphere as well as the reduction on the dependence of non-renewable or imported fuel sources.

3.4   HYDROTHERMAL LIQUEFACTION

Hydrothermal liquefaction (HTL) is a relatively low-temperature (300–400 degrees C), high-pressure process that produces bio-oil from a biomass slurry in the presence of a catalyst and hydrogen. This technology essentially imitates and accelerates the natural production of fossil fuels, but instead of prehistoric biomass becoming subjected to high temperatures and pressures that are produced over millions of years, existing biomass can undergo a similar process in a controlled environment within minutes to hours. Wet or green biomass may be directly utilized without energy-intensive pretreatment (e.g., drying) and converted into a bio-oil and platform chemicals. Woody biomass, which may tend to be dryer than other sources (e.g., food waste, wastewater sludge), would require the addition of water, catalysts, and other additives to pretreat and prepare the biomass to be made into a slurry. The slurry is then compressed, heated in reactors, then separated to extract bio-crude oil and other products (e.g., wastewater, gases). Wastewater is often recycled back into the HTL process to increase the efficiency of bio-oil production from biomass inputs. **Figure 7** depicts the process flow diagram for a HTL unit processing woody biomass. (Pedersen et. al. 2016).
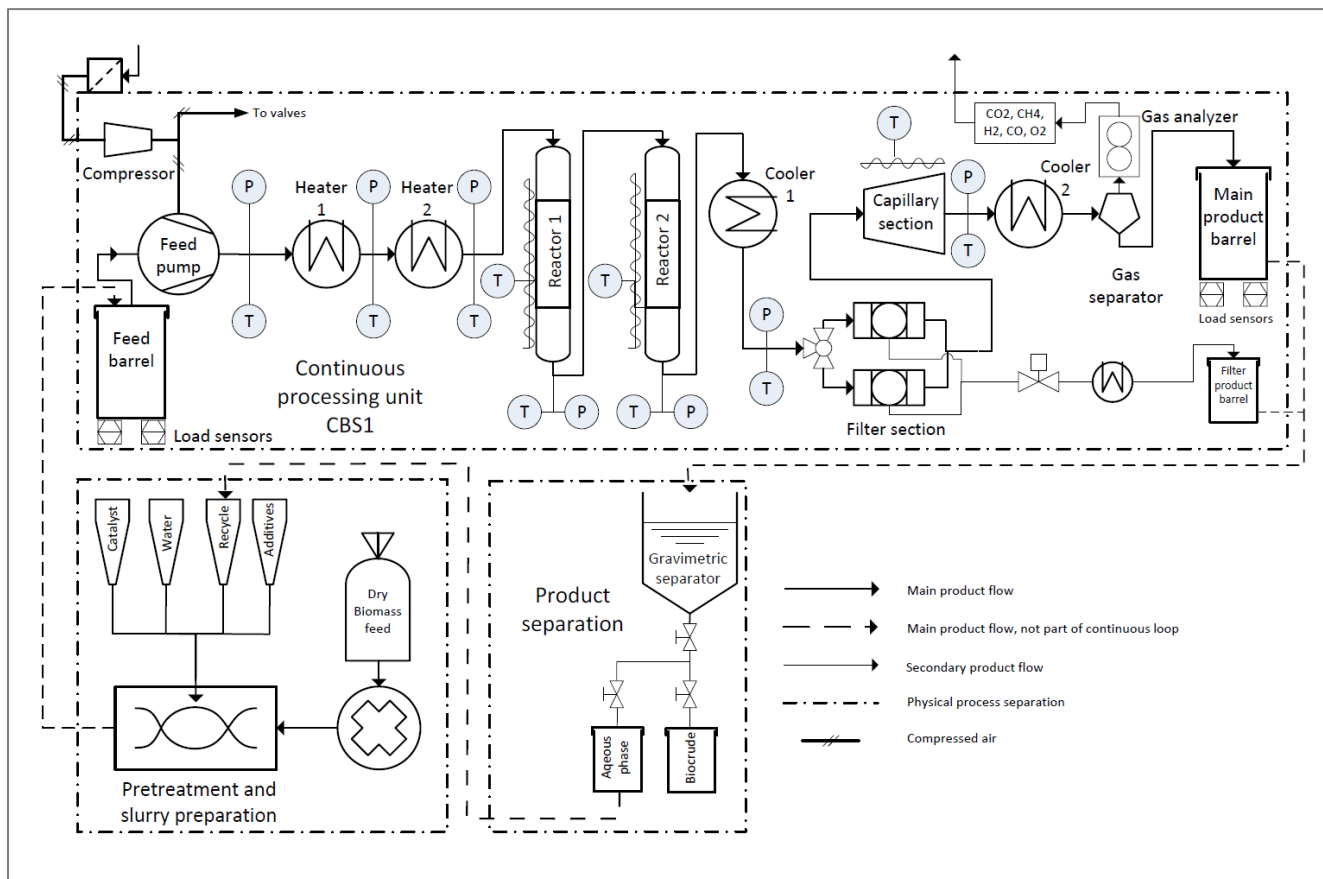
Source: Pedersen et. al. 2016

