Biomass Utilization in Humboldt County

Prepared for:

Redwood Coast Energy Authority

ENGR 492: Capstone Design Project

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Prepared by Team CHaRM:

Cody Barr, Rebecca Burke, Hanna Phillips, and Mikaela Shannon

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Acronyms

GHG	Green House Gas Emissions
RCEA	Redwood Coast Energy Authority
JPA	Joint Powers Agency
CO_2	Carbon dioxide
NO_x	Oxides of nitrogen
SO_x	Oxides of sulfur
$PM_{2.5}$	Particulate Matter 2.5 micron
PM_{10}	Particulate Matter 10 micron
MMBTU	Million Metric British thermal unit
EPA	Environmental Protection Agency
CARB	California Air Resources Board
NCUAQMD	North Coast Unified Air Quality Management District
BECCS	Bio-Energy with Carbon Capture and Storage
O&M	Operation and Maintenance
NPDES	National Pollutant Discharge Elimination System
FAQ	frequently asked questions
ROG	Reactive Organic Gases
NCRWQCB	North Coast Regional Water Quality Control Board
ppm	parts per million
BTM	Behind the Meter
HHV	Higher Heat Value
LHV	Lower Heat Value
TPZ	Timber Production Zone
WWTP	Wastewater Treatment Plant
NPDES	National Pollutant Discharge Elimination System
CO	Carbon Monoxide
N_2	Dinitrogen
CH_4	Methane
ORC	Organic Rankine Cycle
BTU	British Thermal Unit
MMBTU	Million British Thermal Units
kWh	Kilowatt Hours
MW	Megawatts
HHV	High Heating Value
LHV	Low Heating Value
MT	Metric Tons
C: N	Carbon to nitrogen
$	US Dollars
yd^3	Cubic Yard
ft^2	Square Foot
ft^3	Cubic Foot

Executive Summary

Approximately 702,000 metric tons of woody biomass waste from local sawmills are transported to the Scotia and DG Fairhaven power plants in Humboldt County, California. Currently, this biomass is incinerated to produce electricity which is then fed into the local power grid. This report investigates alternatives to use this biomass in alternative processes. Community approval and satisfaction was important in the decision-making process of this research as the local community will be affected by any proposed project.

For a solution to be considered feasible, the alternative was required to satisfy the following three constraints: base operations located in Humboldt County, utilization of a minimum of 80% of the biomass, and following all local, state, and federal regulations and standards. The considered alternatives were ranked based on their overall projected performance in carefully chosen social, economic, and environmental aspects. Below are the criteria that were in the Delphi matrix and Pugh method decision-making processes:

- Community Satisfaction
- Cost (Payback Period)
- Ease of Implementation
- Carbon Sequestration
- Aesthetics
- Local Jobs Created
- Air Quality
- Amount of Biomass Utilized

The necessary design process for each alternative was to brainstorm ideas that meet the client and community's needs, gather information, analyze each alternative, choose a solution, and complete a thorough analysis of the final alternative. The alternatives were selected to meet client and community's desired needs, which were to utilize the biomass without combusting the material. Each option was analyzed qualitatively and quantitatively for each criterion. The four alternatives were unique in how biomass was processed, which resulted in an assessment that each option had a variety of strengths and weaknesses. The final step was to assess the solution, and complete with strong recommendations in processing the product.

There were four design alternatives considered to meet the objective of the project. The alternatives were a gasification facility to produce synthetic natural gas, a pyrolysis facility with the primary goal of producing biochar, a construction manufacturing process to make oriented strand board (OSB), and local wastewater treatment utilization along with a commercial-scale composting facility. At least one output from each process was a saleable good, which would be transported to another locale for wider distribution than possible in rural northern California.

The composting with local WWTP implementation alternative proposed the utilization of excess biomass in four different processes: 1) Class A biosolids production, 2) trickling filter media replacement, 3) odor control media replacement, and 4) compost production. Based on the results from the Delphi and Pugh method, this became the recommended alternative because it outperformed the others given its soil benefits, small payback period of less than three years,

high carbon sequestration (approximately 583,000 tons per year), and negative net CO_2 equivalent emissions (-352,640 tons per year).

The proposed alternative includes the production of Class A biosolids by mixing a portion of the excess biomass with dewatered sludge at the McKinleyville, Eureka (Elk River), Ferndale, and Fortuna WWTPs along with some purchased hay and manure from regional cattle. It additionally suggests replacing the odor control media at the Eureka and Fortuna WWTPs with the excess biomass as well as the plastic trickling filter media at the Eureka WWTP. Both would be replaced every four months and then composted. A composting facility is proposed to utilize the remaining biomass with 379 windrow piles on a 36-acre lot located on the Samoa Peninsula. The composting mixture was calculated to include 45% biomass, 15% manure, and 40% hay by mass based on required moisture, C:N ratio, and density for quality compost. Half of the product would be transported to the Santa Rosa, California area for wider commercial distribution, while only half would supply local demand. Figure 1 illustrates how the excess biomass from the local sawmills supplies the four processes.

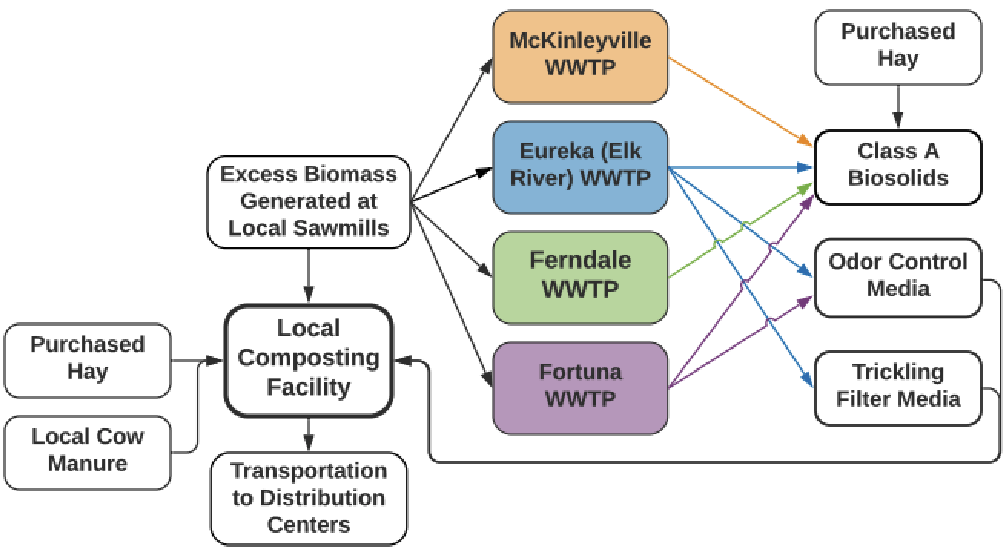

Figure 1. Diagram of recommended alternative utilizing the excess biomass for composting and at local WWTPs (Phillips 2020).

The following are three primary limitations of the recommended alternative design:

- Collection methods are uncertain for the substantial requirement of 207,000 tons per year of manure from Humboldt County dairy cows.
- The projected regional demand may not meet the supply of compost produced under this alternative. Consequences of this scenario would be adverse financial impact and determining alternate local uses for the unsold compost.
- Eighty percent of the biomass produced by local sawmills is used under this alternative, leaving over 140,000 tons per year unaccounted for.

1 Introduction

Humboldt County is the largest timber producer in California and therefore generates a substantial amount of local mill waste, or woody biomass (County of Humboldt 2017a, USDA 2012). Throughout the report, this material will be referred to as biomass. The use of biomass to generate power in Humboldt County as a renewable energy source has produced mixed reactions from county residents. Though biomass-produced energy is seen as a net CO_2 reducing energy production technology, it potentially impacts local air quality negatively and does produce greenhouse gas emissions (GHG). Concerns with alternative uses of the biomass include, but are not limited to reduction in air quality, permitting processes, cost of implementation and impact on the local community. RCEA reached out to Humboldt State University Engineering 492 Capstone class of Spring 2020 to identify alternatives for biomass utilization in Humboldt County. A weighted criteria analysis was used to evaluate the feasibility the alternatives identified.

1.1 Objective

The objective of this project is to identify alternative feasible uses of the biomass currently used to produce power in Humboldt County by incineration and to evaluate them for their technical, economic, and environmental merit in order to identify the best use for one of the Humboldt County's most abundant resources.

1.2 Project Constraints

The following items were identified as constraints for the design use of biomass in Humboldt County:

- **Biomass –** Must use at least 80% of the woody biomass material that is going to the power plants annually.
- **Local -** Geographical location must be in Humboldt County due to the transportation costs and emissions.
- **Regulations –** Must abide by all local, state, and federal regulations and standards.

1.3 Project Criteria

Project criteria were chosen based on their ability to align with the stated project objective; they are outlined with their relative weights in Table 1 and divided into the following three categories: social, economic, and environmental impacts. Weights for each criterion were derived through engineering judgement and discussion with RCEA directly based on their prioritized criteria and organization goals.

1.3.1 Social

Social criteria include community satisfaction and aesthetics. The community satisfaction criterion was based on approval by community members and each alternative's ability to satisfy the concerns addressed in frequently asked questions (FAQs); these are addressed in Appendix A in Table 31 FAQs from RCEA (RCEA 2020b). Because aesthetics can be difficult to quantify, it was broken into the following two subcategories: minimize the height of the facility and population density impacted. The height of the proposed building will be taken into consideration to account for the blockage of view forced upon nearby residents or passersby. The radius of influence was determined to be 1 mile, based on general visibility and view sheds experienced by residents in the Humboldt Bay area.

1.3.2 Economic

Economic criteria include effects on local employment, payback period, and ease of implementation. Payback period accounts for operation and maintenance (O&M) costs based on average annual cost over a 30-year project life and capital costs based on the total construction and implementation cost for each alternative, based on a 30-year solution. The ease of implementation criterion will be ranked by the number of local, state, and federal permits required and approximate time it takes to acquire them for each alternative.

1.3.3 Environmental Impacts

Environmental impact criteria include effects on air quality, carbon sequestration, and excess biomass. Air quality is separated into the following two categories: GHGs and criteria pollutants. Ranking of the air quality criteria was performed by assessing the mass of pollutant emissions under each alternative. The relevant greenhouse gases evaluated under each alternative are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and dichlorodifluoromethane (CCl_2F_2). The six criteria pollutants are ozone (O_3), particulate matter (PM), carbon monoxide (CO), lead (Pb), sulfur dioxide (SO_2), nitrogen dioxide (NO_2). To minimize contribution to the carbon cycle, the carbon sequestration criterion includes minimizing the introduction of sequestered carbon (i.e. fossil fuels) and maximizing the sequestration of carbon (i.e. creation of biochar). To minimize waste, the alternative should maximize usage of biomass available.

Table 1. Project criterion descriptions, methods to weight each criterion, and the weight assigned to each.

Criterion	**Description**	**Quantification**	**Weight**
		Social	
Community Satisfaction	Maximize approval by community members	Number of FAQs, based on common complaints by community members to RCEA, addressed by the alternative	8
Aesthetics	Minimize the height of the facility	The height of the facility that can be seen from the community	1
	Minimize the population density impacted	The population of the community in a 9-mile radius	1
		Economic	
Local Employment	Maximize local employment opportunities	Number jobs added or removed by alternative	2
Cost	Minimize payback period (Capital cost and O&M cost)	Amount of years that the proposed project will be paid off	4
Ease of Implementation	Maximize ability for alternative to meet federal, state, and local regulations	Number of permits required, and amount of time required to obtain clearance	4
		Environmental Impacts	
Air Quality	Minimize greenhouse gas emissions, and local air quality impacts	Mass of GHG pollutant discharged per year	3
	Minimize the mass of criteria pollutants discharged	Mass of criteria pollutants discharged per year	2
Carbon Sequestration	Maximize sequestration of carbon through proposed alternative (i.e. Biochar)	Mass of carbon sequestered annually by alternative	2
Excess Biomass	Maximize percentage of available biomass used	Mass of biomass utilized per year	3

2 Background

The background section includes information regarding the client and stakeholders, biomass characterization and current use, concerns over its use for power generation, alternative site considerations, and regulations.

2.1 Client and Stakeholders

The client for this project is the Redwood Coast Energy Authority (RCEA) and stakeholders range beyond Humboldt County residents as the health and environmental impacts of biomass use have wide-reaching consequences.

2.1.1 Redwood Coast Energy Authority

RCEA is a local government Joint Powers Agency founded in 2003 (RCEA 2020a). According to the California State Legislature (2007), Joint Powers Agencies (JPAs) are government agencies that have agreed to combine their powers and resources to work on their common problems. RCEA's purpose statement is to "develop and implement sustainable energy alternatives that reduce energy demand, increase energy efficiency, and advance the use of clean, efficient and renewable resources available in the region for the benefit of the Member agencies and their constituents" (RCEA 2020a). Their member agencies include the County of Humboldt, the Cities of Blue Lake, Eureka, Ferndale, Fortuna, Rio Dell, and Trinidad, and the Humboldt Bay Municipal Water District (RCEA 2020a). RCEA's goal is to provide 100% clean and renewable electricity by 2030. Currently, biomass accounts for approximately 30% of their renewable energy profile.

2.1.2 California Climate Change Goals

California has continuously developed programs to reduce GHG emissions by initiating movements throughout the state from the following intergovernmental collaborations: federal, local, and tribal groups. The California Global Warming Solutions Act of 2006 set the following climate change goals in California to reduce 40% of GHG emission and increase energy production to 50% of renewable energy by 2030. The path that California envisions for 2030 is to improve public health by increasing air quality, water quality, and energy efficiency. The state, tribal, and local governments and agencies implement plans and policies and develop programs to meet California goals; for example, there are programs to improve the efficiency and sustainability for buildings and vehicles, as well as to reduce waste (CARB 2017). The California Air Resources Board (CARB) is one of the state's agencies, whose role is to protect the public from the effects of GHG pollutants (CARB 2020c).

Wildfires, scarce water supply, and economic impacts due to climate change effects are penalties California will face if they do not reach their goal to decrease GHG emissions by 40%. The temperature rise in California will increase fires that could result in community home loss that is estimated to cost $14 billion per year by 2100. Another harmful effect of climate change is the change in the six economic sectors in California: water, energy, transportation, agriculture, public health, and tourism. The cost of operation and the lack of availability of water resources is estimated to cost $689 million per year by 2050 (CARB 2020c).

Wind, solar, hydroelectric, biomass, and geothermal energy all contribute to the clean energy movement. In 2017, the continuous push to reach the 2030 goal of 50% renewable energy was 29%. The main factor to reach the goal was the leading resource in producing renewable energy in 2017, solar panels (followed by wind) (CARB 2017). The renewable energy supplying California from in and out of state are behind the meter (BTM) solar, solar, wind, hydroelectric, biomass and geothermal; the corresponding percentages can be seen in Figure 2 (Ritter 2018).

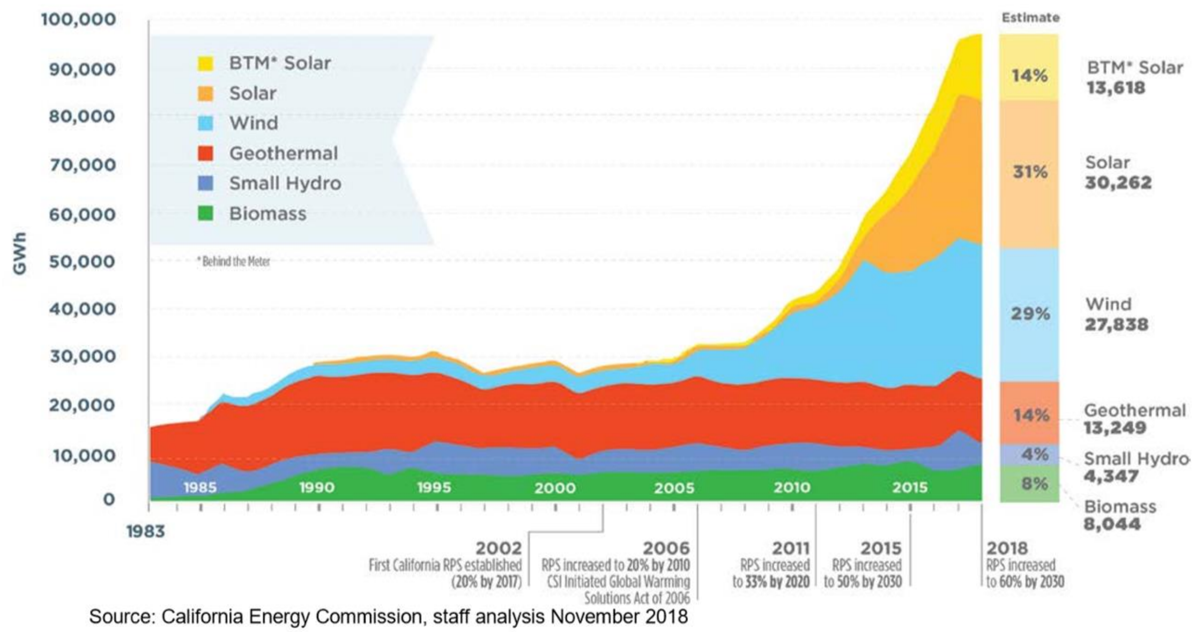

Figure 2. The production of renewable energy serving California in and out of state. The figure illustrates the progress in renewable energy after 2006 when the Climate Global Warming Solutions Act of 2006 was initiated (Ritter 2018).

2.2 Biomass

2.2.1 Biomass Characterization

Biomass can be generally defined as organic matter derived from a biological origin, such as plant waste or animal by-product, which can be used as bioenergy to generate power (RCEA 2020b). Material ready to be industrially processed for bioenergy is considered biomass feedstock (Shelly 2020). Biomass made of non-merchantable wood material, such as logging and sawmill waste, is considered woody biomass (Shelly 2020). This report will primarily focus on analysis and utilization alternatives for woody biomass, which will here be simply referred to as biomass. Woody biomass that is processed at biomass power plants for bioenergy has three primary origins: thinning from wildfire prevention, logging waste, and sawmill waste.

Table 2 shows the typical length, bulk density, and higher heating value for various biomass feedstocks. Fuel size is heavily considered when using automatic feed systems in commercial-scale plants; smaller sizes will limit jamming and increase the longevity of the equipment (Ciolkosz 2010). Additionally, a smaller, more homogenous feedstock that has a high density will aid in a consistent burn rate and increased performance efficiency (Tumuluru 2018).

Table 2. Typical length and bulk density for various biomass fuels (Ashton 2007, Ciolkosz 2010, De Oliveria Maia 2014).

Fuel	Length (m)	Bulk Density (kg/m³)	Higher Heating Value (MJ/kg)
Sawdust	0.0003-0.002	300	16.2
Chopped Straw	0.005-0.025	60	20.4
Green Wood Chips	0.025-0.075	500	9.5
Wood Pellets	0.006-0.008	600	19.8
Biomass Briquettes	0.025-0.010	600	17.9
Cordwood	0.3-0.5	400	22.5

Heating value, which is primarily a function of the material's chemical composition, measures the amount of energy stored in the fuel. It can be expressed as either the higher heating value (HHV) or lower heating value (LHV), where the higher heating value additionally includes the energy within the water vapor (Tumuluru 2018). Though wood varies in HHV from one species to another, the variation is not much greater than the within-species variability, due to differences in climate and soil conditions (Ciolkosz 2010). Figure 3 illustrates the typical range of higher heat values for various biomass species. Wood species tend to have a higher value than agricultural crops partially due to their lower moisture content (Ciolkosz 2010).