Figure 7   Example of a Hydrothermal Liquefaction Unit Process Flow Diagram

The bio-oil has certain similarities to petroleum crude and can be upgraded to the whole distillate range of petroleum-derived fuel products. HTL (also known as direct liquefaction) is essentially pyrolysis in hot liquid water. HTL's main use case involves the conversion of bio-organic waste with high water content, including wet primary and secondary sludges.

Advantages of HTL include:

▶ the ability to convert wet biomass without expensive pretreatment or drying.

▶ substantially reduced greenhouse gas emissions versus other technologies.

▶ production of a crude oil type product that can be distilled into a range of petroleum fuels and chemicals.

▶ recognition of the technology by the US Department of Energy and other agencies.

▶ thermal conversion efficiency of 85-90 percent (i.e., the amount of energy generated in the biofuels produced is six to nine times that required by the process to generate the fuel itself (Gollakota et. al. 2018).

▶ a direct path to convert bio-organic waste to heavy transportation fuels.

▶ generation of both liquid and solid biochar products.

HTL produces four different products: biocrude oil, solid residue, liquids (e.g., acids), and some gases. The gases are produced at a rate of 3 to 7 percent of total biomass tonnage processed (e.g., 100 tons of biomass process through HTL would result in 7 tons of emissions) (Aierzhati et. al. 2021). The gaseous products are primarily a result of the removal of oxygen from the input biomass and mainly include CO_2 with some studies also reporting small percentages of oxygen, carbon monoxide (CO), hydrogen (H_2), and methane, depending on the biomass being converted and the efficiency of the HTL reaction process. Apart from CO, other more common criteria air pollutants (e.g., PM, NOx, ROG) were either not reported in the studies reviewed or only mentioned and not quantified (Aierzhati et. al. 2021, Akhtar et. al. 2011, Gollakota et. al. 2018, Hwang et. al. 2019, Nie and Bi 2018). It is assumed that these other criteria pollutants do not constitute a significant portion of the gaseous by-products from HTL processes.

The portability of HTL technologies has been studied mainly at low volumes (up to 35 liters) for applications such as food waste, wastewater sludge, and woody biomass. It is possible that such technologies can be scaled for vegetation management purposes, but it is uncertain what fuels would be used to power the HTL processes or if the mobile HTL processes can be self-powered through the bio-crude oil produced. The resulting bio-crude oil would also need to be transported to larger processing facilities that can receive the bio-crude oil, such as refineries. (Aierzhati et. al. 2021).

4 METHODOLOGY

To compare emissions from the evaluated biomass processing technologies against those from pile burning, emission factors from the evaluated biomass processing technologies were converted to pounds per acre based on the same fuel loading and consumption factors assumed and shown in Appendix AQ-1 in the CalVTP Program EIR (i.e., fuel load in tons per acre and percent of acreage consumed as fuel). The calculated pounds per acre for each technology are then compared to those presented in Table 3.4-6 of the Program EIR and shown in Table 1, below (see Section 5, "Comparative Impact Analysis"). Calculation details are presented in Appendix A, attached to this paper.

GHG emissions from gasification, pyrolysis, and HRL are discussed qualitatively due to the various factors that affect GHG emissions from these processes (e.g., how heat from these processes would be used, whether or not biomass fuels are delivered to offsite facilities resulting additional truck trips, how any resulting biofuels produced would be used).

Table 1 Air Curtains and Oregon Kilns Percent Reduction in Emissions compared to Pile Burning

Pollutants	Air Curtains	Oregon Kiln
CO_2	54%	54%
CH_4	43%	43%
CO	96%	96%

Pollutants	Air Curtains	Oregon Kiln
NO_X	73%	39%
ROG	96%	98%
$PM_{2.5}$	96%	71%
PM_{10}	96%	71%

Notes: CO2 = carbon dioxide, CH4 = methane, CO = carbon monoxide, NOx = nitrous oxide, ROG = reactive organic gases, PM2.5 = particulate matter with diameters generally 2.5 micrometers and smaller, PM10 = particulate matter with diameters generally 10 micrometers and smaller.

Source: Puettman et. al. 2020.

4.1   AIR CURTAIN BURNER EMISSIONS

To estimate criteria air pollutant and GHG emissions from the combustion of biomass in air curtains, a study from the Journal of Cleaner Production was used which performed a life cycle assessment of biochar produced from forest residues using portable systems. The study compared the biogenic GHG emissions and criteria air pollutants from pile burning with those from an air curtain burner, Oregon kiln, and other proprietary technologies (Puettmann et. al. 2020). The study found the following relative reductions in emissions compared to pile burning, as shown in Table 2.

4.2   PYROLYSIS/CARBONIZATION EMISSIONS

Criteria air pollutant emissions from pyrolysis were identified based on a study on waste timber pyrolysis (Sormo et. al. 2020). The study looked at emissions generated from the combustion of generated pyrolysis gases at the exhaust through flameless oxidation. These gases were the only sources of emissions from the pyrolysis unit as the heat generated in the pyrolysis combustion chamber was fed back into the pyrolysis reactor, as shown in Figure 4. This implies that the evaluated unit was self-powered. The emission factors from this study were converted from grams of emissions per kilograms of biochar produced to emissions per kg of feedstock and then converted to pounds of emissions per acre using the same assumptions used in Appendix AQ-1 of the Program EIR.

4.3   GASIFICATION EMISSIONS

Criteria air pollutant emissions from gasification were based on an air quality study performed for the Tuolumne Biomass LLC Wallowa Resources Community Solutions (TBLLC) project, funded by the Biomass Utilization Fund. This study used criteria air pollutant emission factors provided by the project applicant. The project is a biomass gasification project located in Tuolumne County that uses biomass similar to the biomass that would be created by projects implemented under the CalVTP. The TBLLC project also intends to process biomass into marketable items (e.g., agricultural stakes, wood pellets, wood chips). It is a self-powered facility in that the gasifier uses waste biomass left over from manufacturing as a feedstock and the syngas generated by the gasifier is combusted in a cogeneration engine that provides heat for the gasifier and electricity for the facility as a whole. In addition to gasification process emissions, the air quality study for TBLLC also accounts for additional emissions from biomass transport from forest biomass sources approximately 40 miles away. These calculations are shown in Appendix A.

4.4   HYDROTHERMAL LIQUEFACTION EMISSIONS

The emission of gases from liquefaction is a function of temperature, with higher temperatures leading to a greater percentage of gases being produced through HTL (Akhtar et. al. 2011). HTL studies reporting criteria air pollutant emissions from the processing of woody biomass were not readily available. A study based on food waste HTL processing was used as a proxy (Aierzhati et. al. 2021). The emission factors from this study were converted from grams of emissions per kilograms of feedstock and then converted to pounds of emissions per acre using the same assumptions used in Appendix AQ-1 of the Program EIR.

5 COMPARATIVE ANALYSIS

5.1 CRITERIA AIR POLLUTANT AND PRECURSOR EMISSIONS

With respect to the generation of criteria air pollutants, the four technologies reviewed all substantially reduce ROG and PM emissions when compared to pile burning, ranging between a 91 and 100 percent reduction. For NO_X reductions, air curtains, pyrolysis, and HTL are estimated to reduce NO_X emissions by at least 73, 39, and 97 percent, respectively. However, NO_X reductions are only marginally lower for biomass processed through gasification with a 3 percent reduction compared to pile burning. For the purposes of the comparative analysis, emissions from burning tree/woody biomass were evaluated because this is the most common type of vegetation treatment byproduct. These results are based on a comparison of emission factors (lb/acre) compared to the emissions-per-acre as presented in Table 3.4-6 of the Program EIR. It is reasonably expected that processing shrub and grassland-based biomass using the specialized biomass processing technologies would have similar reductions compared to pile burning, because both feedstocks are woody or herbaceous vegetation. The estimated reduction in emissions account for transport of biomass to off-site facilities, assuming an average of a 40-mile trip, and manual or mechanical treatment needed to process the biomass (e.g., chipping) for use in the biomass processing units. These comparisons are shown in Table 2.