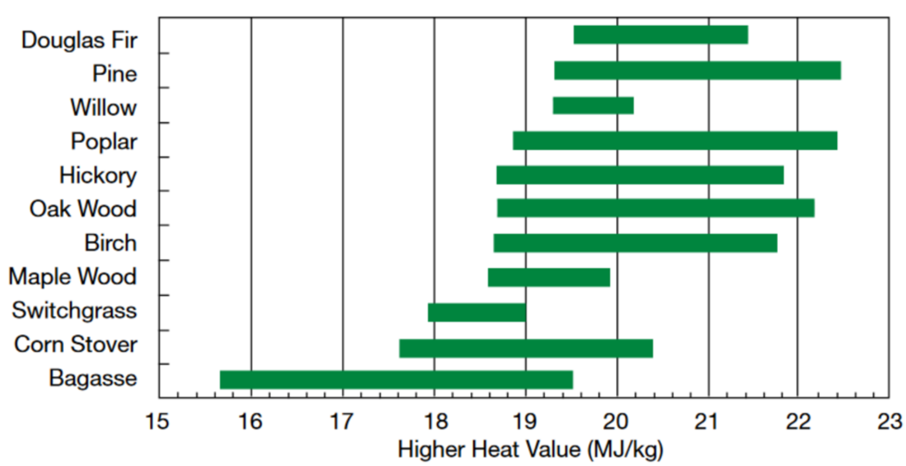

Figure 3. Higher heating value for various fuels (Ciolkosz 2010).

Table 3 reveals the percent ash content, slagging index, fouling index, and percent volatiles for various biomass fuels. Percent ash content refers to the mass fraction of noncombustible material; where coal has a much higher percentage than that of wood (Ciolkosz 2010). When ash melts, it can cause problems such as slagging and fouling to the equipment. The slagging index refers to melted ash deposits that have formed in the base of the combustion chamber, while the fouling index refers to deposits formed on the surfaces of the combustor (Tumuluru 2018). The variability of ash melting at unexpected temperatures can be attributed to the abundance of minerals present in biomass fuels such as chlorine, potassium, and silica (Suzuki et al. 2011). Dirt on the biomass fuel can additionally cause the ash to melt depending on the minerals it possesses (Ciolkosz 2010). The fraction of fuel that will volatize when heated is referred to as the percent volatiles; fuels with a high percent volatile will tend to volatilize before combustion, and those with low percent volatile will burn “primarily as glowing char” (Ciolkosz 2010).

Table 3. Percent ash content, slagging index, fouling index, and percent volatiles for various biomass fuels (Ciolkosz 2010).

Fuel	Percent Ash Content	Slagging Index	Fouling Index	Percent Volatiles
Wood, clean and dry	0.3	0.05	7	82
Bark, dry	1.2	5.6	34	70
Switchgrass	5.2	0.06	4.2	76
Corn Stover	5.6	0.04	8.2	75
Coal	12	0.08	0.13	35

When designing a combustor for biomass, it is important to consider all the parameters noted: fuel length, bulk density, chemical composition, heating value, moisture content, percent ash content, slagging index, fouling index, and percent volatiles. Additionally, it is important to design a system that can account for natural variation in characteristics, being able to handle a range of properties (Ciolkosz 2010).

2.2.2 Wildfire Prevention

Wildfires have been a growing concern in the state of California, as some of the largest and most destructive fires have occurred within the last five years. Forest thinning is a practice often funded by the taxpayers to remove understory brush for preventative fire measures (Hurteau 2018). By targeting the understory brush, it forces wildfires to spread through the crowns of trees which are further apart, making it more challenging for fires to spread at a fast rate of speed (Hurteau 2018). The removed underbrush is now considered biomass waste and needs to be removed.

2.2.3 Logging Waste

Logging waste or slash consists of branches and limbs that are removed during timber harvest (UC Davis 2008). Because the waste generated is directly proportional to harvesting activity, the amount of waste has decreased over time as logging practices in California have been following a downward trend since 1968 (USDA 2012). Slash left on the forest floor can be considered a hazardous fuel that would support wildfires. Open burn piles for logging slash are common because they eliminate the transportation of the non-merchantable waste. Humboldt County's forested land encompasses approximately 80 percent of its total land and roughly 990,000 acres are suitable for production as Timber Production Zone (TPZ), indicating the County's biomass generation potential (County of Humboldt 2017a).

2.2.4 Sawmill Waste

Humboldt County relies heavily on sawmill waste as their primary biomass fuel for two local biomass power plants. Sawmill waste can range among bark, trim ends, shavings, and sawdust, and can vary depending on the type of wood being processed (UC Davis 2008). Compared to the sawlogs that are being processed, their residue or waste is about half the weight because it is much less dense (UC Davis 2008). Sawmills typically purchase softwood tree bores that measure about 10 inches in diameter (UC Davis 2008).

2.3 Biomass Utilization

2.3.1 Energy Utilization

There are multiple viable options for the conversion of sawmill biomass waste into usable power. These methods can produce fuel in different forms in order to better suit the needs of those utilizing the recycled products. Depending on the energy conversion technology used, the biomass can be converted to energy derived from pure heat generation, a combustible synthesis gas, and bio oil. A benefit to sourcing energy from biomass is its baseload function, which is the ability to consistently provide a specific energy output needed to meet baseload demand (RCEA 2020b). Power plants using this technology can produce more precise and on demand energy levels. This is a strong option of renewable energy to pair with the inconsistent availability of solar and wind power (RCEA 2020b). The following sections overview biomass energy production technologies.

2.3.1.1 Combustion

Combustion is the process of burning fuel while in the presence of air to create heat which can be harnessed for energy production (Carlson 2015). Other than the production of electricity through the process of heating steam, this heat can be used for various in-plant purposes such as the drying of biomass feedstock or heating the immediate building vicinity (Carlson 2015).

2.3.1.2 Gasification and Pyrolysis

Pyrolysis is a thermochemical treatment that can be used in the treatment of any type of biomass. This forces a chemical and physical decomposition that residues with different and more practical qualities. Pyrolysis creates a combustible, synthetic gas along with a bio oil, which is condensed syngas, that can both be used for fuel. Pyrolysis can be performed in the following two ways, named for their general speed of reaction: fast or slow. Fast pyrolysis, which promotes gas production, is done by heating the biomass at varying high temperatures while under pressure and in the absence of oxygen (Suzuki 2011); generally slow pyrolysis refers to a lower heat range of 200-500°C. This encourages a longer reaction time and higher yields of carbonaceous biochar which is the carbon-rich charred remnants from the decomposition process (Mazlan et al. 2015). This solid is not used to produce energy but has great value in farm use and the sequestration of carbon (USDA 2017). Controlled variables in the gasification and pyrolysis processes, such as temperature and air inputs, can be tailored to optimize the ratio of resulting product yields (Mazlan et al. 2015). Figure 3 shows a rough estimation of different product yields due to specified temperature of pyrolysis.

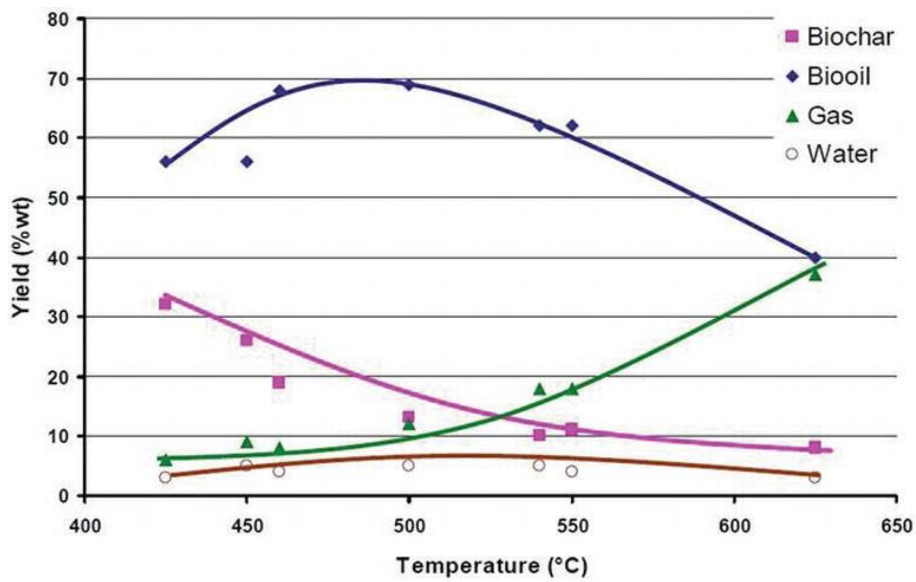

Figure 4. Decomposition products of pyrolysis of biomass (IEA 2006).

The gasification of fuel heats feedstock under low pressure and low oxygen conditions allowing for only partial combustion. Pyrolysis briefly occurs at the beginning of the gasification process when the biomass is devolatilized. From there, gasification pushes the temperature higher than temperatures commonly used during pyrolysis, exceeding 700 degrees Celsius (EERE 2020). The byproducts of this method CO, CO_2, and H_2 among other chemicals. This gas mix is treated leaving a combustible gas called syngas. This synthetic gas is a feasible alternative fuel for locations that use natural gas for the generation of heat and electricity (EERE 2020). Pyrolysis is a more flexible technology compared to gasification in terms of desired output priority. The process can be manipulated to prioritize either biochar, bio-oil, or syngas. Stopping at the pyrolysis stage is required to retain the bio-oil. Although bio-oil is easier to transport and store, it requires more treatment to be implemented as a fuel source. Along with having a low heating value, it is too acidic, viscous, and unstable to be used in its raw form (Han et al. 2019). Gasification produces more readily usable products in combustible gas and biochar.

Both options can be useful in conjunction with a site that produces biomass waste. For example, Evergreen Pulp owned a Kraft pulp mill in Eureka, California and planned on implementing a gasification system to produce syngas to supplement their natural gas usage utilizing their on-site wood waste prior to going bankrupt in 2008 (DEC 2013).

2.3.1.3 Anaerobic Digestion

Anaerobic digestion, also known as bio-digestion, is the use bacteria to break down biomass in the absence of air. This reaction creates a combustible bio-gas (CH_4) that can be used to produce energy. A leftover solid product, called digestate, remains that can be utilized as fertilizer (Carlson 2015). The lignocellulose present in wood and sawdust is not easily biodegradable when used as the lone feedstock source. The process is enhanced with the addition of cow manure to boost the break down process, as nitrogen and moisture-rich materials are required, in general (Ali 2019). This option minimizes GHG emissions and incorporates other bio wastes that would otherwise be detrimental to air quality and water quality with the added benefit of energy generation.

Depending on the method of bio-energy production, there is the possibility of creating a carbon sink via sequestration. Sequestration in the context of biomass energy is the capture and storage of carbon in a solid form thus removing it from the atmosphere’s natural carbon cycle. The long-term use of bioenergy with carbon capture and storage (BECCS) has the potential to slow the progression of cumulative carbon dioxide (CO_2) in the atmosphere and possibly create a net reduction if coupled with low fossil fuel utilization (Obersteiner 2001).

2.3.2 Non-Energy Utilization

There are many ways to use excess biomass that do not produce renewable energy but are in line with sustainability practices.

2.3.2.1 Sustainable Landscaping

Sustainable landscaping is a practice that encompasses multiple techniques for the purpose of utilizing environmentally and socially conscious tactics for biomass use. Strategies for sustainable landscaping practices include composting, mulching, erosion control and creating habitats among others (CalRecycle 2020a).

2.3.2.2 Compost and Mulch

Composting biomass amends soil through the aerobic decomposition of organic matter (Kumar et al. 2011). This utilization of materials does not produce energy but creates a fertilizer and soil amendment that can be used in local agricultural land. It is a low-maintenance and low-cost method that conserves landfill volume and reduces the amount of GHGs, methane most notably, (Kumar et al. 2011).

Mulch is the organic matter that does not experienced decomposition. Common examples of mulch include the following: grass clippings, bark chips, wood chips, leaves, and even newspaper. It can prove helpful as a top layer over soil providing benefits such as diminishing weed growth, moisture retention, and protection from weather elements like wind and temperature (CalRecycle 2020b).

Compost works well to control erosion control because it bonds easily with the soil below, filling voids that water would normally run through and loosen soil. The U.S. Department of Agriculture reports that about 2 billion tons of fertile topsoil and organic matter are disturbed due to erosion which makes it difficult for plants to sprout and last (Risse and Faucette 2015). Forms of control include the following: compost blankets placed in areas susceptible to excessive runoff due to insufficient infiltration, filter socks that slow runoff flow and filter pollutants, and the creation of retaining walls that reduce the erosion of banks and keep roads clear of sediment and debris (CalRecycle 2019c).

2.3.2.3 Animal Bedding

Livestock animal bedding is regularly chosen based on comfort, moisture content, cleanliness, inertness, and particle size (University of Massachusetts Amherst 2017). Biomass such as straw, hay, wood shavings, wood chips, and sawdust is commonly used because it meets a large portion of the recommended characteristics (University of Massachusetts Amherst 2017). Some livestock owners in Humboldt County are known for using mill residue from the local sawmills for animal bedding because it absorbs moisture and odor well (Furniss 2019).

2.4 Biomass Utilization in Humboldt County

Biomass has been used in Humboldt County to generate power since the late 1980s. Lumber manufacturing has been in Humboldt County for a century, which produced high volumes of unusable woody biomass (Furniss 2020). Local consumption of biomass for heating homes and animal bedding production are two uses of local biomass waste; however, the primary consumers of biomass in Humboldt County are the power plants. While the two local biomass power plants have performed some upgrades over the years to comply with state and federal emissions standards, concern remains about the potential adverse local public health and broader environmental consequences of combusting biomass.

2.4.1 Domestic Biomass Consumption

In Humboldt County, energy is consumed by three primary sectors: 1) transportation, such as gasoline and diesel (49%), 2) home heating such as natural gas, wood, and propane (33%), and 3) electricity (18%) (Zoellick 2005). Figure 5 illustrates this distribution of energy with wood only contributing a very small fraction, approximately 3% (Zoellick 2005).

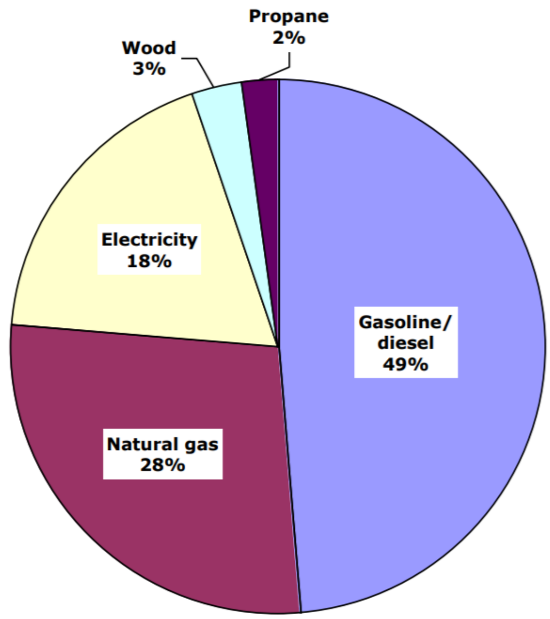

Figure 5. Energy usage in Humboldt County (Zoellick 2005).

According to a 2005 study, Humboldt County used 10,846 tons/year of wood fuel (combination of cord wood and manufactured logs) for fireplaces and 25,635 tons/year of wood fuel (combination of cord wood, compressed wood logs, and pellets) for all wood stoves (CARB 2015). Table 4 shows the total emissions associated with burning wood fuel in fireplaces and wood stoves for Humboldt County including CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2, Reactive Organic Gases (ROG), and NH_3 (CARB 2015).

Table 4. Emissions from wood burning in 2005 for Humboldt County in units of lbs per ton of fuel burned (CARB 2015).

Fuel Use	CO (lb/ton)	NO_x (lb/ton)	$PM_{2.5}$ (lb/ton)	PM_{10} (lb/ton)	SO_2 (lb/ton)	ROG (lb/ton)	NH_3 (lb/ton)
Fireplaces	805	15	128	133	3	106	9
Wood Stoves	2,416	33	298	309	5	454	17

2.4.2 Method of Power Generation

Humboldt County has two local sources of biomass power production, DG Fairhaven Power in Samoa and Humboldt Redwood Company in Scotia. Together, the two make up approximately 22% of renewable power purchased by RCEA (RCEA 2019). RCEA buys power from the two biomass plants and sells it to PG&E who owns the grid and distributes the power to Humboldt

County. RCEA projects that by 2030, there will be a major shift in local renewable power supply, as shown in Figure 6.

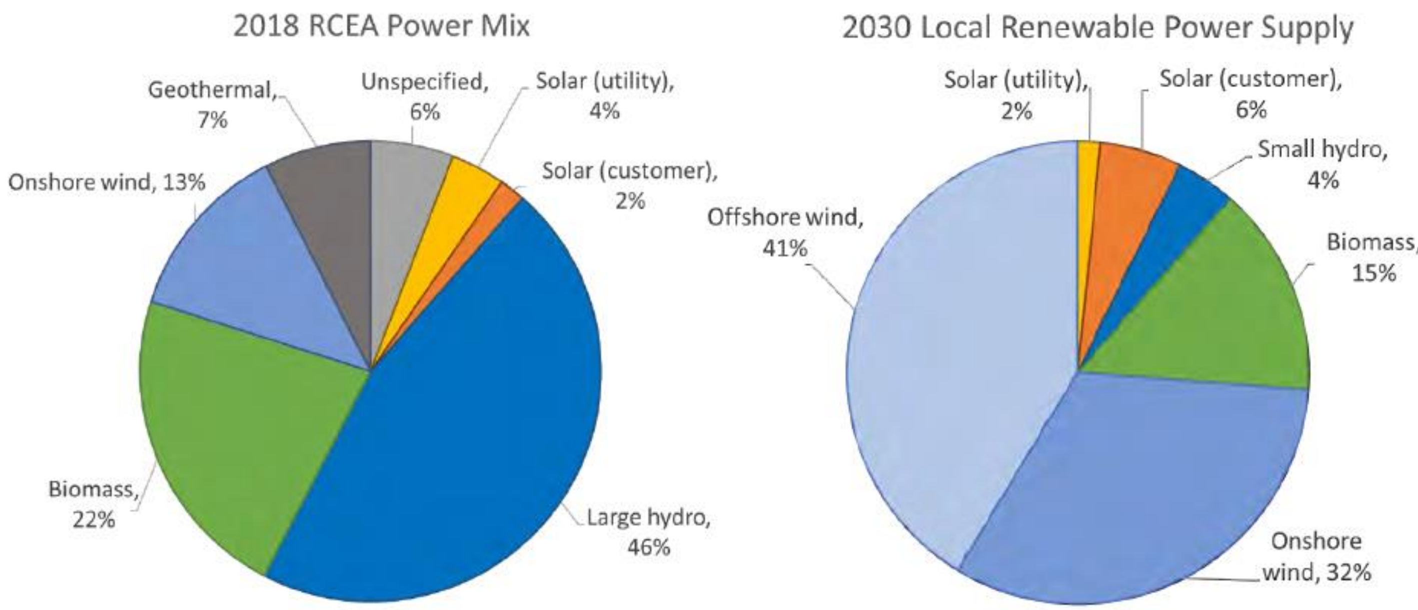

Figure 6. The source of energy serving Humboldt County in 2015 (RCEA 2019).