Table 2   Comparison of Criteria Air Pollutants by Biomass Processing Technology

	Emissions per Acre Treated (lb/acre) ROG	Emissions per Acre Treated (lb/acre) NOx	Emissions per Acre Treated (lb/acre) PM$_{10}$	Emissions per Acre Treated (lb/acre) PM$_{2.5}$
Pile Burning (Prescribed Burning)[1]	2,187	166	1,421	1,421
Direct Combustion (air curtain - on-site)[2]				
Emissions Factor	81	45	54	54
Difference	-2,106	-121	-1,367	-1,367
Percent Reduction	-96%	-73%	-96%	-96%
Pyrolysis (on-site) (Oregon Kiln)[2]				
Emissions Factor	44	101	417	417
Difference	-2,143	-65	-1,004	-1,004
Percent Reduction	-98%	-39%	-71%	-71%
Pyrolysis (on-site)[3]				
Emissions Factor	52	10	6	6
Difference	-2,135	-156	-1,415	-1,415
Percent Reduction	-98%	-94%	-100%	-100%
Pyrolysis (off-site)[3, 4]				
Emissions Factor	52	11	6	6
Difference	-2,135	-155	-1,415	-1,415
Percent Reduction	-98%	-93%	-100%	-100%
Gasification (on-site)[5]				
Emissions Factor	46	163	127	127
Difference	-2,141	-3	-1,294	-1,294
Percent Reduction	-98%	-2%	-91%	-91%

	Emissions per Acre Treated (lb/acre) ROG	Emissions per Acre Treated (lb/acre) NOx	Emissions per Acre Treated (lb/acre) PM$_{10}$	Emissions per Acre Treated (lb/acre) PM$_{2.5}$
Gasification (off-site) [3, 5]				
Emissions Factor	46	163	127	127
Difference	-2,141	-3	-1,294	-1,294
Percent Reduction	-98%	-2%	-91%	-91%
HTL (on-site) [6]				
Emissions Factor[4]	44	4	1	1
Difference	-2,143	-162	-1,421	-1,421
Percent Reduction	-98%	-97%	-100%	-100%
HTL (off-site) [6, 3]				
Emissions Factor	44	5	1	1
Difference	-2,143	-161	-1,420	-1,420
Percent Reduction	-98%	-97%	-100%	-100%

Notes: HTL = hydrothermal liquefaction

[1] From Table 3.4-6 of the Program EIR. The emissions estimates for prescribed burning, which may consist of pile burning or broadcast burning, consist of the emissions that would be generated by the combustion of vegetative fuels. They do not include emissions generated by trucks hauling equipment to and from treatment sites.

[2] Calculated based on results from Puettman et.al. 2020.

[3] Calculated based on results from Sormo et. al. 2020

[4] Trips to off-site locations are assumed to occur twice per day, 260 days per year, and using 30-ton trucks travelling 40 miles each way.

[5] Calculated based on analysis performed for a gasifier project under the Biomass Utilization Fund

[6] Calculated based on results from Aierzahti et. al. 2021. HTL does not produce any noticeable emissions of ROG, NOₓ, or PM. The emissions shown here are directly related to manual or mechanical pre-processing.

As shown in Table 2, air curtains, HTL, and pyrolysis have the lowest criteria pollutant emissions across all evaluated pollutants when compared to prescribed burning. The addition of transportation emissions of biomass to off-site processing facilities, as shown in the off-site results in Table 2, do not substantially affect the potential for these alternative biomass processing technologies to reduce emissions. The estimate emissions for gasification, pyrolysis, and HTL do not include any potential emissions that would be generated from energy fuels needed to power those processes. However, these technologies have high thermal efficiencies from 70 to over 90 percent (Babu et. al. 2013, Hanif et. al. 2016, Gollakota et. al. 2018). This means that the energy generated in the fuel produced by these three technologies would be at least twice that required to power the systems themselves. Additionally, pyrolysis and gasification systems, especially those at stationary large facilities, are often self-powered/heated through combined-heat and power systems. Pyrolysis systems use the heat self-generated by the syngas oxidation process to sustain its own process without the need of external heat sources such as fossil fuels.

Identifying the exact fuels that would be used to power these potential systems would be speculative, but those located at off-site stationary facilities would most likely be either self-powered or use electricity from the grid and not result in local air quality concerns. There is uncertainty surrounding the particular type of fuels portable biomass processes (except for air curtains) would use, because the feasibility of portable placement of these technologies is still being researched (Aierzhati et. al. 2021).

For the reasons explained above, each of the four evaluated biomass processing technologies would clearly result in a net reduction of criteria air pollutant emissions, which would provide environmental advantages, compared to pile burning.