Figure 7 illustrates the mass flow of woody residue to the two power plants; the county sawmills produce 700 loads per week and distribute to both biomass power plants. Fairhaven receives 245 truckloads per week, and Scotia receives 350 truckloads per week; the power plants receive roughly 100% of the woody material received by the power plants is waste feedstock from sawmills (Furniss 2020).

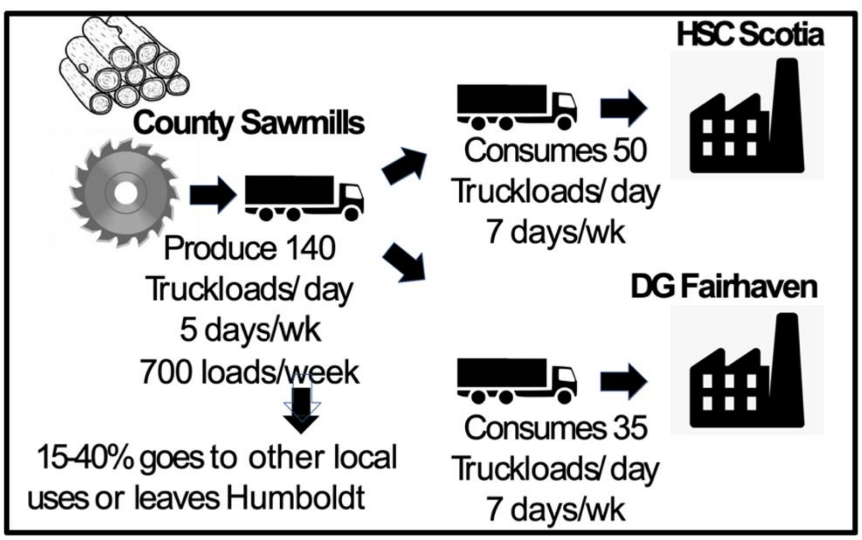

Figure 7. The process from the sawmills to the two biomass power plants: Fairhaven and Scotia Biomass Power Plants. One truckload equals 120 cubic yards (Furniss 2020).

The differences between the two RCEA power plants were the total electricity produced, the emission control equipment, and the total permitted air pollutant discharge.

2.4.2.1 Humboldt Redwood Company | Scotia, CA

The Humboldt Redwood Company is physically connected to the Scotia Biomass Power Plant; this significantly reduces the carbon footprint from trucking the biomass. The Humboldt Redwood Company has a 5-year contract with RCEA and has an average capacity of 13.25 megawatts (MW). The permitted air pollutant discharge of particulate matter (PM) is 0.10 pounds per million metric British thermal units (MMBTU) (Furniss 2020). Types of air control equipment that maximize air quality at this facility include multiple cyclones, electrostatic precipitator, and an overfire air system (Furniss 2020).

Cyclones

The cyclones are used to control and filter the particulate matter. Depending on the efficiency and cost of the equipment, the cyclones can filter particulate matter less than 10 micron-diameters (PM_{10}). The cyclone has more efficiency in filtering when the particulate matter increases in density, therefore other equipment is used to collect smaller particulate matter (EPA and NSCEP 2003).

More information about cyclones can be found in Appendix B.

Electrostatic Precipitator

The electrostatic air filter emits electric currents to charge the particles and cause them to stick to the plates surrounding them. This equipment emits ozone pollution, but compared to ozone generators, it releases less (State of California 2020a).

Overfire Air System

The overfire air system controls and reduces nitrogen oxide (NOx) pollutants. The system controls the NOx pollutant by converting the pollutant to dinitrogen (N_2) by separating the combustion air between primary and secondary flow sections (IEA 2018).

2.4.2.2 DG Fairhaven | Samoa, CA

The DG Fairhaven Power biomass power plant has a 1-year contract with RCEA and produces an average 10 MW of electricity to the grid. According to the general manager (GM) of the DG Fairhaven power plant, Bob Marino, the plant can produce 180,000 lbs. of steam per hour and generate one MW of power for every two tons of feedstock burned. He further claims that 1.75 MW of power produced each day is used to run facility operations. The permitted air pollutant discharge of PM for this power plant was 0.04 pounds per million metric British thermal units (MMBTU), as shown in Appendix C (Furniss 2020). The following types of equipment maximize air quality at this facility: mechanical multi-cyclone collector, electrostatic precipitator/collection plates, and overfire air system. The electrostatic precipitator has a transformer/rectifier attached that separates into three sections to filter out the PM.

Transformer/Rectifier

The transformer/rectifier is used to convert high voltage to a lower voltage, to increase efficiency of electricity consumption used to power the electrostatic precipitator/collection plates (Furniss 2020). The transformer/rectifier are separated into three sections that consist of wires to make an electrostatic precipitator (Marino, B. 2020).

Electrostatic Precipitator/Collection Plate

Electrostatic Precipitator/Collection Plates are used to filter the air coming from the combustion process of the woody biomass by charging the PM. This device requires high maintenance to ensure efficiency and performance (Permatron 2020). This process is significant due to it being the last air filter process before the air is released into the environment. According to the DG Fairhaven GM, the PM that is collected in this process is registered as organic and given to an outside source to be used by farmers for soil amendment, free of charge.

2.4.3 Public Perception

RCEA has reported frequent inquiries and complaints from Humboldt County community members about their use of biomass generated power. Currently, biomass accounts for approximately 22% of their local renewable energy source portfolio (RCEA 2019). Concerns generally fall under two categories: 1) greenhouse gas emissions, and 2) local air quality and public health.

One concern from community members is that biomass is not a zero GHG emissions renewable energy source, such as wind, hydropower, and solar power, as its combustion releases CO_2. With rising concerns over climate change, GHG emissions are of immediate importance because of implications such as extreme weather, food supply disruptions, increased wildfires, and sea level rise (NHE 2015).

The second category of public concern is local air quality. Criteria pollutants are produced by the current biomass power plants. Though the plants comply with all laws and regulations, including emissions limits, perception is that biomass as a renewable energy source does not feel like clean energy. Like coal generation, woody residue biomass power generation releases criteria pollutants, including carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), and fine particulate matter ($PM_{2.5}$ and PM_{10}) (Zielinska and Samburova 2011; EPA 2018, Zhou et al. 2019). Figure 8 shows a breakdown of public opinion on RCEA's renewable energy sources profile. The source for this data is a mix of feedback from sixty people attending four workshops assembled by RCEA in multiple parts of the county and approximately 390 written comments from community members (A. Singh, personal communication, 3/13/2020). The use of biomass as a renewable energy source is commonly debated. Benefits of its use, outlined above, are primarily in its use of a readily available waste product as well as its consideration as a carbon neutral renewable energy source by the state of California (CPUC 2020). Critics' concerns stem primarily from the air quality impacts and GHG emissions.

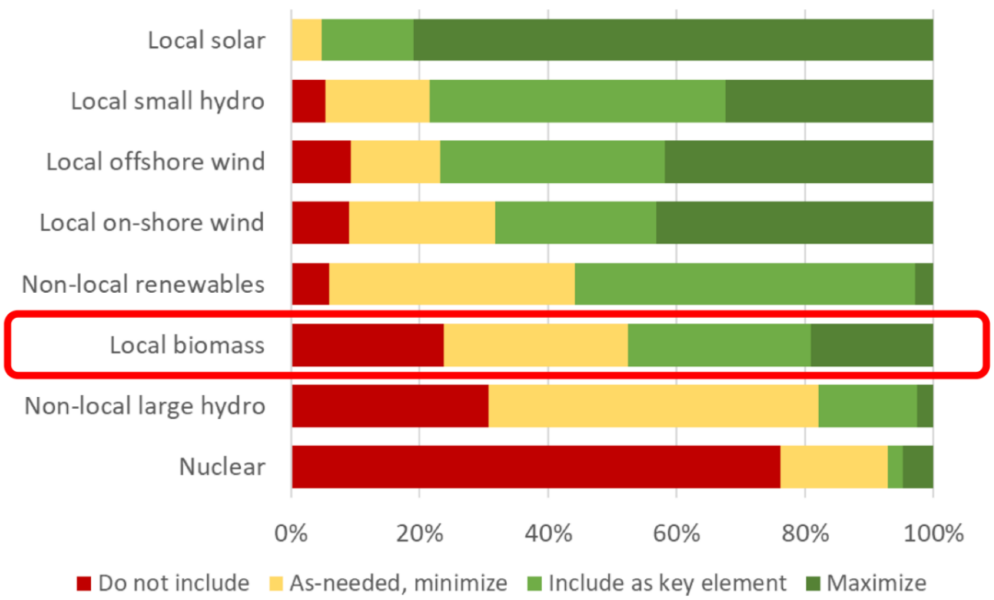

Figure 8. Public response to different sources of renewable energy contained in RCEA's renewable energy profile (RCEA 2020b). Local public perception of RCEA's renewable energy portfolio was sourced from a mix of feedback from sixty people attending four workshops assembled by RCEA in multiple parts of the county and approximately 390 written comments from community members (A. Singh, personal communication, 3/13/2020). Local biomass is circled in red (RCEA 2020b).

RCEA has reported frequent written comments from Humboldt County community members about its use of biomass as a part of their renewable energy portfolio; the following is an approximate breakdown of public perception and opinion sourced from a mix of feedback from sixty people attending four workshops assembled by RCEA in multiple parts of the county and approximately 390 written comments from community members (A. Singh, personal communication, 3/13/2020, RCEA 2020b):

- 24% wanted to eliminate the use of biomass for power generation
- 29% wanted use of biomass on an as-needed basis and to minimize its use
- 48% were in support of its use

It should be noted that the precise sample of the population is unknown and there is likely some bias introduced by survey locations. In Scotia, for example, a small town built around the lumber industry, community members could see the sawmill and associated power plant as a source of employment where jobs are scarce and would be likely to look on biomass power generation more favorably (Town of Scotia 2020). The City of Eureka, however, has a population of approximately 27,000, indicating that there are a sufficient number of jobs available in a more widely varied job market and the negative air quality effects outweigh the benefit of employment opportunities provided by the DG Fairhaven power plant (U.S. Census Bureau 2020a). Anamika Singh of RCEA stated that they try to get perspectives from different parts of the county to maximize community participation; however, the spatial demographics of the 390 written comment authors is unknown.

2.5 Alternative Site Considerations

There are two primary considerations for the feasibility of biomass use alternatives in Humboldt County: 1) that Humboldt County is a rural area, not easily accessible by land transportation, and 2) that the Humboldt Bay region is vulnerable to flooding from sea water inundation and rising groundwater levels due to climate change.

2.5.1 Transportation To, From, and Around Humboldt County

Important transportation considerations for alternatives stem from the County's location in non-urbanized northern California with a low population density of approximately 38 residents per square mile (USDA ERS 2019; US Census Bureau 2020b; County of Humboldt 2017b). Figure 9 shows Humboldt County's location relative to other areas of the state. Because Humboldt County is not as heavily populated as other areas of California, its roadway infrastructure is not as developed. Access to and from the County by land transportation is limited to three major thoroughfares; Highway 36, Highway 101, and State Route 299; the latter two are the main paths into and out of the County taken by commercial trucks (County of Humboldt 2017). Highway 101 and State Route 299 are both classified for Terminal Access under the federal Surface Transportation Assistance Act of 1982 while Highway 36 is classified as a 65-foot California legal truck route, where travel is advised against for certain trailer lengths (Caltrans 2020).

The primary alternative to ground transportation of timber and biomass products has been boat transportation, termed marine cargo, out of Humboldt Bay. According to the Humboldt Bay Maritime Industrial Use Market Study performed by BST Associates (2018), Humboldt Bay has 1,380 acres of property zoned for Coastal-Dependent Industry (CDI); though once in high demand due to pulp transport from the timber industry, declines in this industry have reduced the demand for CDI. This property is an option for the transportation of physical biomass products, though a decline in available CDI acreage is anticipated due to sea level rise (BST Associates 2018).

2.5.2 Sea Level Rise

Substantial work has been performed by local professionals to identify the time it will take for sea level rise to occur as well as vulnerability assessments to identify areas of particular concern for different increase thresholds; these areas include private residences, commercial and municipal infrastructure, major highways, and utilities serving the county (Laird 2018; NHE 2015).

Estimates for sea level rise in Humboldt County include the following timeline for high-end projections: 2030 (0.9 ft), 2050 (1.9 ft), 2070 (3.2 ft), and 2100 (5.4 ft). Approximately 58% of the 52 miles of Humboldt Bay shoreline are vulnerable to inundation with 3 feet of sea level rise, projected by NHE (2015) by year 2017. Shoreline protection is still in planning phases so considerations should be made when considering construction in the Humboldt Bay region.

Sea level rise, while not directly affecting all potential alternative sites, is an important consideration when planning long-term solutions for the use of Humboldt's biomass as transportation, utilities, infrastructure, and sites themselves are vulnerable to inundation.

Figure 9. Map showing Humboldt County in the context of California (Burke 2020).

2.6 Regulations

Regulations applicable to this project are those related to the current function of biomass as power generation in Humboldt County, which include air quality impacts, greenhouse gas emissions, and other potential uses, including solid waste and water quality impacts.

2.6.1 Impacts of Biomass Use

Often the environmental effects of operating biomass combustion plants are assessed on a large-scale or even global level to analyze climate change and global warming. Before these emissions spread through the atmosphere, they start as a concentrated point source. The negative effects that these emissions have on air quality, environmental impact, and public health are felt strongest in the local community.

The predominant particle diameter of emissions produced from the combustion of woody biomass is less than 2 microns (Dockery et al. 2012); particles of this size, referred to as $PM_{2.5}$ for having diameters less than 2.5 microns, are hazardous to human health. Epidemiological studies show that inhalation of PM is linked to a shortened life expectancy and more specifically, health effects such as asthma, heart attacks, and chronic obstructive pulmonary disease among other things (Dockery et al. 2012). $PM_{2.5}$ are extremely fine and can penetrate all sections of the respiratory system where they can then infiltrate the bloodstream causing systemic effects (Dockery et al. 2012). Sensitive population groups such as those with existing heart or lung disease, children, and the elderly are especially susceptible to the health effects of these emission and can experience complications at lower exposure levels (EPA 2019).

Along with particulate matter, GHGs are released into the atmosphere during the combustion of woody biomass. Among these are CO_2, N_2O, and CH_4 (EPA 2003). Though CO_2 is the most abundant gas polluting the air, N_2O has a global warming potential up to 300 times higher than CO_2 (Fern 2018). As the biomass power plants continue to meet emissions standards set by their Title V permits, the process of trucking the biomass to the plants from the sawmills still exists, contributing to total emissions load (RCEA 2020a). Using fossil fuel-powered trucks introduces new carbon into the atmosphere. Until the use of decarbonized transportation, such as electric vehicles, becomes the primary biomass transport method, there will continue to be a source of carbon into the atmospheric cycle.

As of January 2020, the Mauna Loa Observatory measured the earth's CO_2 concentration to be 413 parts per million (ppm) (NOAA 2020). The current rate of GHG emissions forced into the atmosphere by humans equates to approximate 37 billion tons of CO_2 (Fern 2018). The 2015 Paris Agreement on climate change is a near global pact with a shared goal to keep global temperature rise below 2 degrees Celsius for this century; at our current emission rate, we will fail to meet this goal within five years (Fern 2018). On a smaller scale, the pollutants can create a haze in the immediate vicinity of the biomass plant that reduces visibility which damages the aesthetic quality of local national parks and sightseeing (EPA 2019).

2.6.2 Local Regulations

Humboldt County's current biomass power generation plants and possible alternatives considered must comply with all local planning requirements. The permitting authority for land-based electricity generators under 50 MW are City, County, and tribal governments (Phinney 2011). Current and potential regulators include agencies overseeing air quality standards, water quality standards, the use/disposal of waste products, and project compliance permitting and reporting through the California Environmental Quality Act (CEQA) and/or the National Environmental Policy Act (NEPA), whose assessment would be made and reviewed at the local level.

2.6.2.1 Air Quality

The North Coast Unified Air Quality Management District (NCUAQMD) issues Title V permits to three biomass plants in Humboldt County, including the two operating plants, the Scotia plant, owned by Humboldt Redwood Company, LLC, and the Fairhaven plant, DG Fairhaven Power, LLC. The third plant, located in Blue Lake, is no longer in operation. Furniss (2020) noted in his January 2020 report that emissions monitoring occurs at the stack of the operating plants, but ambient air quality monitoring does not occur at the locations at which residents would be exposed to these emissions; these locations include Eureka and Fairhaven. Locally enforceable general requirements, covered in both permits, include the following (NCUAQMD 2019a; NCUAQMD 2019b):

- Applicability
- Emissions and Operation
- Permit Term
- Administration
- Records and Training
- Severability

2.6.2.2 Water Quality

Local water quality oversight is performed by the Region 1 of the California State Water Board, the North Coast Regional Water Quality Control Board (NCRWQCB). It is not likely that the preferred alternative will discharge to surface water but if it does it will require a National Pollution Discharge Elimination System (NPDES) permit, designated by the NCRWQCB.

2.6.2.3 Use or Disposal of Waste Products

Solid waste produced by the Humboldt County biomass incineration power plants includes char, also called biochar, and fly ash. According to Bob Marino, General Manager of DG Fairhaven Power, their biochar goes to a local company that produces charcoal filters and they give their wood ash, also called fly ash, to local farmers as an organic soil amendment used to reduce the pH of soil; the latter method of disposal requires testing according to their NPDES permit, section VI.C.6.b. In general, if waste products from incineration plants are not recycled, they are disposed of in a landfill, which would not result in a permitting requirement as the transported materials would not be hazardous.

2.6.3 State Regulations

The state of California regulates air quality through Division 26 of the Health and Safety Code of California. Because the state does not have restrictions specific to emissions for biomass, California adopts the federal regulations under 40 CFR Part 71. The California Air Resources Board (CARB) is responsible for setting California's emissions standards for a range of pollution sources including vehicles, consumer products, and fuels (CARB 2020b). Under AB2588, the Air Toxics "Hot Spots" Information and Assessment Act, it is required that stationary sources such as biomass power plants, routinely report emissions (CARB 2020a). Enacted in 1987, the Hot Spots act is used to identify and access facilities with potential "local sized impacts" (CARB 2020a).

2.6.4 Federal Regulations

The federal regulations regarding air quality, water quality, and energy are found in 40 CFR Part 71, Title V: Protection of Environment. These regulations have requirements for the following standards: emission limitations, permit durations, and monitoring. Emission limitations are a set amount of pollutant discharge allowed into the environment. The Title V permit duration includes a 5-year term which cannot be exceeded, unless the permit is for a solid waste incineration unit, where the permit duration is 12 years and reviewed every 5 years. The monitoring required by the permit includes data logging and the ability to be able to inform the agencies, mentioned below, of the values that are required from the regulators (Federal Register 2020).

The federal departments and agencies that deliver policies and regulations for biomass energy are the Environmental Protection Agency (EPA), United States Department of Agriculture (USDA), and Department of Energy (DOE). The President issued the Consolidated Appropriations Act on March 23, 2018, containing policies for biomass energy. The act addresses the mission to establish policies and regulations issued by the EPA, the USDA, and the DOE and states that the policies should originate from forest products, not by cutting down trees or changing the forests' ecosystems strictly for biomass power production (Royce 2018). The policies were addressed to the agencies, who responded to congress to ensure that the biomass reflects characteristics of renewable energy. Federal departments and agencies responded to the enactment with research stating that a billion tons of biomass annually can be used for energy to meet clean, cost-efficient, and safe energy goals (Wheeler et al. 2018).

2.6.4.1 Environmental Protection Agency

The EPA's goal is to protect human health and the environment. To ensure public and environmental health, there are laws that the congress writes, and the EPA regulates which include the Clean Air Act, Clean Water Act, and Toxic Substances Control Act, etc. The EPA can reach its goals by distributing grants, researching, and developing environmental policies, and educating the public and etc. (US EPA 2013).

2.6.4.2 United States Department of Agriculture

The USDA supports the following information for public policy: agriculture, natural resources, and rural development, etc. Their policies help preserve natural resources through conservation and restoration of forests, watersheds, and private working lands (USDA 2020).

2.6.4.3 Department of Energy

The DOE has many scientific research programs aimed at energy efficiency, renewable energies, fossil fuels use. They also maintain a database of electricity consumption. The DOE funds these programs to provide education and solutions for sustainability and improvements in energy and the environmental preservation (U.S. Global Change Research Program 2020).

3 Alternatives

Four feasible alternatives were evaluated for their ability to address criteria based on the objective of the project. Each alternative was assessed assuming a 50 percent moisture content, 247 kg/m^3 density, and a total of 561,600 metric tons (MT) per year of biomass which utilizes only 80% of the County's source of excess biomass. To simplify comparative analysis across preliminary alternatives, the following assumptions were made: 1) Humboldt Redwood Company, LLC delivers excess biomass directly to alternative facility site in Samoa, and 2) no trucking emissions were accounted for in comparative emissions analysis.

3.1 Alternative 1 | Production of Synthetic Natural Gas via Gasification

3.1.1 Project Description

The first alternative evaluated was power plant utilizing a gasification system that would produce electricity via production and combustion of syngas along with a consistent production of high-quality biochar. It is assumed that the plant would be located on the Samoa peninsula and would continue to receive the biomass from local mills in Humboldt County by truck. The electricity generated by the system would be fed directly into the local power grid which would generate most of the plant's revenue by charging buyers on a per kWh basis. The biochar byproduct would be sold and trucked to another entity where it would be distributed as soil amendment or used to produce products such as air or water filters.

The design plant consists of 9 modular gasification systems that would produce approximately 3 MW of electricity per unit with the design biomass throughput amount of 561,600 MT per year. This number of units allows for the use of 80 percent of the biomass waste that would otherwise go to DG Fairhaven and Scotia power plants.

Each system consists of the following processes, in order of treatment train:

I. Metering Bin
II. Dryer
III. Rotary Gasifier
IV. Thermal Oil Heater
V. Organic Rankine Cycle Generator

The metering bin stores and consistently feeds high-moisture biomass onto a conveyer that leads to the dryer. The dryer heats the biomass to evaporate water to a target moisture content of 10%. The reduction of moisture prior to gasification reduces emissions and improves the efficiency of the system (Granö 2013).

Generally, gasification is performed at temperatures exceeding 900° C. The rotary gasifier heats the biomass at a lower temperature, approximately 450-600° C, without combusting it to produce a combination of HHV producer gas and combustible vapors (Summers et al. 2016). The producer gas consists of a combination of CO, H_2, CH_4, N_2, CO_2, ethylene (C_2H_4), and ethane (C_2H_6).

Formation of the syngas is driven by the following two chemical reactions (Basu 2010):

- $C + H_2O \rightarrow H_2 + CO$ steam producing monoxide
- $CO + H_2O \leftrightarrow CO_2 + H_2$ water gas shift reaction

During the gasification process, air is injected into the gasifier. West Biofuels LLC performed a study in 2019 that showed when air is injected into a gasifier, the volume of producer gas increases and is more readily combustible while reducing the portion of biomass converted into biochar (Summers et al. 2019). The thermal oil heater is a heat exchanger that is used to combust the HHV producer gas and present vapors sending the resulting heat to a hydraulic fluid. The fluid is circulated in a loop to constantly heat air which powers an Organic Rankine Cycle (ORC) turbine generator to produce electricity. Waste heat produced by the thermal oil heater is redirected and utilized in the drying process prior to gasification. The ORC generator does not use steam but rather uses a hydrocarbon working fluid to heat air. These types of generators, when compared to engines, have lower maintenance cost and have been shown to be more reliable (Summers et al. 2019). Figure 10 shows the process of biomass goes through in order to generate electricity and biochar.

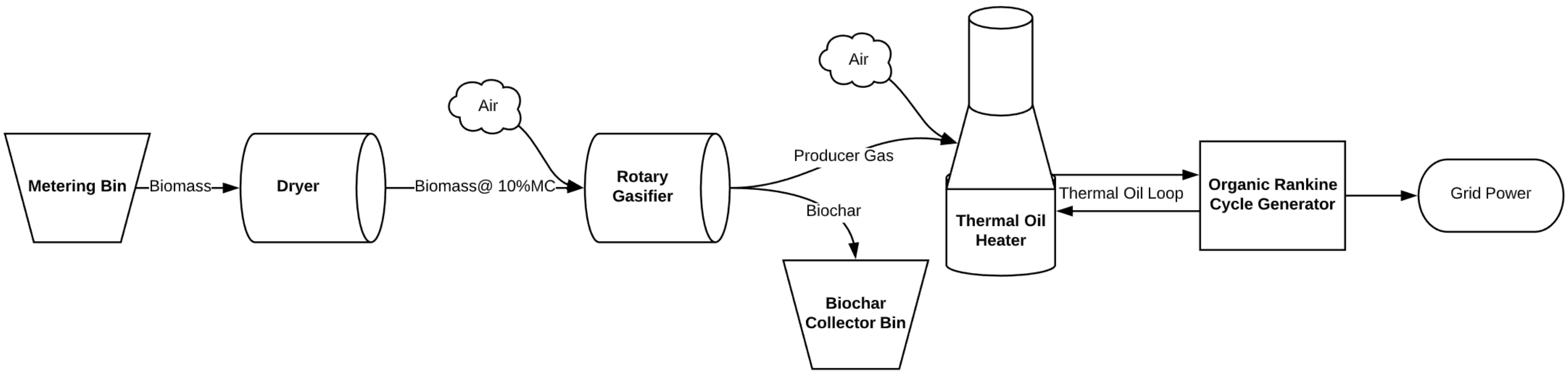

Figure 10. Diagram of energy and gas production via gasification (Barr 2020).

Air and woody biomass at 10% moisture control are the only two inputs required for gasification. The mass/energy outputs of the gasification process include the following end products (Summers et al. 2019): 1) HHV producer gas (45% of biomass dry weight), 2) combustible vapors, water, and C_3+ compounds (38% of biomass dry weight), and 3) biochar (17% of biomass dry weight).

3.1.2 Analysis of Social Criteria

Looking to the frequently asked questions and concerns that the public conveyed to RCEA (Appendix A), this alternative effectively addresses three of the six. It is not necessary to cut down trees to provide feed for the plant, gasification is considered a more modern alternative than combustion, and a large amount of biomass is being reused in the form of biochar instead of energy production. The proposed location of the plant encompasses enough land for the 10 acres needed for the modular gasifiers. The plant height is estimated to be 30 feet based on a similar torreactor system designed by TSI Inc (TSI 2014). Comparable thermal oil heaters dictate the height requirement as most components of the system are horizontally oriented (TSI 2014). Population impacted by plant operations is based on the number of residents within a 1-mile radius. There are approximately 1,000 people within a mile of the Samoa Peninsula.

3.1.3 Analysis of Economic Criteria

Capital costs include the cost of land, and parts and equipment required to assemble each modular system. The following costs are estimated for one modular unit: truck unloading and fuel yard equipment ($200,000), feedstock sizing equipment ($350,000), metering and conveyance ($200,000), feedstock dryer ($600,000), rotary gasifier ($2,500), thermal oil heater ($2,600), ORC generator ($4000), and interconnection gear ($300,000). These costs, affiliated with the construction of one modular 3MW gasifier system, were simplified to a $5625/kW ratio. Costs were scaled up by 9 to accommodate the necessary throughput taking capital costs to approximately $152,625,000. These cost estimations projected by West Biofuels are shown in Appendix D.

Annual O&M costs considered were manager-level staff, labor-level staff, trucking of biochar product, insurance, property taxes, utilities, administration. The following is a breakdown of these costs: eight employees ($700,000), insurance, property taxes, utilities, and administration combined ($225,000). Annual maintenance costs of various equipment, such as the generator, conversion system, and feedstock handling equipment equate to $664,000 per year. These O&M costs were simplified to $684/kW and scaled up by the number of units required. When the annual cost of trucking the biochar out of the facility is included, $2,807,000, the total annual O&M are estimated to be $21,275,000 per year.

Revenue is provided through the sale of electricity and biochar. It is assumed that $0.065 is made for every kWh produced (Engel and Singh 2020). With an estimated 27 MW power production, the plant is projected to create over 236,520,000 kWh of energy generating around $15,374,000 in revenue through electricity sales. A conservative estimate for biochar sales was set at $500 a ton. The plant can produce about 48,000 tons of char per year to sell for approximately $23,868,000. Total expected annual revenue comes out to approximately $39,242,000.

Payback period was determined through a cash flow analysis of the annual revenues and O&M costs. The factors used to determine the payback period are shown in Table 5. It was determined that it would take approximately 8.5 years for the net cash inflow to offset the initial investments of the facility.

Table 5. Costs used to calculate payback period for gasification alternative

Financial Item	Cost	Item Description
Total Capital Required	$ 152,625,000	Building, land, machines only
Annual O&M	$ 21,275,000	Electricity, water, corporate taxes, employees, land taxes, equipment maintenance, shipping price
Annual Gross Income	$ 39,241,800	Electricity and Biochar Revenue
Annual Net Cash Flow	$ 17,967,000	O&M less Gross Income
Payback Period (Years)	**8.5**	

3.1.4 Analysis of Environmental Impacts Criteria

In general, gasification emits fewer criteria pollutants by mass per unit of energy than combustion (Basu 2010). Table 6 shows the annual GHG and criteria pollutant emissions produced by the plant's operations. Pollutant performance characteristics are based on a next generation thermochemical conversion power plant that provides a lb/MMBTU output (Carreras-Sospedra et al. 2016). This table of characteristics comparing different biomass energy plants can be found in Appendix E.

Table 6 . Emissions comparison for gasification plant with median annual pollutant emissions from the Humboldt County biomass power plants, Humboldt Sawmill Co. and DG Fairhaven Power LLC from 2011 – 2017 (CARB 2020d & Carreras-Sospedra et al. 2016).

Emission	Gasifier Operation Emissions	Current Combustion Plant(s) Emissions	Percent Reduction of Pollutant
NO_x, tons yr^{-1}	3.2	329	99%
SO_x, tons yr^{-1}	0.8	60	99%
PM, tons yr-1	12.9	129	90%
CO, tons yr^{-1}	16.9	2,217	99%
VOC, tons yr-1	1.2	48	98%
CO_2, tons yr-1	280,000	474,000	41%

Approximately 17% of product that is fed through the gasifier is converted into biochar (Summers et al. 2016). Annually, his amounts to about 52,600 tons of high-quality biochar containing a carbon percentage of nearly 70%. The CO_2 equivalent (CO_2e) of carbon sequestered via biochar is estimated to be 121,700 tons per year. This carbon would be prevented from entering the atmosphere as emitted pollutants and can be used by the community and sent to distributors. This alternative can utilize all the biomass currently used to generate power through combustion at the two current plants with the installation of 9 modular gasification systems. In order to reach the minimum amount of biomass usage under the project's constraints, 80%, 7 of these systems would be required.

3.1.5 Summary of Advantages and Disadvantages

The advantages of the gasification alternative are the following:

- Produces 2 different products of value
- Lower criteria pollutant and GHG emissions compared to current use
- Significant carbon sequestration

The disadvantages of the gasification alternative are the following:

- High capital cost and lots of equipment
- Longer payback period relative to other alternatives
- Requires lots of equipment

3.2 Alternative 2 | Biochar Production

3.2.1 Project Description

Biochar is a carbon-rich solid material produced by the low-oxygen to anaerobic decomposition of biomass (Abdel-Fattah 2015, Amonette et al. 2016). It is essentially produced by a process that uses heat to break down carbonaceous material. Its production dates back an estimated 9,000 years to the *terra preta* of Central America, where it was used as a soil amendment in soils of low fertility (Sohi et al. 2010). The primary uses of biochar today are to amend soils for commercial crop yield improvement and contaminated site remediation with the co-benefit of sequestering carbon (Chew et al. 2020, Wang et al. 2015, Abdel-Fattah 2015). Biochar's adsorptive properties also make it an excellent remediation medium, as it has the ability to treat contaminated air and water (Oginni et al. 2020, Wan et al. 2020).

A low-quality Biochar is currently generated as a byproduct of combustion in the Humboldt County biomass plants. As biochar production is not the primary goal of the power plants, its production and profitability are not optimized. The biochar produced by DG Fairhaven could be purchased for use by a local carbon filter producer and the fly ash is given to local farmers for use as a soil amendment.

There are various methods of producing biochar and the method chosen is based on the end-product desired, as facilities that produce biochar can also produce heat, bio-oil, gases, syngas, and carbon black, a paracrystalline carbon-based industrial chemicals (WASDE 2011, Toth et al. 2018). As the optimization of gas production as a possible alternative was addressed in section 3.1, the choice of reactor was based on the targeted final product of biochar. Biomass to biochar conversion machines are available on the commercial market so comparisons of key variables were made amongst available technologies, which generally accept biomass inputs of 50 to 1,000 kg per hour (Amonette et al. 2016, Manyà et al. 2018, Severy et al. 2018). The machine that aligned best with the criteria defined for this project was chosen for further analysis as a preferred equipment for the alternative.

The chosen technology essentially consists of a crusher, a dryer, a pyrolysis 'carbonization host', and a briquetting machine. Combustible gas is purified and transported to the burner to heat the pyrolysis furnace while other and excess gases are flared (Beston 2020). This process is shown in more detail in Figure 11.

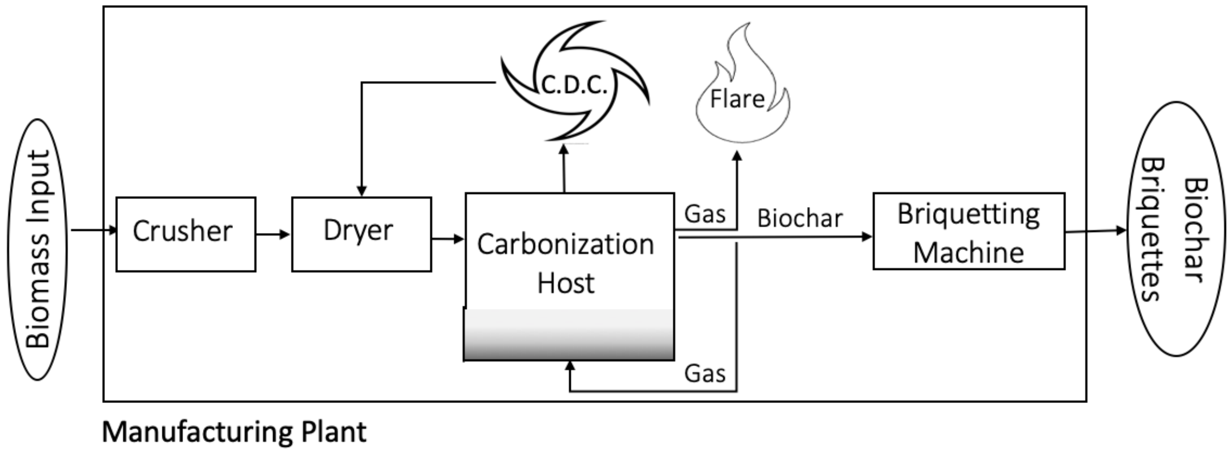

Figure 11. Diagram of process to produce biochar from Humboldt County biomass supply (Burke 2020).

The process of conversion of the dried and crushed biomass to high-quality biochar is performed in the absence of oxygen, at temperatures ranging from approximately 300°C to 450°C, which is termed slow pyrolysis and is optimal for the production of biochar over gases. The major chemical reaction involved in pyrolysis reactions is shown below, where wood with some moisture content reacts with applied heat to form CO in the reactor; those gas outputs are flared to produce steam and pollutant gases.

$$C_xO_yH_z + heat \rightarrow CO + H_2 + H_2O$$

Analysis of the chosen biochar production technology was performed by the creators of the machine for ease of operation, conversion efficiency, and emissions produced (Beston 2020). CHaRM was given a quote, technical specifications, and emissions values for Beston’s highest capacity machine, the Carbonization System BST-30, specifically recommended for the type of biomass under consideration in Humboldt County and the desired final product (B. Hao, personal communication, 2020). The unit would need to be scaled up by 21 times to use the 80% of the mass currently consumed by power plant operations in Humboldt County, estimated to be approximately 562,000 MT per year.

3.2.2 Analysis of Social Criteria

The organic soil amendment and air and water cleansing properties of high-quality biochar make it an easily accepted end-product for the biomass generated in Humboldt County, as County residents are generally receptive to products that improve the natural environment. Also, producing biochar with the identified method shows a substantial reduction in emissions in its production, indicating that it would likely be a more acceptable use of the material than the current use of power production. As the biochar production alternative does not produce energy, it addresses three of the FAQs addressed by the public to RCEA (Appendix A).

The production facility site was chosen based on accessibility from the sawmills generating the biomass as well as minimizing the height of the facility and the population density within a one-mile radius. The site chosen for this alternative is the current site of the DG Fairhaven power plant and surrounding parcels to make up sufficient land for the required 20-acre area. It was assumed that there are enough available CDI parcels to accommodate the site needs.