5.2 DIESEL PARTICULATE MATTER EMISSIONS AND RELATED HEALTH RISK

Diesel emissions result from the combustion of diesel in both off-road and heavy-duty on road vehicles. Of the four biomass processing technologies evaluated, only air curtains would not result in additional off-road equipment usage beyond that used in collecting biomass for pile burning as air curtains can accept unprocessed biomass (e.g., whole logs and branches). The other three technologies evaluated (i.e., pyrolysis, gasification, and HTL) could require some additional off-road equipment to preprocess the biomass in preparation for the conversion systems, such as through chipping, depending on the exact technologies used. The chipping needs would be consistent with chipping activities associated with the mechanical and manual treatments evaluated in the Program EIR. Additionally, any transport of biomass to off-site conversion facilities would also require the use of on-road diesel haul trucks. However, manual and mechanical treatment activities as well as hauling would not take place near the same people for an extended period of time. Thus, diesel PM generated by treatment activities would not expose any person to an incremental increase in cancer risk greater than 10 in one million or a Hazard Index of 1.0 or greater.

5.3 TOXIC AIR CONTAMINANT EMISSIONS AND RELATED HEALTH RISK

Toxic air contaminants (TACs) resulting from the combustion of biomass are generally organic in nature (e.g., formaldehyde, polycyclic aromatic hydrocarbons [PAHs], benzene) and are, therefore, a subset of ROG emissions. As shown in Table 1, the evaluated biomass conversion technologies would reduce the level of ROG emissions by at least 93 percent when compared to pile burning of equivalent areas. Therefore, the exposure of persons to TACs and related health risks would likely be substantially lower with the use of biomass conversion technologies as compared with pile burning. As a result, the use of biomass conversion technologies would provide substantial environmental advantages in place of pile burning.

5.4 EXPOSURE TO ODORS

5.4.1 Diesel Exhaust

Each of the biomass processing technologies evaluated herein, except for air curtains, could require some additional off-road equipment to preprocess the biomass in preparation for the conversion systems, such as through chipping, depending on the technologies used. For transport of biomass to offsite processing facilities, additional diesel exhaust may result from haul truck transportation. These haul trucks would be moving in and out of on-site areas and would not be idling for long periods of time (i.e., not longer than 5 minutes). However, these odor sources would be temporary, would not be generated at any one location for an extended period, and would dissipate rapidly from the source with an increase in distance. Exposure potential would be further minimized in less populated, rural, or undeveloped areas, where human receptors are sparse, which is where treatment activities are typically implemented.

5.4.2 Smoke

When compared to smoke emitted from pile burning, which is composed of criteria air pollutants and GHGs, all biomass processing technologies evaluated herein would substantially reduce smoke through filtering (e.g., air curtains) or eliminate smoke altogether (e.g., gasifiers, pyrolysis, HTL). As a result, the operation of biomass conversion technologies would provide substantial environmental advantages in place of pile burning.

5.5   GREENHOUSE GAS EMISSIONS

GHG emissions from pile burning generally consist of CO_2, CH_4, and N_2O emissions. According to Appendix AQ-1 of the Program EIR, CO_2 emissions account for 90 percent of GHG emissions when evaluated on a CO_2-equivalent basis. The carbon emissions that result from pile burning are generally considered to be biogenic (e.g., produced by living organisms). These carbon emissions, though released through anthropogenic means, are part of the current carbon cycle where CO_2 is absorbed into plants during photosynthesis and growth, building up the plant biomass. In the natural carbon cycle, carbon stored in biomass is released into the soil after the death of a plant through on-site decomposition or is consumed by fauna that then respire CO_2 back into the atmosphere. This CO_2 is then reabsorbed by plants during photosynthesis, completing the cycle. Combustion of biomass is another pathway through which CO_2 can be released into the atmosphere. The cycle can be unbalanced through the combustion of fossil fuels, which are made from biomass that are millions of years old and cannot be quickly replenished from existing biomass decomposition, and through excess combustion of existing biomass (e.g., high-intensity anthropogenic wildfires resulting from prolonged fire suppression). Because the proposed pile burning activities would reduce the severity of wildfire emissions, the CO_2 emissions from pile burning can be considered as biogenic.