3.2.3 Analysis of Economic Criteria

Economic analysis of the biochar production alternative was performed through a determination of the number of local jobs provided under the alternative, a payback period for the facility, and the ease of implementation of the facility. The payback period analysis was an even cash flow simple assessment and included a net balance of the capital cost to build the facility, O&M costs, and sales of the final product. As the facility generates over 60% of the GHG emissions and over 99% of the criteria pollutant emissions and community questions stem from air quality concerns, implementation of the alternative is not predicted to be difficult. One issue with the production of biochar in Humboldt County is that there is not a sufficient local demand for all of the product so it must be transported out of the area. As the issue of transportation around and out of Humboldt County makes it more difficult to industrially produce consumables; transportation was a major consideration for economic criteria and made up approximately one third of the annual operation and maintenance expenses and was based on the quote shown in Appendix F. The cost of land was estimated at $76,000 per acre and was based on an available CDI-zoned parcel (Appendix G). Table 7 shows the primary categories of costs used to determine the payback period of 2.5 years, which is the ratio of the cost of investment to the annual net cash flow. A full breakdown of the costs can be seen in Appendix H.

Table 7. Costs used to determine the payback period for the biochar production alternative.

Financial Item	Cost	Item Description
Total Capital Required	$129,182,000	Building, land, machines
Salvage Value	$437,000	10% Cost
Cost of Investment	$128,745,000	Capital costs minus salvage value
Annual O&M	$33,690,000	Electricity, water, corporate taxes, employees, land taxes, equipment maintenance, shipping price
Annual Gross Income	$84,240,000	Biochar sales (COGS)
Annual Net Cash Flow	$50,551,000	Gross Income less O&M
Payback Period (Years)	**2.5**	

3.2.4 Analysis of Environmental Impacts Criteria

The following table, Table 8, shows a comparison of the estimated emissions from the scaled production unit (Appendix I) with the median annual pollutant emissions from the Humboldt County biomass power plants, Humboldt Sawmill Co. and DG Fairhaven Power LLC from 2011 – 2017 (CARB 2020d, CARB 2020e).

Table 8. Emissions comparison for Beston biochar production machine unit with Humboldt County biomass power plants (Beston 2020); Median annual pollutant emissions from the Humboldt County biomass power plants, Humboldt Sawmill Co. and DG Fairhaven Power LLC from 2011 – 2017 (CARB 2020d, CARB 2020e).

	Biochar Production Machines	Electricity Used by Machines	Total from Both Power Plants	% Reduction of Pollutant
CO_2, tons yr^{-1}	188,881[1]	0.765	434,251	56.5
NO_x, tons yr^{-1}	0.021	0.00	329	100
CO, tons yr^{-1}	0.020	-	2,217	100
SO_2, tons yr^{-1}	0.000	-	60	100
Hydrogen sulfide, tons yr^{-1}	0.000	-	-	-
PM, total tons yr^{-1}	0.002	-	129	100

1. Obtained through mass balance as was not reported by SGS emissions report on machine.

The emissions report conducted for the Beston machine did not include CO_2 so it was calculated using a mass balance approach, which accounted for the incoming biomass containing 53.5% carbon and the carbon content of the biochar and the recalcitrant portion of the biochar being 79% and 97%, respectively (Gaur and Reed 1995, Timmons et al. 2017). Electricity emissions were calculated using the 2018 California Electricity Profile (US EIA 2020).

Along with the reduction in most pollutant emissions, the environmental benefits of biochar production include co-benefits of carbon sequestration and the end-product usefulness for remediation activities. The negative environmental impacts of biochar production, in general, could potentially be outweighed by its benefit to remediation activities. Though this is not a measurable effect, biochar production's advantage of carbon sequestration and remediation capacity indicate its usefulness in helping to meet global climate change and general environmental health goals.

3.2.5 Summary of Advantages and Disadvantages

The advantages of the biochar production alternative are the following:

- Reduces criteria pollutant emissions under current use by over 99%
- Production of a material used for soil enhancement for agricultural uses
- Relatively short payback period
- Addresses several community concerns over biomass power production
- 60% lower CO_2 emissions than current use

The disadvantage of the biochar production alternative is the following:

- Relatively high capital cost, would require substantial investment(s)
- Low local job creation

3.3 Alternative 3 | Composting with Local WWTP Utilization

3.3.1 Project Description

Wastewater treatment plants (WWTPs) are complex biological systems present in most communities. Their already existing large footprint and ability to break down organic matter make them a potential entity to utilize woody biomass. Six local wastewater treatment plants in Humboldt County were evaluated to implement biomass utilization including McKinleyville, Arcata, Eureka (Elk River WWTP), Ferndale, Fortuna, and Rio Dell.

Wastewater treatment plants can utilize biomass several ways; this could include mixing dewatered sludge with biomass to make Class A biosolids, using biomass as the primary media in trickling filters, and controlling odor from the biogas with biomass. Excess biomass will be composted at a local 36-acre site on the Samoa Peninsula, as described in Appendix J. Because these local WWTPs are already existing facilities, the only additional inputs would be biomass; outputs would include Class A biosolids, filtered air, treated water, and compost.

Class A biosolids are a nutrient-rich byproduct of treated dewatered sludge that are virtually free of pathogens; they have strict standards with regards to metals, vector attraction, and pathogens as specified by 40 CFR Part 503 (Lystek International 2020). As a Class A biosolid, it enables it to be used for any land application (Lystek International 2020). McKinleyville, Eureka, and Ferndale all fail to produce Class A biosolids; with a more efficient dewatering process and mixture with biomass, the three plants could potentially produce Class A biosolids through utilization of biomass (City of Eureka 2020, McKinleyville Community Services District 2020, NCRWQCB 2018a). The WWTPs of Arcata, Fortuna, and Rio Dell all currently produce Class A or Class A Excellent Quality biosolids (City of Rio Dell 2020, Institute for Local Government 2015, NCRWQCB 2011). Fortuna currently mixes green waste with their dewatered sludge to decrease the percentage of violating parameters such as metals (NCRWQCB 2011). The green waste could be replaced with the County's excess biomass. The mixing ratio of biosolids to biomass was calculated based on required moisture content (40-60%), density (less than 600 kg/m^3), and carbon to nitrogen ratio (20-40 C:1 N) (Rynk 1992). It was determined that the mixture would consist of 20% hay, 61% biosolids, and 19% biomass. The amount of biosolids produced at each treatment facility is based on Fortuna's production and scaled based on each individual wastewater influent.

Trickling filters are aerobic systems that use microorganisms attached to a medium as a biological film to consume organic matter (EPA 2000). As the wastewater is sprayed evenly across the top of the media in a tower or column, the microorganisms treat the water. When the biological film becomes too thick, it will fall through the media to be collected in a clarifier (Beychok 2017). The Eureka WWTP currently has two trickling filters with a combined 12 million gallon per day capacity (NCRWQCB 2016). It is assumed that each filter is approximately 100 feet in diameter and 30 feet tall, each possessing a volume of 235,619 ft^3. By replacing the current plastic media with biomass, it would aid in alternative utilization of the County's excess biomass. The media used in trickling filters needs to be durable, light weight, low cost, allow air to flow through, and have a high surface area to support biofilm formation (Eawag and Spuhler 2020); all of which biomass should be able to support. It is assumed that the media in the trickling filter would be replaced every four months (Pleasant 2010). Once removed, it is assumed that the media will be composted at the commercial composting facility designed under this alternative. Figure 12 shows a schematic of a typical trickling filter used for wastewater treatment (Beychok 2017).

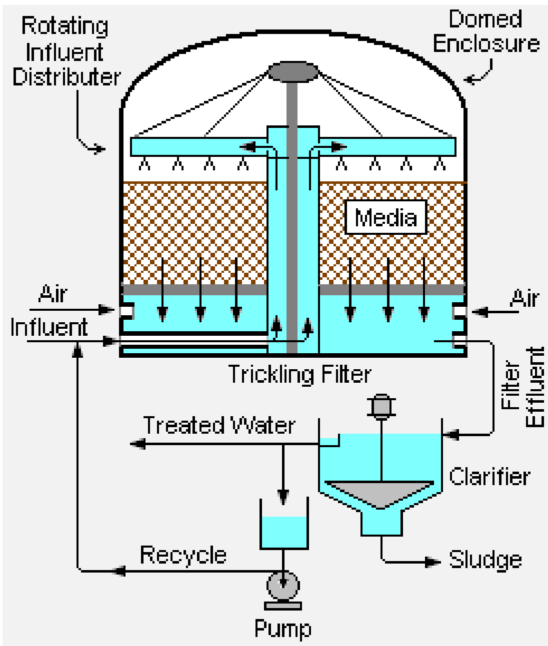

Figure 12. Schematic of typical trickling filter used for wastewater treatment (Beychok 2017).

Odor is a primary concern associated with wastewater treatment plants. The Fortuna and Eureka WWTP both implement odor controlling processes to minimize smell to the nearby community. Fortuna utilizes two large wood chip piles to cover the aeration from the headworks each approximately 8 ft wide, 65 ft long, 2 ft tall, for a total of 1,040 ft^3 (NCRWQCB 2011). Eureka has a more complex air purifier that uses activated carbon to reduce smell from the wastewater going into the trickling filters (NCRWQCB 2016). It is assumed that the Eureka WWTP's odor control system is approximately 12 ft in diameter and 30 ft tall (1,131 ft^3). Both facilities could replace their current air filtration with the excess biomass. Like the media in the trickling filter, the media in the odor control would be replaced every four months and composed at the off-site facility once depleted.

Figure 13 illustrates the proposed process of distributing excess biomass to compost along with local wastewater treatment plant utilization. Arcata and Rio Dell would not able to implement any of the proposed utilization practices.

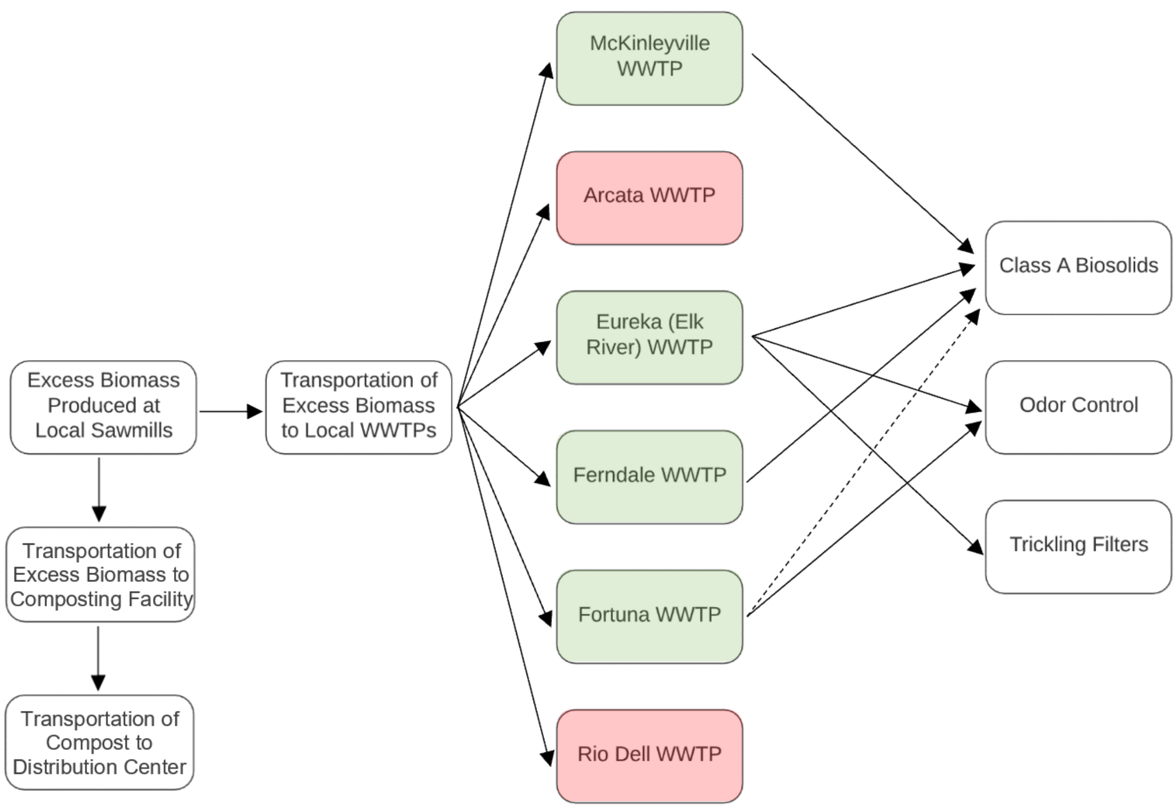

Figure 13. Compost and local WWTP biomass utilization flowchart (Phillips 2020).

Composting is the process of decomposing organic matter which can be used as a soil amendment (Tchobanoglous and Kreith 2002). The proposed composting facility would require 379 long piles (referred to as windrows) assuming a semi-circle shape, each 200 feet long, 6 feet tall, and 9 feet wide. This is based on utilizing only 80% of the excess biomass in Humboldt County, subtracting out the biomass that would be used for producing Class A biosolids. A half-cylinder shape is best suited for Humboldt County due to its annual amount of rainfall, opposed to a rectangular shaped pile that would collect more water (Tchobanoglous and Kreith 2002). There would be no forced aeration systems implemented, just aeration by turning the piles every three days with a bucket loader. It is assumed that local cow manure, density of 65 lb/ft^3, will be donated to mix with the compost (Lorimor and Powers 2004). Hay would be purchased for $220/ton and would be blended with the other components in the composting process (USDA 2020b). The compost would require a mixture of 40% hay, 15% manure, and 45% biomass to meet the moisture, C:N ratio, and density requirements. Due to less compost demand in Humboldt County, half of the compost will be to a distribution center weekly in the Santa Rosa, California area, where the demand from farmers is high. A freight cost quote for transporting the compost to Santa Rosa can be seen in Appendix F.

3.3.2 Analysis of Social Criteria

By eliminating the combustion of biomass for power, the local air quality would increase, addressing a majority of the public's concerns. Three of the six frequently asked questions RCEA composed based on public concerns (Appendix A) would be addressed. Aesthetically, the proposed alternative enables the excess biomass to be utilized locally at already existing facilities so no additional buildings would need to be constructed other than the 36-acre lot used for the composting which would consist of 6-foot high piles. The radius of those impacted by the WWTP implementation is already existing based on where the WWTPs are located; those impacted by the composting include 1,000 people within a 1-mile radius.

3.3.3 Analysis of Economic Criteria

With regards to local employment, the implementation of this alternative would require 75 compost workers, assuming it would create 1 job for every 18,500 tons per year of compost ($43,342 per employee per year) (Glassdoor 2020, IWMC 2019). Cost was evaluated using a payback period that accounted for O&M, profit, and capital costs as shown in Table 9, O&M costs would account for the 75 employees ($3.25 million), trucking expenses ($40.5 million), hay cost ($121.6 million), cleaning the trickling filters ($3.3 million), and O&M associated with composting ($1.5 million) (Eriksson et al. 1996, EPA 2000, Tchobanoglous and Kreith 2002, USDA 2020b). Profit is based on selling half of the compost for $20 per cubic yard (/yd^3) with a 30% discount selling directly to a distributor and half locally for $38/yd^3 totaling over $178 million per year (Faucette et al. 2004, Grow Organic 2020, Sonoma Compost 2020, Wes Green Landscape Materials 2020). The cost associated with the odor control maintenance and producing Class A biosolids would be accounted for in the current salary for employees at each WWTP. Capital costs would cover the property for composting ($2.7 million), equipment such as bucket loaders and shredders ($1.5 million), construction ($691,709), engineering ($287,940), and utility hookups ($236,988) (Tchobanoglous and Kreith 2002). An inflation rate of 197.4% was accounted for the values that were scaled from Tchobanoglous and Kreith from 1990 (Dixon

2020, Tchobanoglous and Kreith 2002). The cost of the property is based on the average $75,000 per acre for Samoa Peninsula, as explained in Appendix G. Given the O&M and capital costs, the payback period would be approximately 2.8 years, calculated using an averaging method, where the payback period is the ratio of capital costs to annual cash flow.

Table 9. Summary of expenses associated with composting and WWTP utilization.

Financial Item	**Cost**	**Item Description**
Capital Costs	$2,700,000	Cost of land
	$1,540,000	Equipment (bucket loader, shredder)
	$1,216,637	Construction, engineering, utility hookup
Annual O&M	$3,251,000	Employee salary
	$40,534,000	Trucking expenses
	$3,301,200	Trickling filter maintenance and operation
	$121,557,000	Hay costs for compost mix
	$1,517,000	Composting maintenance and operation
Annual Income	$170,126,000	Income from compost sales
Payback Period (Years)	**2.8**	

Because each wastewater treatment plant already has a National Pollutant Discharge Elimination System (NPDES) Permit, the modifications of this alternative could be easily added to it. For the composting facility, there is a total of five required permits including a NPDES permit, Compostable Materials Handling Facility Permit, permission to operate permit, construction permit, and an air quality permit (State of California 2020b).

3.3.4 Analysis of Environmental Impacts Criteria

Air quality would increase regarding the reduction of GHGs and criteria pollutants being emitted from the biomass power plants. The implementation of this alternative would add the air pollutants listed in Table 10 to the atmosphere from composting the biomass (BioMRF Technologies Inc. 2020, Clements et. al 2010, Hellebrand and Kalk 2001, Williams et. al 2019). Note that the emissions associated with trucking the compost to the distribution center is not included. The alternative's contribution to carbon sequestration, solely based on composting is approximately 582,764 tons per year.

Table 10. Criteria pollutant emissions from the median annual power plant values from 2011-2017 and estimated emissions from the composting and WWTP use alternative (CARB 2020d, CARB 2020e, BioMRF Technologies Inc. 2020, Clements et. al 2010, Hellebrand and Kalk 2001, Williams et. al 2019).

Pollutant	Compost/WWTP Alternative	Power Plants	% Reduction
CO, tons yr^{-1}	0	2,217	100
SO_2, tons yr^{-1}	0	60	100
NO_x, tons yr^{-1}	0	329	100
TVOC, tons yr^{-1} as C_3H_8	11	48	78
$PM_{2.5}$, tons yr^{-1}	5	62	92
PM_{10}, tons yr^{-1}	85	67	-26
PM_{TOTAL}, tons yr^{-1}	90	130	24

3.3.5 Summary of Advantages and Disadvantages

The advantages of the composting with local WWTP utilization alternative are the following:

- Little impact on community aesthetics
- Production of a valuable product used for agriculture
- Utilization of excess biomass at local WWTPs
- Short payback period
- Addresses several community concerns of biomass power production
- Large amount of carbon sequestration

The disadvantages of the composting with local WWTP utilization alternative are the following:

- Relatively high capital cost, would need substantial investments or subsidies
- Only 80% of the local excess biomass is being utilized

3.4 Alternative 4 | Oriented Strand Board (OSB) Production

3.4.1 Project Description

Wood has been commonly used as a construction material for many centuries and is not strictly limited to larger diameter wood such as lumber. In Humboldt County, the excess biomass available consists of smaller wood material, including trimmings, sawdust, and bark which can be used to produce the following composite products: green and refined wood chips, and molded materials (Rowell 2007). A type of molded material that prolongs carbon sequestration, the storage of carbon, can be biomass mixed with cement or resin to produce permeable concrete or oriented strand boards (OSB) (Furniss 2020, Puettmann et al. 2017). OSBs are composed of multiple layers of wood strands from softwood, hardwood, and bark compressed together by resin and wax (used as an adhesive) and can be used for wall and roof sheathing as well as floor underlayment (Fisette 2005).

OSBs and wood chips are two products that will be further assessed for the construction materials alternative. OSBs are engineered wood products that consume more biomass to produce than most other construction materials and produce wood chips as a byproduct (Puettmann et al. 2017). The process of producing construction materials from Humboldt County's excess biomass can be found in Figure 14; this figure illustrates the inputs, processes to make the material at the industrial plant, and outputs of the products. The processes in detail can be found in Section 3.3.4 Analysis of Environmental Impacts Criteria. Annually, OSB facilities consume approximately 700,000 green tons of raw material per year, which is necessary under project constraints; however, the outputs consist of emissions, wood waste, and wastewater, which could be difficult to permit and may negatively impact the environmental criteria assessment.

The life cycle assessment (LCA) used to determine the materials' inputs, outputs, and processes, were estimated by a consultant firm called WoodLife Environmental LLC (Puettmann et al. 2017These project variables are displayed by the research organization, Consortium for Research on Renewable Industrial Materials (CORRIM). CORRIMs' goal is to provide life cycle assessments to become an easy, accessible database to quantify environmental impacts and economic costs for renewable materials (CORRIM 2017). The life cycle assessments from CORRIM used to assess this biomass utilization alternative are for OSBs and are quantified based off the production of one cubic meter of OSB; one cubic meter of OSB is composed of the following materials: bark, 74% softwood, 26% hardwood, resin, and wax (Puettmann et al. 2017).

Wood chips can generally come in two different moisture contents; wood chips that are high in moisture can be sold as green wood chips and those that are dried can be sold as refined wood chips. The refined wood chips would result in higher energy consumption due to the intake of heat thermal equipment (Puettman 2017). Wood chips can be used as mulch for landscaping, which adds nutrients to the soil, destroys weeds, and provides moisture retention. Wood chips can also be used for the following: erosion protection, landscaping, playground and dog park surfaces, and retaining walls.

For each criteria analysis, the calculations were scaled to be able to utilize 1.3 million tons per year of biomass from the sawmills. A large OSB facility produces approximately 800,000 tons of OSB per year (The Beck Group 2015). To consume all the biomass from the mills annually, the OSB facility would need to produce approximately 1,600,000 tons of OSB per year; therefore, all the calculations of the size of the facility, cost, and emissions were scaled by a factor of 2. More information on the data used in this OSB production analysis can be found in Appendix K and Appendix L.

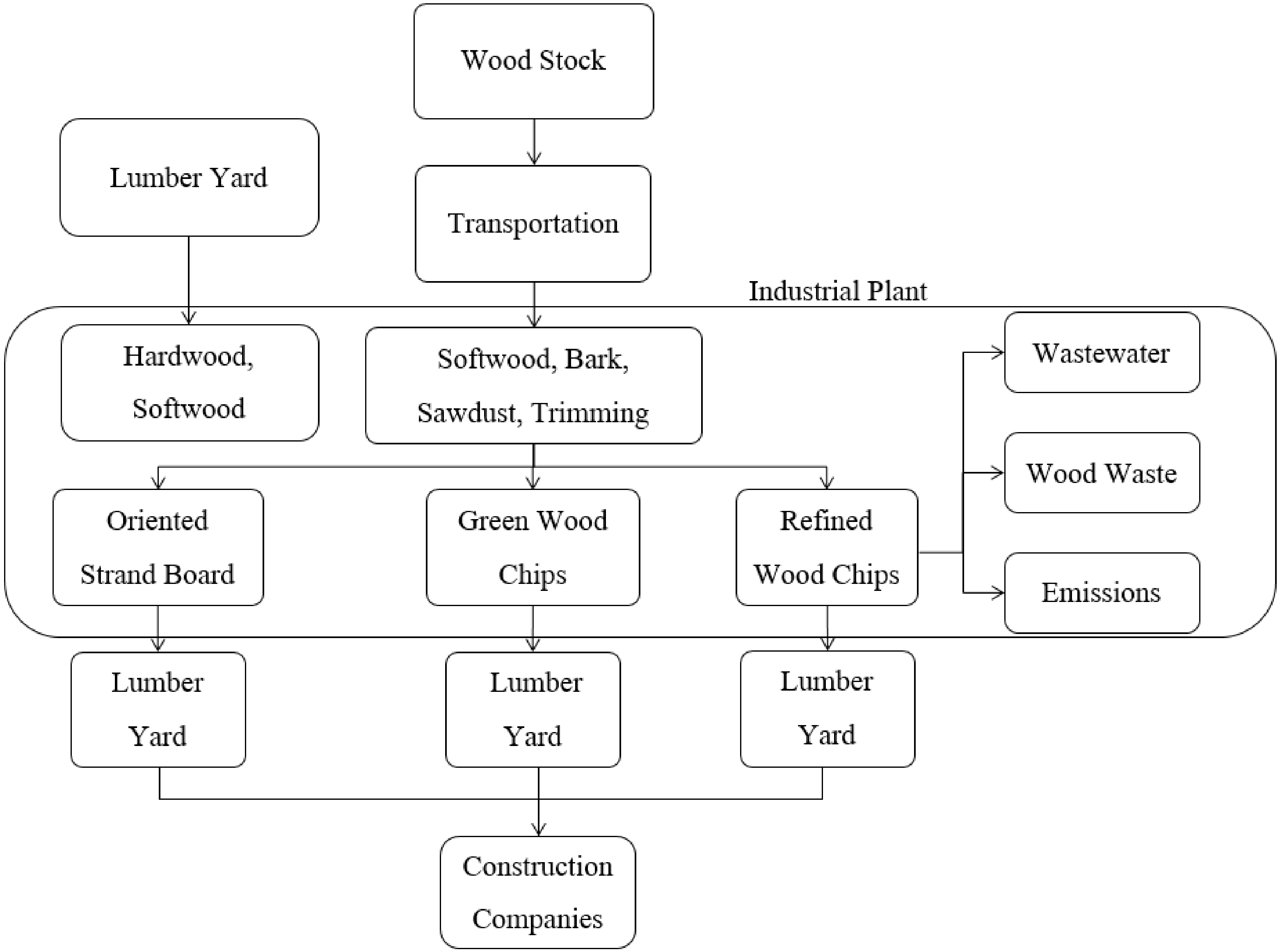

Figure 14. The flow chart for the construction material alternative of oriented strand boards and wood chips (Shannon 2020).

3.4.2 Analysis of Social Criteria

In Humboldt County, the community is surrounded with redwood and sequoia trees, encompassing nature as a culture. Most of the buildings in this area are composed of wood material, constructed from materials sold by local lumber yards, and built by local construction companies. Currently, Humboldt County needs 3,390 housing units for very-low to above-moderate income households (RTPA 2018). However, this need would require a high-scale industrial plant in Humboldt County to produce oriented strand boards and woodchips to consume approximately 1.3 million tons of green raw material per year from the local sawmills (Puettmann et al. 2017). This industrial plant would require purchasing approximately 160 acres of land and potentially assembling a two- to three-story height building, roughly 30 feet high. The height of the OSB factory would have a negative impact on the aesthetics of the neighboring community within a 1-mile radius of 1,000 residents. A map of the proposed location for the facility, Samoa Peninsula, is referred in Appendix J.

A total of two out of six community concerns provided from RCEA (Appendix A) were addressed by the construction material alternative. The concerns from the community for the air quality and particulate matter due to the current combustion of biomass was addressed by this alternative. Another concern that was addressed by this alternative is that the biomass power plants would be able to retire and the ~30% energy source of could be replaced with solar or other form of renewable energy.

3.4.3 Analysis of Economic Criteria

The capital cost to implement this alternative includes the cost of buying land, building the industrial plant, and permitting. A total of three permits would be required to operate the facility and regulate the air emissions and wastewater outputs. The construction materials production alternative would require operation and maintenance costs, input material cost, and transportation cost. The inputs to produce the OSB include hardwood, softwood, bark, resin, and wax, which partially aligns with the biomass supply already available. The hardwood material could either be substituted with softwood or purchased from the mills; more materials to purchase are resin and wax. During operation hours, the amount of electricity per one cubic meter of OSB is 134 kWh of electricity, which results in $20.72 per cubic meter of OSB. The breakdown of annual costs for operating an OSB manufacturing plant including labor, land, and construction of the building, along with equipment and permits, is summarized in Table 11.

Table 11. The capital cost for a large OSB facility (The Beck Group 2015).

Financial Item	Cost	Item Description
Capital Costs	$6,000,000	Cost of land
	$250,000,000	Building, Equipment, and Permits
Annual O&M	$92,400,000	Manufacturing Cost and Labor
	$57,000,000	Electricity, Hardwood, Softwood, Resin, and Wax
Annual Income	$164,400,000	10% Profit
Payback Period (Years)	**17.2 years**	

Utilizing 80% of the biomass, the OSB facility produce roughly 870,000 m^3/yr, which would result in transporting to local lumber yards as well as out of county to be sold to construction companies and distributors; therefore, a cost of gasoline for trucks to transport to southern California was included. More information on the trucking can be found in Appendix F.

3.4.4 Analysis of Environmental Impacts Criteria

There are positive and negative environmental impacts from developing an OSB industrial plant. A positive environmental impact is that the production of one cubic meter of OSB, consumes high volumes of renewable materials as a non-fuel resource, which would otherwise potentially be disposed of in a landfill. It is assumed that 80% of the biomass supplied from the mills would be used for the softwood supply needed to produce OSB, while 20% of the softwood to produce OSB must be purchased. To consume all the biomass from the mills (1.3 million tons per year), the OSB facility would need to produce 870,000 cubic meters of OSB per year; therefore, all the calculations for the emissions were scaled. It is assumed the facility consumes approximately 134 kWh per cubic meter of OSB due the following processes: flaking, pressing, debarking, drying, screening, blending, forming, and finishing (Peuttman et al. 2017).

- **Flaking**: includes the debarking process which has energy input and wood waste output. The stranding process, which produces wood strands that are 6 inches long and 1 inch wide. Wood material that does not meet these requirements become green wood chips.
- **Drying**: The green strands go through a drying process to reduce the moisture content to 4-8%. This process has an input of natural gas as fuel. The wood waste outputs are refined wood chips. The air emission outputs are VOCs.
- **Screening:** Screening results in refined wood chips as a co-product and consumes electricity.
- **Blending:** The blending process is when the resin, wax and strands are mixed, which consumes electricity.
- **Forming**: The forming process consumes electricity. Pressing the material can require high electricity and thermal energy consumption. Both processes emit air pollutants:

VOCs and Hazard Air Pollutants (HAPS), a very toxic air pollutant that may cause cancer (EPA 2018).

- **Finishing: OSB input:** The following are inputs for this process: electricity and fuel for the forklift and packaging material. The following outputs are packaged OSB, wood waste and air emissions VOCs and HAPs.

Negative impacts of this alternative include pollutant emissions and chemicals discharged with the outputs. VOCs and HAPs are particulate matter that are created from the forming, pressing, and blending process in making the oriented strand boards. The current electricity resources for California emits 0.8 pounds per MWh of NO_x and 491 pounds per MWh of CO_2 (EIA 2018). The total greenhouse gas emissions are shown in Table 12.

Table 12. The OSB production versus the Humboldt County median annual power plant values from 2011-2017 and estimated emissions scaled to represent the OSB facility (Puettman, et al. 2017).

	OSB Production Emissions	**Humboldt County Biomass Power Plant Emissions**	**% Increase of Pollutant**
CO_2, metric tons yr^{-1}	60,326	255,736	-76
NO_x, tons yr^{-1}	285	170	68
CO, tons yr^{-1}	276	1,978	-86
SO_x, tons yr^{-1}	26[1]	35	-27
TVOC, tons yr^{-1} as C_3H_8	244	41	496
$PM_{2.5}$, tons yr^{-1}	70	36	93
PM_{10}, tons yr^{-1}	115	35	229

1. This number represents only SO_2

Additionally, this alternative has more negative environmental impacts, such as chemicals introduced to the wastewater and solid waste. Trucking the material out of the county to other distributors contribute approximately 70 tons of CO_2 annually.

The positive impacts are that the biomass material will be molded with materials that prolongs carbon sequestration and the wood chip output can be used in a beneficial way. In *Biomass Power in Humboldt County*, molded biomass was estimated to be sequestered in 100+ years (Furniss 2020). The LCA reported that each cubic meter of OSB stored roughly 1150 kg of CO_2e. The 80% of biomass used from the mills annually releases roughly 117,500 tons of CO_2e, and sequesters 534,300 tons of CO_2e, which equates to a positive net carbon of 416,800 CO_2e.

3.4.5 Summary of Advantages and Disadvantages

The advantages of the OSB production alternative are the following:

- High employment
- Large amount of carbon sequestration
- Production of building material

The disadvantages of the OSB production alternative are the following:

- High capital cost and annual cost of material
- Long payback period
- Lack of community concerns addressed
- Only 80% of excess biomass is utilized

4 Decision Analysis

To determine the alternative that was most appropriate for our client based on the constraints and weighted criteria outlined, the Delphi Matrix Method and Pugh Method were utilized. The process for each method is briefly described along with the resulting alternative.

For the application of the Pugh Method (Appendix M), three alternatives were compared to the baseline alternative with either a plus, minus, or zero for each criterion. The plus revealed that the compared alternative was more satisfactory than the baseline, where the minus was less satisfactory, and the zero was neutral; the number of pluses and minuses for each alternative were summed. This process was performed iteratively with the highest-scoring alternative becoming the new baseline. The compost/WWTP alternative was used as the first baseline as it resulted in a relatively fast payback period and high carbon sequestration potential, as well as addressing most of the FAQs from community members, which was the most highly weighted criterion. In the comparison of all other alternatives to the baseline it remained the most attractive option as all other alternatives resulted in negative scores. As the criteria were not weighted in this section, a second method of analysis was performed.

For the application of the Delphi Matrix Method, weights were normalized by the total available number of points for all criteria. Bins were developed for each criterion with a range of one to five based on the ranges of each determined for each alternative (Table 15). Each alternative was scored according to their placement in the criteria bins and those scores were multiplied by the normalized score for each criterion. The normalized scores for each were summed for their total score to determine the preferred alternative (Table 13).

Table 13. Delphi Matrix analysis for the four alternatives.

			Alternative: Gasification		Alternative: Biochar Production		Alternative: Compost/WWTP		Alternative: OSB	
Social	Score	Normalized Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Community Satisfaction	8	0.27	3	0.80	3	0.80	3	0.80	1	0.27
Aesthetics: Height	1	0.03	3	0.10	3	0.10	5	0.17	2	0.07
Aesthetics: Population Impacted	1	0.03	5	0.17	5	0.17	5	0.17	5	0.17
Economic										
Cost, Payback Period	2	0.07	4	0.27	5	0.33	5	0.33	2	0.13
Local Employment	4	0.13	2	0.27	2	0.27	5	0.67	5	0.67
Ease of Implementation	4	0.13	4	0.53	4	0.53	3	0.40	4	0.53
Environmental										
Air Quality, GHGs	3	0.10	4	0.40	5	0.50	5	0.50	5	0.50
Air Quality, Criteria Pollutants	2	0.07	2	0.13	5	0.33	5	0.33	5	0.33
Carbon Sequestration	2	0.07	1	0.07	1	0.07	5	0.33	5	0.33
Biomass Use	3	0.10	1	0.10	1	0.10	1	0.10	1	0.10
Total				**2.83**		**3.20**		**3.80**		**3.10**

The Delphi Matrix Method revealed ranks for each alternative (Table 14). The highest-ranking score was associated with the composting with WWTP alternative, which was chosen as the preferred alternative. The results were close with three of the four alternatives scoring within 0.37 points of each other. The lowest score was the gasification alternative due to the lack of local employment, high criteria pollutant production, and low carbon sequestration under the alternative.

Table 14. Ranks of alternatives based on Delphi Matrix Method scoring.

Alternative	**Rank**
Compost/WWTP	1
Biochar Production	2
OSB Production	3
Gasification	4

The main criteria that the compost and WWTP alternative had that determined its winning score was the low payback period, high local employment, low emissions, and high carbon sequestration. The criterion values determined for each alternative are shown in Table 15.

Table 15. Criteria weighting bins for Delphi Matrix Analysis.

Criteria	Descriptor of Quanitification	1 Poor	2 Below Average	3 Average	4 Fair	5 Exceptional
Social						
Community Satisfaction	Number of frequently asked questions addressed	≤1	2	3	4	≥5
Aesthetics	Height of facility	>48'	36-48'	24-35'	12-23'	<12'
	Population impacted	>8,000	6,000-7,999	4,000-5,999	2,000-3,999	<2,000
Economic						
Cost	Minimize payback period to offset capital and O&M costs (Years)	>20	16-20	11-15	6-10	0-5
Local Employment	Number of jobs supported by implementation of alternative	<5	5-9	10-20	21-50	>50
Ease of Implementation	Number of permits required to execute	>10	8-10	5-7	1-4	0
Environmental						
Air Quality	Minimize GHG emissions and local air quality impacts (tons/yr)	>1,000,000	700,000-999,999	400,000-699,999	200,000-399,999	<200,000
	Minimize mass of criteria pollutants discharged (tons/yr)	>25,000	25,000-10,000	10,000-5,000	5,000-1,000	<1,000
Carbon Sequestration	Maximize sequestration of carbon through proposed alternative (tons/yr sequestered CO_2e)	<200,000	200,000-300,000	300,000-400,000	400,000-500,000	>500,000
Excess Biomass	Maximize percentage of available biomass used	<85%	85-89.9%	90-92.5%	92.6-95%	>95%

Table 16. Criteria values for each alternative used to evaluate Delphi Matrix Method.

	Gasification	OSB	Compost	Biochar
Social				
Community Satisfaction	2.5	1	3	3
Aesthetics: Height	30	40	6	24
Aesthetics: Population Impacted	1,000	1,000	1,000	1,000
Economic				
Cost, Payback Period	8.5	17.2	2.8	2.5
Local Employment	8	169	386	8.5
Ease of Implementation	4	3	5	3
Environmental				
Air Quality, GHGs	281,417	60,657	559,305	188,881
Air Quality, Criteria Pollutants	10,601	730	101	0.05
Carbon Sequestration	121,723	534,299	582,764	142,315
Biomass Use	80%	80%	80%	80%

5 Recommended Alternative

The alternative recommended for the utilization of the biomass currently used to generate electricity in Humboldt is to use a portion of it to improve local WWTP operations and to compost a large portion of it directly, without prior WWTP use. This alternative use of waste streams from local sawmills leverages a natural process to produce a saleable product that organically enhances soils for agricultural applications. Half of the product would be transported to Santa Rosa for wider commercial distribution, while it is estimates that there is sufficient demand for half of the compost locally. Design specifications, detailed criteria analyses, and sensitivity analyses for key process variables will be presented in this section.

5.1 Specifications of Design

The recommended alternative proposes the utilization of excess biomass in four different processes: 1) Class A biosolids production, 2) trickling filter media replacement, 3) odor control media replacement, and 4) compost production. Figure 15 illustrates how the excess biomass from the local sawmills supplies the four processes. Table 17 gives the amount of biomass, manure, and compost in cubic feet per year being transferred between each node.