5.5.1   Air Curtains and Oregon Kilns

Compared to pile burning, air curtains and Oregon kilns would reduce the CO_2 emissions from the combustion of biomass. This reduction is the essential purpose of their function and design. According to a 2020 study of biomass, air curtain burners and Oregon kilns emit 54 percent less CO_2 emissions compared to pile burning (Puettman et. al. 2020: Table 5). This is likely because both technologies combust biomass at high temperatures and produce larger quantities of ash and biochar than pile burning. Instead of being released into the atmosphere as emissions, ash and biochar retain some of the carbon from the original biomass fuel. Thus, the operation of air curtain burners and Oregon kilns would reduce GHG emissions, resulting in an environmental advantage compared to pile burning.

5.5.2   Gasification, Pyrolysis, and HTL

The net GHG emissions generated from gasification, pyrolysis, and HTL are dependent on multiple factors. The vast majority of the input biomass feedstock into these processes is converted into liquid or gaseous biofuels, such as bio-oil and syngas, as well as solid products such as biochar and ash, with a small percentage of gaseous outputs (Sormo et. al. 2020). Some of these fuels can also be used to power the processes themselves (e.g., combined heat and power engines), thereby eliminating the need for external heating sources and fuels. Emissions may also result from the transport of biomass to off-site facilities or to portable equipment locations in the field or from biomass preprocessing (e.g., chipping) prior to conversion. The resulting biofuels can be used to offset equivalent fossil fuels, such as gasoline, diesel, and natural gas. In general, life cycle assessments of the resulting biofuels have concluded that, while accounting for the upstream external inputs (e.g., energy needed for heating, transportation, and chipping), biofuels produced using these methods can reduce GHG emissions by at least 70 percent compared to equivalent petroleum fuel (Nie and Bi 2018, Argonne National Laboratory 2021). The application of biochar and ash as soil amendments would sequester carbon by improving the health of soils, which enables greater carbon sequestration (Ukwattage et. al. 2013). This improved capacity to sequester carbon coupled with the elimination of carbon through the combustion of biofuels results in a net benefit with respect to GHG emissions.

Regardless of the biomass technology, all technologies evaluated herein would result in lower GHG emissions than those generated by pile burning, whether by offsetting petroleum fuels through the production of biofuels or through the sequestration of carbon in the form of biochar and ash. Therefore, the operation of gasification, pyrolysis, and HTL units would reduce GHG emissions, providing an environmental advantage compared to pile burning.

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Appendix A

Biomass Technology Air Quality and GHG Calculations

Prescribed Burn
Tree & Shrub & Grass Fuel Types

Method
Total emissions from a fire are estimated by multiplying an emission factor by the biomass consumed and an accurate assessment of the total acreage burned. For instance, assume that 10 tons/acre of fuel is consumed during a 200-acre landscape prescribed fire in a ponderosa stand in the western U.S. After the fire, ground surveys and aerial reconnaissance indicate a mosaic fire pattern and only 100 acres of the 200 acres within the fire perimeter actually burned (i.e., "black acres"). Because the emission factor for PM2.5 for pine fuels is approximately 46 lb/ton, then total emission production would calculated using the following equation:

Fuel consumed (tons/acre) x PM2.5 emission factor (lb/ton) x area burned (acres) = total emissions PM2.5 (lb)
10 tons/acre x 46.4 lb/ton x 100 acres = 46,400 lb or 23.2 tons of PM2.5 emissions

Table A. Calculated Prescribed Burn Emissions (Per Acre)

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	130,396.80	8,568.00	395.76	2,203.20	1,432.08	167.28	126.48	12.24	85.68	143,938.32	65.29
Shrub Fuel Type	12.6	1	0.80	33,647.40	1,487.40	74.37	351.75	141.71	44.22	30.15	5.03	14.07	37,004.10	16.78
Grass Fuel Type	5.4	1	0.92	16,947.70	606.34	19.38	166.50	84.49	21.87	14.91	N/A	6.96	17,432.28	7.91

Notes: Tree Fuel Type is based on emission factors for prescribed burns in Northwest conifer forest, and fuel loading and consumption factors from Pacific Northwest Douglas fir/hemlock, with the conservative assumption that the burn occurs after large fuels cure. Shrub Fuel Type is based on emission factors for prescribed burns in Western shrub land, and fuel loading and consumption factors from California chaparral, with the conservative assumption of lower frequency burns. Grass Fuel Type is based on emission factors for prescribed burns in grassland, and fuel loading and consumption factors from Midwest grassland, with the conservative assumption that no ungulates have grazed the area.

* These values are calculated based on Emissions Factors in Table B.
** These values are taken from Table C.
*** It is assumed that the estimate for NMOC is approximately equivalent to ROG.
**** It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.

Table B. Fire Average Emissions Factors (Flaming and Smoldering Average)

Prescribed Burn Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Northwest conifer forest (CA, MT, OR, BC)	3,196	210	9.7	54	35.1	4.1	3.1	0.3	2.1
Western shrub land	3,348	148	7.4	35	14.1	4.4	3	0.5	1.4
Grassland	3,410	122	3.9	33.5	17	4.4	3	N/A	1.4

Source: Urbanski, S. Wildland fire emissions, carbon, and climate: Emission factors. *Forest Ecology and Management* . 317: 51–60 (as presented in NWCG 2018)

Table C. Fuel Loading and Fuel Consumption Factors

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)	Size (acres)	Calculated Total Available Fuel (tons)*	Total Fuel Consumption (tons)	Calculated Fuel Consumption Factor**
Pacific Northwest Douglas fir/hemlock (burn before large fuels cure)	76.4	100	7640	2042	27%
Pacific Northwest Douglas fir/hemlock (burn after large fuels cure)	76.4	100	7640	4080	53%
California chaparral (burn more frequently)	7.9	100	790	556	70%
California chaparral (burn less frequently)	12.6	100	1260	1005	80%
Midwest grassland (ungulates)	2.5	100	250	228	91%
Midwest grassland (no ungulates)	5.4	100	540	497	92%

Source: Values generated with Consume 4.0 (as presented in NWCG 2018)
Prichard, S.J., Ottmar, R.D., Anderson, G.K. 2007. *Consume user's guide.*
http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume30_users_guide.pdf.
*Calculated total available fuel by multiplying total fuel loading by size of test plot
**Calculated fuel consumption factor by dividing total fuel consumption by calculated total available fuel.

	value	units	source
global warming potential of methane	298	unitless	wksht: Unit Conversions
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions

Notes
1 These emission level estimates do not include emissions generated by worker commute trips, transport of equipment, or the use of drip torches or Heli torches. The level of emissions from these sources would be nominal to the level of emissions generated by the burning of vegetative fuels.

Air Curtains
Tree & Shrub & Grass Fuel Types

Table D. Calculated Air Curtain Incinerator Emissions (Per Acre)

Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	60,183.14	106.08	182.66	36.72	53.04	40.80	0.00	5.65	4.08	64,749.60	29.37

These values are calculated based on Emissions Factors in Table E.
**These values are taken from Table C.*
***It is assumed that the estimate for NMOC is approximately equivalent to ROG.*
****It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.*

Table E. Air Curtain Incinerator Average Emissions Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Forest vegetation/wood	1,475	2.6	4	0.9	1.3	1		0.14	0.1

Source: (Forest: CO, VOC, PM2.5, NOX, SO2) https://www.valleyair.org/busind/pto/emission_factors/Criteria/Criteria/Air-Curtain-Incinerators/EF-Determination-Analysis.pdf (Table 3)

GHGs: https://www.sciencedirect.com/science/article/abs/pii/S0959652619344348 (Air Curtains reduce 54% of biogenic GHGs compared to pile burning) (Table 5)

	value	units	source
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions

Gasifier
Tree & Shrub & Grass Fuel Types

Table F. Calculated Gasifier Emissions (Per Acre)

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	124,848.00	13.51	709.92	2.27	126.02	158.69	0.00	0.00	0.00	142,596.00	64.68
Off-Site (Tree)	76.4	1	0.53	325.31	0.03	0.00	0.01	0.00	0.41	0.00	0.05	0.00	0.00	0.00

These values are calculated based on Emissions Factors in Table G and H.

**These values are taken from Table C.*

****It is assumed that the estimate for NMOC is approximately equivalent to ROG.*

*****It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.*

Table G. Gasifier Average Emissions Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Forest vegetation/wood	3,060	0.33	17	0.06	3.09	3.89			

Source: Criteria Air Pollutants: TBLLC AQ Study. CO2 and CH4 from Ahmed et. al. 2018

(https://www.researchgate.net/publication/329793033_Emissions_Factors_from_Distributed_Small-

Scale_Biomass_Gasification_Power_Generation_Comparison_to_Open_Burning_and_Large-Scale_Biomass_Power_Generation)

Table H. Gasifier Off-Site Transportation Emission Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel transported) (Assuming 40-mile trips)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
All types	7.97	0.00	0.00	0.00	0.00	0.01		0.00	

Source: TBLLC AQ Study

	value	units	source
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions

Oregon Kiln
Tree & Shrub & Grass Fuel Types

Table I. Calculated Oregon Kiln Emissions (Per Acre)

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	60,183.14	341.15	226.65	0.00	416.61	96.35	0.00	0.00	0.00	65,849.31	29.87
Off-Site (Tree)	76.4	1	0.53	325.31	0.03	0.00	0.01	0.00	0.41	0.00	0.05	0.00	0.00	0.00

These values are calculated based on Emissions Factors in Table J and K.