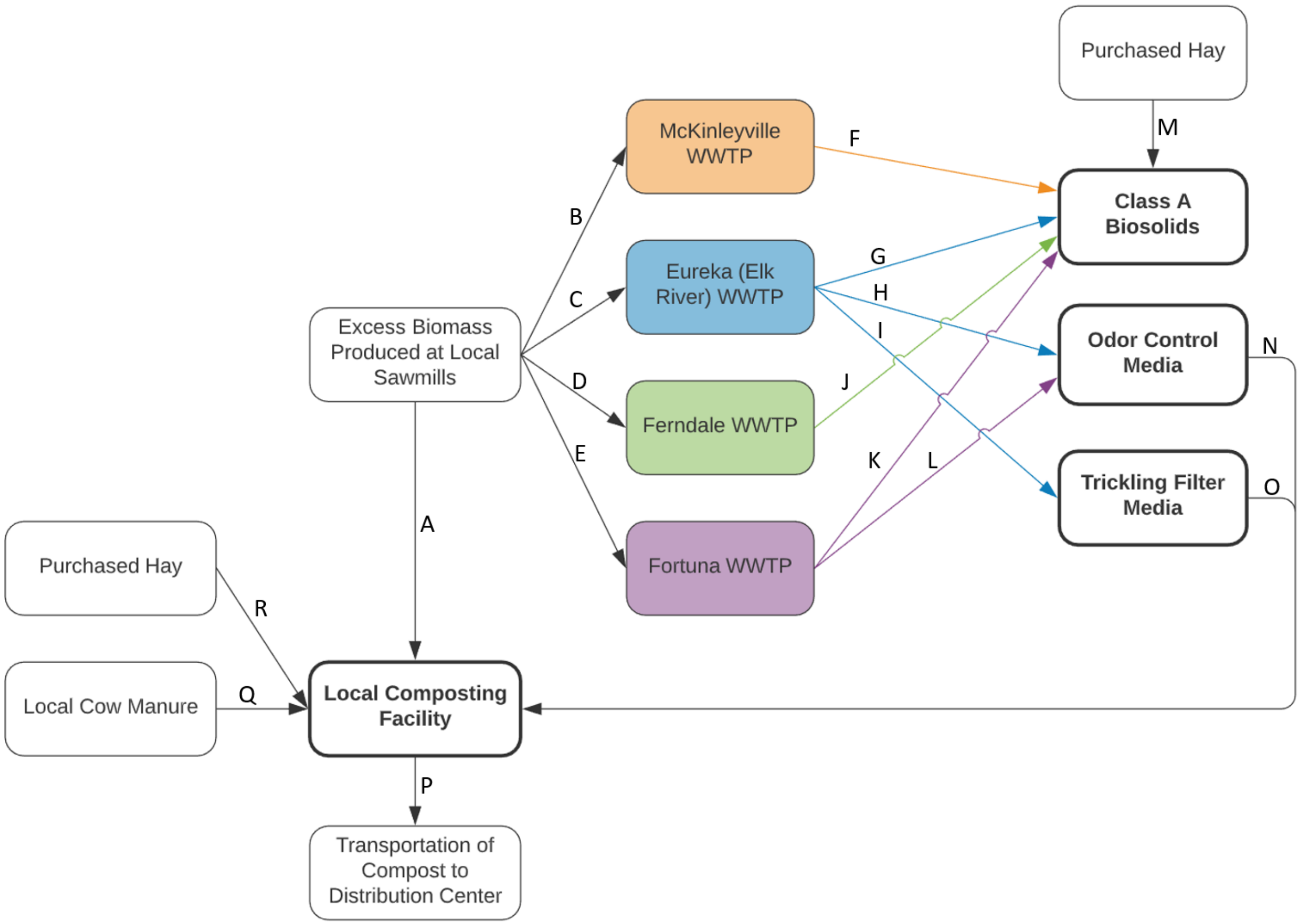

Figure 15. Diagram of recommended alternative utilizing the excess biomass for composting and at local WWTPs (Phillips 2020). The arrows represent the flow path of the biomass and the letters account for the volume of material being transferred to a different process, outlined in Table 17.

Table 17. Amount of biomass, compost, manure, and hay transferred between each node in the system.

Path	Amount (ft^3/yr)	Product
A	80,293,256	Excess Biomass
B	193	Excess Biomass
C	1,417,845	Excess Biomass
D	77	Excess Biomass
E	3,331	Excess Biomass
F	193	Excess Biomass
G	738	Excess Biomass
H	3,393	Excess Biomass
I	1,413,714	Excess Biomass
J	77	Excess Biomass
K	211	Excess Biomass
L	3,120	Excess Biomass
M	1,707	Hay
N	6,513	Used Biomass
O	1,413,714	Used Biomass
P	89,373,822	Compost
Q	6,369,297	Manure
R	92,085,090	Hay

The proposed location of the composting facility is on the Samoa Peninsula in Humboldt County. This area is primarily zoned industrial so few residents would be impacted by the project. The proposed site is shown in Figure 16. As this parcel is 42.2 acres, only 85% would be required for the composting facility so it is assumed that the owner would lease a portion of the parcel or it could be purchased if subdivided. The parcel number is 401-121-012-000 and is zoned miscellaneous light industrial.

Figure 16. Proposed site for Humboldt County's biomass composting facility (Burke 2020). Sources of imagery and parcel map are 2016 NAIP aerial imagery and Humboldt County GIS download, respectively.

5.1.1 Class A Biosolids Production

For the production of Class A biosolids, the recommended alternative suggests mixing a portion of the excess biomass (1,220 ft^3/yr) with dewatered sludge at the McKinleyville, Eureka (Elk River), Ferndale, and Fortuna WWTP. Being Class A quality, the biosolids are able to be used for any land application including edible crops because they are virtually free of pathogens

(Lystek International 2020). The mixing ratio of biosolids to biomass was calculated based on required moisture content (40-60%), density (less than 600 kg/m^3), and carbon to nitrogen ratio (20-40 C:1 N) (Rynk 1992). It was determined that the mixture would consist of 20% hay, 19% biosolids, and 61% biomass. The density of dry Class A biosolids and hay is assumed to be 10 lb/ft^3 and 12 lb/ft^3 respectively (City and Borough of Juneau 2017, BEEF 2016). Fortuna WWTP already produces Class A biosolids utilizing local landscaping waste (NCRWQCB 2011). For this analysis, it is assumed that Fortuna would replace their biomass supply with the County's excess biomass. The amount of biosolids produced at each treatment facility is based on Fortuna's current production (1,050 yd^3/yr) and scaled based on each individual wastewater influent (NCRWQCB 2011). Table 18 shows the average dry weather influent for each WWTP of interest, the scaled Class A biosolids production, and the resulting amount of required biomass for each plant (NCRWQCB 2011, NCRWQCB 2016, NCRWQCB 2018a, NCRWQCB 2018b).

Table 18. Biomass required for Class A biosolid production given average dry weather influent for each WWTP (NCRWQCB 2011, NCRWQCB 2016, NCRWQCB 2018a, NCRWQCB 2018b).

Parameter	Fortuna WWTP	Ferndale WWTP	McKinleyville WWTP	Eureka (Elk River) WWTP
Average Dry Weather Influent (mgd)	1.5	0.6	1.4	5.2
Class A Biosolids Produced (yd^3/yr)	1,050	385	959	3,668
Biomass Required (lbs/yr)	3,259	1,195	11,383	18,813
Hay Required (lbs/yr)	3,548	1,301	3,241	12,395

5.1.2 Trickling Filter Media Replacement

With regards to the trickling filter media replacement, the recommended alternative suggests replacing the plastic media in the two trickling filters at the Eureka (Elk River) WWTP with a portion of the County's supply of excess biomass (1,413,714 ft^3/yr). By visual estimate, it is assumed that each filter is approximately 100 feet in diameter and 30 feet tall, each possessing a volume of 235,619 ft^3. In order for the microorganisms that attach to the media to effectively treat the water that is sprayed along the top, the media used must be durable, light weight, low cost, allow air to flow through, and have a high surface area to support biofilm formation (Eawag and Spuhler 2020), all of which biomass should be able to support. It is assumed that the biomass media would be replaced every four months (three times a year) based on a decomposition study of sawdust by Ohio State University (Pleasant 2010). After the media was replaced, the waste would then be sent to the composting facility to be processed (Pleasant 2010).

Table 19 reveals the total volume available in the trickling filters along with the volume to be replaced every year accounting for the four-month turnover.

Table 19. Eureka WWTP trickling filter volume to be filled with excess biomass.

Process	Volume (ft^3)	Volume (ft^3/yr)
Eureka Trickling Filter	471,238	1,413,714

5.1.3 Odor Control Media Replacement

The odor control media replacement suggests replacing the media in the odor control systems at the Fortuna and Eureka (Elk River) WWTPs with a portion of the County's source of excess biomass (6,513 ft^3/yr). Fortuna utilizes two large wood chip piles to cover the aeration from the headworks each approximately 8 ft wide, 65 ft long, 2 ft tall, for a total of 1,040 ft^3 (NCRWQCB 2011). The current supply of wood chips is from a local landscaping company; it is suggested that that supply be replaced with the County's source of excess biomass. Eureka has a more complex air purifier that uses activated carbon to reduce smell from the wastewater going into the trickling filters (NCRWQCB 2016). It is assumed that the odor control system at Eureka is 12 ft in diameter and 30 ft tall (1,131 ft^3) based on visual estimate. The activated carbon is suggested to be replaced with the excess biomass. Like the media in the trickling filter, the media in the odor control would be replaced every four months and composed at the off-site facility once depleted (Pleasant 2010). Table 20 reveals the total volume available in the two odor control systems along with the volume to be replaced every year accounting for the four-month turnover.

Table 20. Volume of biomass required for Fortuna and Eureka WWTP odor control operation.

Process	Volume (ft^3)	Volume (ft^3/yr)
Fortuna Odor Control	1,040	3,120
Eureka Odor Control	1,131	3,393

5.1.4 Compost Production

Compost production utilizes the largest portion of the County's source of excess biomass (98%) for the recommended alternative. Of the 80,293,256 ft^3/yr of biomass, 78,873,029 ft^3/yr comes directly from the sawmills, while 1,420,227 ft^3/yr is waste media from the trickling filter and odor control processes at Eureka and Fortuna WWTP. The proposed composting facility was modeled based on calculations and examples in the *Handbook of Solid Waste Management* (Tchobanoglous and Kreith 2002). It was assumed that local cow manure would be donated to mix with the compost and hay would be purchased at $220/ton (USDAb 2020b). The compost would require a mixture of 40% hay, 15% manure, and 45% biomass to meet the moisture, C:N ratio, and density requirements. Using this ratio, 6,369,297 ft^3/yr of manure would be required assuming a density of 65 lb/ft^3 and 92,085,09 ft^3/yr of hay would be purchased assuming a density of 12 lb/ft^3 (Lorimor and Powers 2004, BEEF 2016). The proposed composting facility would require 379 long piles (referred to as windrows) assuming a semi-circle shape, each 200 feet long, 6 feet tall, and 9 feet wide. A half-cylinder shape is the best suited shape for Humboldt County due to its annual amount of rainfall, opposed to a rectangular shaped pile that would collect more water (Tchobanoglous and Kreith 2002). There would be no forced aeration systems implemented; aeration would be provided by turning the piles every three days with bucket loaders. Prior to mixing the biomass with the manure, a shredder would be used to break down the biomass into uniform sizes. Because of the large amount of compost produced (89,373,822 ft^3/yr) and the lack of demand in Humboldt County, half of the compost is assumed to be shipped to a distribution center weekly in Santa Rosa, California where the demand for farmers is higher; the other half is assumed to be sold locally. Assuming a 9-foot distance between windrow piles for the bucket loader to maneuver and a 12-foot perimeter around the total area of the piles, 35.16 acres would be required (Tchobanoglous and Kreith 2002). The site recommended rounds up to an even 36 acres as a factor of safety.

5.2 Social Impact

5.2.1 Community Satisfaction

The WWTP alternative positively addresses three questions posed to RCEA that are shown in Appendix A. The community voiced concerns about the number of trees needing to be cut down for biomass power production. This alternative does not require any trees to be cut down for the sole purpose of feeding this process nor does it produce electricity as all biomass is recycled and used for agricultural or waste treatment purposes. Public input also suggested negative feelings toward the production of electricity and specifically mentioned composting as a desired route of processing. While some biomass is sent to WWTPs, most of the biomass is to be composted and distributed. A question was asked about whether improvements can be made specifically to reduce GHGs and PM emissions. The current use of sawmill biomass waste is processed by incineration which produces significant PM emissions. By using the biomass at wastewater treatment plants and as a compost mix, the particulate matter is reduced by 24%.

5.2.2 Land Specifications and Aesthetics

The portion of biomass sent to WWTPs will not require purchasing more land, installing new equipment, or increasing the height of any buildings. The portion of biomass to be used at the WWTPs has essentially zero new negative impact on the surrounding populations. Therefore, populations in McKinleyville, Eureka, Fortuna, and Ferndale will remain unaffected.

The 36 acres of land used for compost windrow piles will be the only new visual impact of the alternative. Because the windrow piles are only 6 feet in height, there is no visual impairment to the surrounding community. Odor is the main concern; composting guarantees the reduction of odors. These odors can be minimized by turning the windrows during optimal conditions such as heavy-still wind times and between the hours of 10am and 3pm (Coker 2016). Heavy-still wind occurs when the wind speed is below 4 miles per hour and the ambient and dew-point temperatures are similar. Between 10am and 3pm the atmosphere is most heated and encourages vertical mixing which minimizes odor exposure to ground-level surroundings. With the composting facility being located on the Samoa Peninsula, a small population is assumed to be affected.

5.3 Economic Impact

5.3.1 Cost

The cost of the composting facility was modeled from the *Handbook of Solid Waste Management* written by Tchobanoglous and Kreith (2002). Given costs for a 12-acre composting facility that was both fully equipped and minimally equipped, the recommended alternative was scaled from 12 acres to 36 acres using a minimally equipped facility (Tchobanoglous and Kreith 2002). The minimally equipped facility is most practical for this alternative because it has no forced aeration systems, just aeration by turning with bucket loaders; it is also an outdoor facility that utilizes windrow piles.

As discussed in Section 3.3.3, the cost was evaluated using a payback period that accounted for O&M, profit, and capital costs as shown in Table 21. O&M costs would account for the 75 employees ($3.25 million), trucking expenses ($40.5 million), hay cost ($121.6 million), cleaning the trickling filters ($3.3 million), and O&M associated with composting ($1.5 million) (Eriksson et al. 1996, EPA 2000, Tchobanoglous and Kreith 2002, USDA 2020b). The trucking expenses are based on a fixed rate per truck noted in Appendix F. Profit is based on selling half of the compost for $20 per cubic yard ($yd^3$) with a 30% discount selling directly to a distributor and half locally for $38/$yd^3$ totaling over $178 million per year (Faucette et al. 2004, Grow Organic 2020, Sonoma Compost 2020, Wes Green Landscape Materials 2020). The cost associated with the odor control maintenance and producing Class A biosolids would be accounted for in the current salary for employees at each WWTP. It is assumed that the cost associated with the odor control maintenance and producing Class A biosolids would be accounted for in the current salary for employees at each WWTP. Capital costs would cover the property for composting ($2.7 million), equipment such as bucket loaders and shredders ($1.5 million), construction ($691,709), engineering ($287,940), and utility hookups ($236,988) (Tchobanoglous and Kreith 2002). An inflation rate of 197.4% was accounted for the values that were scaled from Tchobanoglous and Kreith from 1990 (Dixon 2020, Tchobanoglous and Kreith 2002). The cost of the property is based on the average $75,000 per acre for Samoa Peninsula, as explained in Appendix G. The averaging method was used to calculate a payback period of 2.8 years, which is the ratio of capital costs to annual cash flow.

Table 21. Summary of expenses associated with composting and WWTP utilization in greater detail.

Financial Item	Cost	Item Description
Capital Costs	$2,700,000	Cost of land
	$1,540,000	Equipment (bucket loader, shredder)
	$1,216,637	Construction, engineering, utility hookup
Annual O&M	$3,251,000	Employee salary
	$40,534,000	Trucking expenses
	$3,301,200	Trickling filter maintenance and operation
	$121,557,000	Hay costs for compost mix
	$1,517,000	Composting maintenance and operation
Annual Income	$170,126,000	Income from compost sales
Payback Period (Years)	**2.8**	

5.3.2 Local Employment

It is assumed one job is created for every 18,500 tons of incoming feedstock (IWMC 2019). The recommended alternative would require composting approximately 689,281 tons per year which would require hiring a total of 75 employees, each assumed to make $43,000 per year (Glassdoor 2020, IWMC 2019). Table 22 shows an improvement in the number of local jobs created by the composting with WWTP utilization alternative compared to DG Fairhaven.

Table 22. The number of direct employees required for DG Fairhaven and the proposed alternative.

Operation	Total
DG Fairhaven	22
Composting/WWTP Alternative	75

The proposed alternative would increase employment by over 240% compared to DG Fairhaven's current employment status.

5.3.3 Ease of Implementation

To begin the permit process, the local enforcement agency (LEA), Humboldt County Department of Health and Human Services, must approve the project and documentation that is applied to the regional environmental regulatory agency for air and water, North Coast Air Quality Management District (NCAQMD), and North Coast Water Board (NCWB). The NCAQMD reviews the process of the project, including the machinery, and predicted emission air pollutant outputs. The NCAQMD requires documentation to regulate pollutant discharging in waste and storm water systems. This documentation is then sent to the state Department of Resources Recycling and Recovery (CalRecycle), who approves operation for a compostable material handling facility permit (CalRecycle 2020). The process in obtaining the five permits is illustrated in Figure 17.

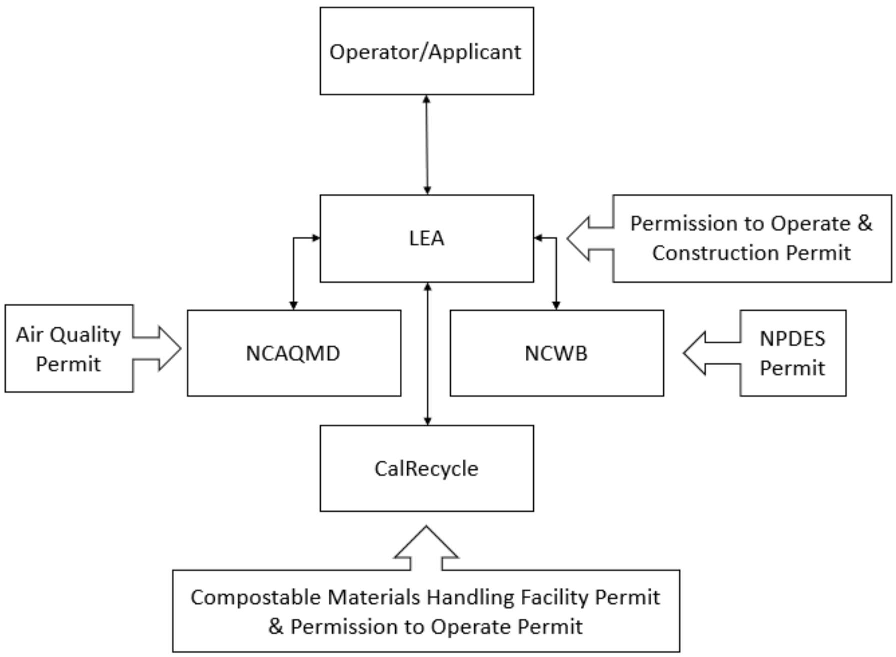

Figure 17. The permit process in obtaining the five permits for composting (Shannon 2020).