**These values are taken from Table C.*

****It is assumed that the estimate for NMOC is approximately equivalent to ROG.*

*****It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.*

Table J. Oregon Kiln Average Emissions Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Forest vegetation/wood	1,475.1	8.4	5.6	0.0	10.2	2.4			0.0

Source: Criteria Air Pollutants: Sormo et. al. 2020 (https://www.sciencedirect.com/science/article/pii/S0048969720308457)

Table K. Oregon Kiln Off-Site Transportation Emission Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel transported) (Assuming 40-mile trips)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
All types	7.97	0.00	0.00	0.00	0.00	0.01		0.00	

Source: TBLLC AQ Study

	value	units	source
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions
mass conversion factor	453.59	g/lb	
mass conversion factor	2.20	lb/kg	

Pyrolysis
Tree & Shrub & Grass Fuel Types

Table L. Calculated Pyrolysis Emissions (Per Acre)

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	0.00	66.42	0.00	8.16	5.69	6.17	0.00	0.00	0.00	0.00	0.00
Off-Site (Tree)	76.4	1	0.53	325.31	0.03	0.00	0.01	0.00	0.41	0.00	0.05	0.00	0.00	0.00

These values are calculated based on Emissions Factors in Tables M and N.
**These values are taken from Table C.*
****It is assumed that the estimate for NMOC is approximately equivalent to ROG.*
*****It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.*

Table M. Pyrolysis Average Emissions Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Waste Timber		1.63	0.00	0.20	0.14	0.15			

Source: Criteria Air Pollutants: Sormo et. al. 2020 (https://www.sciencedirect.com/science/article/pii/S0048969720308457)

Table N. Pyrolysis Off-Site Transportation Emission Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel transported) (Assuming 40-mile trips)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
All types	7.97	0.00	0.00	0.00	0.00	0.01		0.00	

Source: TBLLC AQ Study

	value	units	source
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions
mass conversion factor	453.59	g/lb	
mass conversion factor	2.20	lb/kg	

Hydrothermal Liquefaction
Tree & Shrub & Grass Fuel Types

Table O. Calculated HTL Emissions (Per Acre)

Prescribed Burn Vegetation Type	Total Fuel Loading (tons/acre)**	Size (acres)	Fuel Consumption Factor**	Pollutant Emissions (lb/acre burned)*										CO2e (MT/acre)
				CO2	CO	CH4	NMOC***	PM2.5****	NOx	NH3	N2O	SO2	CO2e	
Tree Fuel Type	76.4	1	0.53	3,807.37	294.17	48.33	0.00	0.00	0.00	0.00	0.00	0.00	5,015.56	2.28
Off-Site (Tree)	76.4	1	0.53	325.31	0.03	0.00	0.01	0.00	0.41	0.00	0.05	0.00	0.00	0.00

These values are calculated based on Emissions Factors in Tables P and Q.

*** These values are taken from Table C.*

**** It is assumed that the estimate for NMOC is approximately equivalent to ROG.*

***** It is assumed that the estimate for PM2.5 is approximately equivalent to PM10.*

Table P. HTL Average Emissions Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel consumed)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
Waste Timber	93.318	7.21	1.1845	0.00	0.00	0.00	0.00	0	0

Source: Aerzahti 2015 (https://www.sciencedirect.com/science/article/abs/pii/S0306261915014075)

Table Q. HTL Off-Site Transportation Emission Factors

Vegetation Type	Pollutant Emission Factors (lb of emissions/ton of fuel transported) (Assuming 40-mile trips)								
	CO2	CO	CH4	VOC	PM2.5	NOx	NH3	N2O	SO2
All types	7.97	0.00	0.00	0.00	0.00	0.01		0.00	

Source: (Forest: CO, VOC, PM2.5, NOX, SO2) https://www.valleyair.org/busind/pto/emission_factors/Criteria/Criteria/Air-Curtain-Incinerators/EF-Determination-Analysis.pdf (Table 3)

	value	units	source
global warming potential of methane	25	unitless	wksht: Unit Conversions
mass conversion factor	2,204.62	lb/MT	wksht: Unit Conversions
mass conversion factor	453.59	g/lb	
mass conversion factor	2.20	lb/kg	