The operator/applicant must obtain and complete the documentation required by all agencies. The operator/applicant must have the permission to operate and construction permit from the LEA. The air and NPDES permit are acquired by the NCAQMD and NCWB. All the documentations are reviewed by CalRecycle, who completes the approval for the permission to operate permit and provides the compostable materials handling facility permit to the operator/applicant.

5.3.4 Transportation

Transportation of the composted material to the Santa Rosa area would occur once weekly. It is estimated that compost distributers would require approximately 30% of the profit from sales and that, conservatively, could be sold for $20 per cubic yard (Grow Organic 2020, Sonoma Compost 2020). Potential commercial distributers include the following businesses:

- H & M Landscape Materials Inc. in Santa Rosa, CA
- Cold Creek Compost in Santa Rosa, CA
- Sonoma Compost Co. in Nicasio, CA
- Wheeler Zamaroni in Santa Rosa, CA
- Ramm Rock Landscape Supply in Santa Rosa, CA
- Soiland in Cotati, CA
- Grab N' Grow Soil Products in Santa Rosa, CA

Transportation of the compost was estimated by C.H. Robinson (2020) at $1,370.20 per truckload, with each truckload able to transport 44,798 pounds. The total annual cost to transport the compost would be approximately $40.5 million per year. Assuming demand at least matches the supply of compost, the sales to these facilities would total $178.7 million gross; this accounts for half of the mass of compost selling locally for $38 per cubic yard and half selling in the Santa Rosa are for $20 per cubic yard. Section 3.3.3 outlines all other costs associated with implementing this alternative, which has a payback period of 2.8 years. It is assumed that the some of the local market demand is currently met through class A biosolids already produced by some WWTPs and local landscaping supply companies. It is important to note that the local sales, therefore, of a large quantity of compost supplied to the local market under this alternative would shift the demand and, ultimately, the price.

It was assumed that the cost and emissions associated with the delivery of excess biomass to each WWTP and to the composting facility would be covered by the primary sawmill waste distributer, Humboldt Redwood Company LLC in Scotia. Table 23 quantifies the total mileage the trucks would travel to distribute biomass throughout the recommended alternative's site locations.

Table 23. Total mileage required for distribution of biomass.

Origin	Destination	Miles from Origin to Destination (mi)	Amount of Biomass (ft^3/yr)	Trucks Required (trucks/yr)	Total Mileage (mi/yr)
Scotia	McKinleyville WWTP	41.3	193	1	41
Scotia	Eureka (Elk River) WWTP	26.4	1,417,845	438	11,563
Scotia	Ferndale WWTP	17.7	77	1	18
Scotia	Fortuna WWTP	11.3	3,331	2	23
Scotia	Local Composting Facility	33.9	80,293,256	24,782	840,110
Eureka (Elk River) WWTP	Local Composting Facility	8.2	1,417,107	438	3,592
Fortuna WWTP	Local Composting Facility	23.9	3,120	1	24

5.4 Environmental Impact

Environmental impacts that were assessed for the alternative include air pollutants, categorized as GHGs and criteria pollutants, the mass of carbon sequestered under the alternative, and the percent of the biomass used under the alternative that is currently used to generate electricity.

To compare emissions between the current biomass use process and the proposed alternative use, the median annual values from 2011-2017 from the current process was retrieved from CARB's pollution mapping tool and from CARB's Facility Search Engine (CARB 2020d, CARB 2020e). The sum of the seven-year median emissions from the two power plants is shown in the final column of Table 24.

Table 24. Median annual pollutant emissions from the Humboldt County biomass power plants, Humboldt Sawmill Co. and DG Fairhaven Power LLC from 2011 – 2017 (CARB 2020d).

Both Plants	Unit	DG Fairhaven	Humboldt Sawmill Co.	Total, Both Plants
CO[1]	Tons	1,341	876	2,217
CO_2	Tons	200,466	273,569	474,035
CH_4	Tons	68	88	155
N_2O	Tons	9	12	21
Biomass CO_2	Tons CO_2e	197,751	253,629	451,381
Non-Biomass GHG	Tons CO_2e	6,880	6,194	13,073
Total GHG	Tons CO_2e	204,631	259,620	464,251
Covered GHG	Tons CO_2e	0	0	0
VOC	Tons	19	30	48
NO_x	Tons	158	171	329
SO_x	Tons	28	32	60
PM_{10}	Tons	31	37	67
$PM_{2.5}$	Tons	29	34	62
Benzene	lbs	9,271	11,574	20,845
Chromium, Hexavalent	lbs	1	1	2
Diesel PM	lbs	60	57	117
Formaldehyde	lbs	9,717	12,830	22,547
Hydrochloric Acid	lbs	41,938	442	42,380
Nickel	lbs	7	9	17

1. (CARB 2020e)

This section will present emissions data and under the alternative process to compare with the current process emissions. Also, as the trucking emissions were not factored into initial alternative analyses to simplify comparison amongst the alternatives, this will now be evaluated to provide more information on the total environmental impact of the proposed alternative.

5.4.1 Criteria Pollutant Emissions

Criteria air pollutants are six of the most common air pollutants, for which national air quality standards were established by the EPA in order to protect public health. As public health was one of the primary concerns of local community members, the criteria pollutants that would be emitted under the preferred alternative were compared with reported emissions from the two local biomass power plants. The criteria pollutant emissions median annual power plant values from 2011-2017 from the biomass power plants is shown in Table 25, along with estimated emissions under the proposed alternative (CARB 2020d, CARB 2020e, BioMRF Technologies Inc. 2020, Clements et. al 2010, Hellebrand and Kalk 2001, Williams et al. 2019). The estimate of criteria pollutant emissions under the alternative would decrease for every pollutant except for PM_{10}, which is estimated to have a 26% increase.

Table 25. Criteria pollutant emissions from the median annual power plant values from 2011-2017 and estimated emissions from the composting and WWTP use alternative (CARB 2020d, CARB 2020e, BioMRF Technologies Inc. 2020, Clements et. al 2010, Hellebrand and Kalk 2001, Williams et. al 2019).

Pollutant	Compost/WWTP Alternative	Power Plants	% Reduction
CO, tons yr^{-1}	0	2,217	100
SO_2, tons yr^{-1}	0	60	100
NO_x, tons yr^{-1}	0	329	100
TVOC, tons yr^{-1} as C_3H_8	11	48	78
$PM_{2.5}$, tons yr^{-1}	5	62	92
PM_{10}, tons yr^{-1}	85	67	-26
PM_{TOTAL}, tons yr^{-1}	90	130	24

5.4.2 GHG and Net Carbon Dioxide Equivalent Emissions

Carbon sources and sinks are counted to the net quantity to determine the climate change impact of a process. The net carbon dioxide equivalent (CO_2e) emissions represent the net effect of greenhouse gases on the environment. This alternative's CO_2e emissions were negative, due to its high carbon sequestration capacity; the net CO_2e emissions were approximately -353,000 tons per year. Emissions from composting biomass are considered biogenic, as the emission source is plant matter. It should be noted that biogenic emissions do not require payment under AB 32, a legislature bill requiring CARB to take action to reduce global warming in California that resulted in a cap and trade program (EDF 2011). As composting process emissions are biogenic, AB 32 would not require the compost facilitator to 'surrender an allowance' for each ton of GHG pollution emitted as it does for other industrial processes producing GHG emissions (EDF 2011).

Annual process GHG emissions from the composting alternative totaled an estimated 559,305 tons and are comprised of CO_2, N_2O, and CH_4 (BioMRF Technologies Inc. 2020, Clements et. al 2010, Hellebrand and Kalk 2001, Williams et al. 2019). Though the mass of the CO_2e of these emissions is predominantly direct CO_2 emissions at approximately 554,655 tons per year, N_2O and CH_4 also contribute approximately 125,756 and 116,250 tons per year CO_2e, respectively, which are not insignificant amounts, based on emissions per feedstock mass input by BioMRF Technologies Inc. (2020), Clements et. al (2010), Hellebrand and Kalk (2001), and Williams et. Al. (2019). However, the total CO_2e emissions from composting are offset by the significant carbon sequestration potential, estimated at 2,135,509 tons per year. CO_2e sequestered was calculated with a carbon mass balance, subtracting the mass of carbon emitted through pollution from the carbon input from the feedstock, assuming the biomass was 53.5 percent carbon, which is the carbon content of redwood (NREL 1995). This mass of carbon was then multiplied by the ratio of the molar mass of CO_2 to carbon, which is 44.01:12.01 (Kotz et al. 2019). Therefore, the net CO_2e sequestered is 1,388,714 tons per year, reducing net CO_2e emissions from the current power plant use by 200% and acting as an overall benefit to climate goals by acting as a significant carbon sink. Note that the estimate of sequestered carbon is conservative due to the following two factors: 1) it does not account for the additional CO_2 pulled from the atmosphere by increased photosynthesis of plants, due to higher quality growth medium, and 2) manure emissions would be higher if left to decompose in a business as usual scenario than when they are composted with the biomass considered in this design, including wood waste and hay.

Table 26. CO_2e balance for WWTP/Composting biomass solution.

	Form	**Mass (tons/yr)**
Source (CO_2e)	CO_2	+ 554,655
	N_2O	+ 125,890
	CH_4	+ 116,250
Sink (CO_2e)	Sequestered	- 2,135,509
Net CO_2e		**- 1,388,714**

When only considering emissions, the composting alternative is predicted to emit approximately 72% more GHGs in CO_2e than the current biomass use. Research performed by Zhu-Barker et al. (2017) and Vergara and Silver (2019) indicate that careful management of O_2, temperature, and moisture may reduce overall greenhouse gas emissions and careful balancing of inputs and external conditions can shift the chemical species produced by the composting process.

5.4.3 Transportation Emissions

Emissions from trucks transporting the compost to commercial distributors in the Santa Rosa, California area were determined using a road transportation life cycle assessment by Eriksson et al. (1996) as guidance. The distribution trucks were assumed to be a "Heavy Truck" type used for regional distribution. The number of truckloads of compost per year were determined to be 16,562 and the miles traveled would be approximately 220. Using these numbers, mass estimates were calculated for the following pollutants: CO_2, NO_x, CO, PM, and SO_x (Table 27).

Table 27. Annual emissions from heavy trucks used to transport composted biomass from the facility on the Samoa Peninsula in Humboldt County to Santa Rosa, California.

Pollutant	g/vehicle km[1]	Ton[2]/Year
CO_2	473	5,686
NO_X	5.73	68.9
CO	2.45	29.5
PM	0.34	4.1
SO_X	0.08	1.0

1. Values used for estimates were sources from Eriksson et al. (1996)
2. Tons of pollutant are reported in US short tons.

CO_2 was the largest pollutant mass value emitted by the trucks but when compared with process emissions it was a very small contributor to overall alternative emissions; this is due to the trucks emitting only 1% of the total CO_2 emitted by composting the biomass. The criteria pollutants emitted by transportation totaled 103.5 tons per year, which could have a more substantial effect, as this value approximately doubles the value of the criteria pollutants emitted under the proposed alternative. However, the GHG emissions from transportation were less than 1% of the current biomass use process. As the local concern over criteria pollutants is over the health of Humboldt County residents specifically and these emissions are not localized to Humboldt County, this additional pollution would not alter the decision based on criteria evaluated.

5.5 Sensitivity Analysis

Sensitivity analyses were performed for the design compost composition and economics of the proposed alternative. Sensitivity analyses were performed on key variables of the composting process, as it utilized a majority of the County's excess biomass compared to the implementations at the local WWTPs. Two design variables analyzed were the biomass input and the mixing ratio of biomass to compost. These inputs were evaluated for their effect on the payback period and emissions data, as these were criteria that were important to the decision process and this alternative's selection as the preferred alternative. Additionally, the payback period key alternative variables are shown in Table 28.

Table 28. Base values of the recommended alternative given current parameters to compare for the sensitivity analysis.

Criteria Pollutants (tons/year)	GHG (tons/year)	Payback Period (year)
101	559,305	2.8

5.5.1 Percent Excess Biomass Utilization

This alterative is designed to utilize 80% of the available biomass waste from local sources. Sensitivity analysis were performed to determine the effect of using more or less biomass on masses of pollutant emissions.

The change in biomass results in a linear change in the GHG and criteria pollutant emissions. Figure 18 shows the sensitivity analyses for both pollutants as they have the same trend when used biomass percentage is altered. If this alternative were to utilize 100% of the biomass, 702,000 tons, GHG emissions would increase from 559,000 tons per year to 622,000 tons per year, which is an 11% increase. The same percent change would occur for criteria pollutants increasing from 101 tons per year to 112 tons per year. Calculated estimates of all pollutant emissions for these sensitivity analyses are shown Appendix N: Sensitivity Analysis.

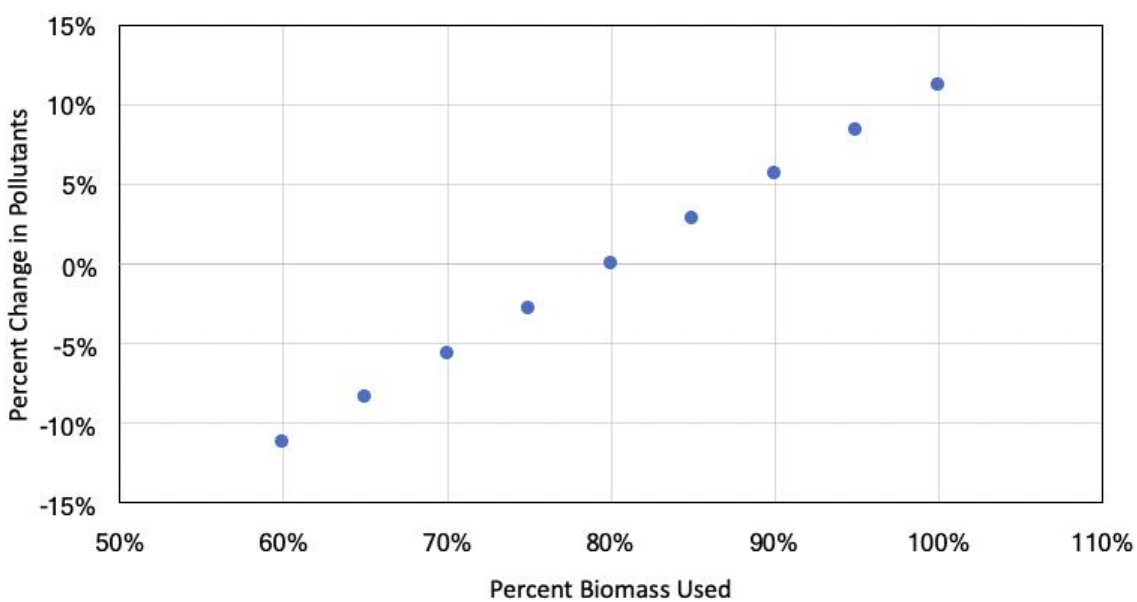

Figure 18. Sensitivity analyses of percent biomass utilized and effect on pollutant emissions (GHG and criteria pollutants).

5.5.2 Moisture Content of the Biomass

The parameters used to produce the optimal compost mix include the following: the density must be less than 600 kg per cubic meter, the moisture content must be between 40 and 60 percent, and the carbon-to-nitrogen ratio must be between 20:1 and 35:1 (Rynk 1992). Table 29 below shows the individual moisture content and the total carbon for the carbon-to-nitrogen (C:N) ratio for each material used for the compost mix.

Table 29. The moisture content of the material for the optimal compost mix (Rynk 1992).

Material	Moisture Content (%)	C:N
Woodchips	50	600
Leaves/Trimmings	40	55
Bark	14	496
Hay	10	20
Manure (Cattle)	80	20

The optimal mix did not meet moisture and carbon-to-nitrogen the constraints, stated above, without the material hay, due to the woodchips, leaves/trimmings, and bark (biomass) having high moisture and C:N values. For example, the woodchips have a high value of C:N and moisture content, whereas bark had a high C:N value. Therefore, the sensitivity analysis on the moisture content of each biomass material was evaluated. The moisture content is a control variable in composting either drying or saturating the materials. The base values for each parameter for the optimal compost mix can be seen in Table 30. Each material's moisture content was changed from 0 to 90 percent, which can be seen in Appendix N: Sensitivity Analysis.

Table 30. The calculated base values for the optimal compost mix.

Density (kg/m^3)	Moisture (%)	C:N
262	40	35

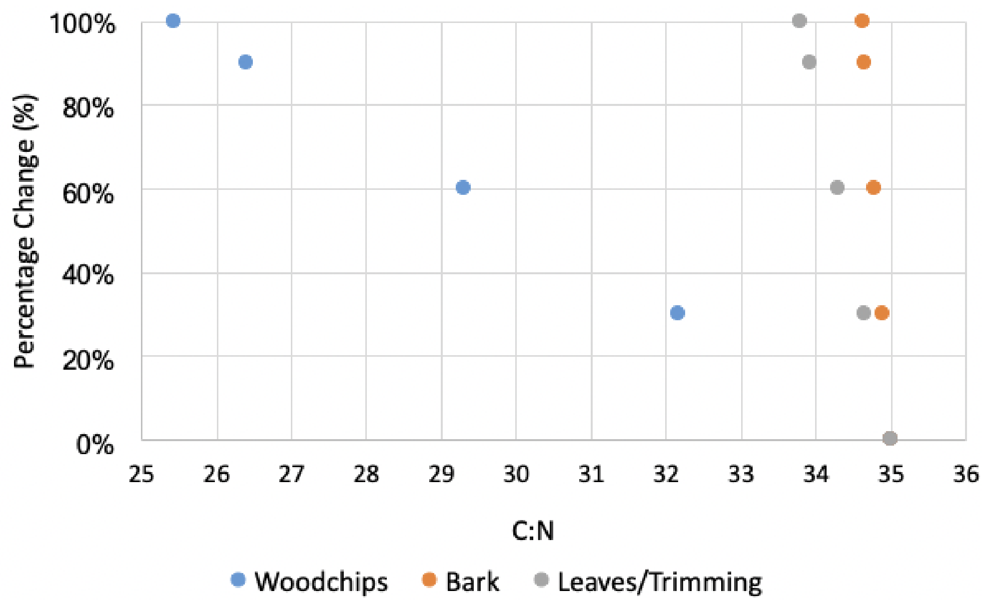

Figure 19 shows the effects of the moisture content of the individual material inputs to the compost mix's carbon-to-nitrogen ratio. The woodchips are more likely to change the ratio from 35 to 26.4 with 90% increase of moisture; with this amount of moisture, the compost mix still lies between the parameter constraints, 20 and 35.

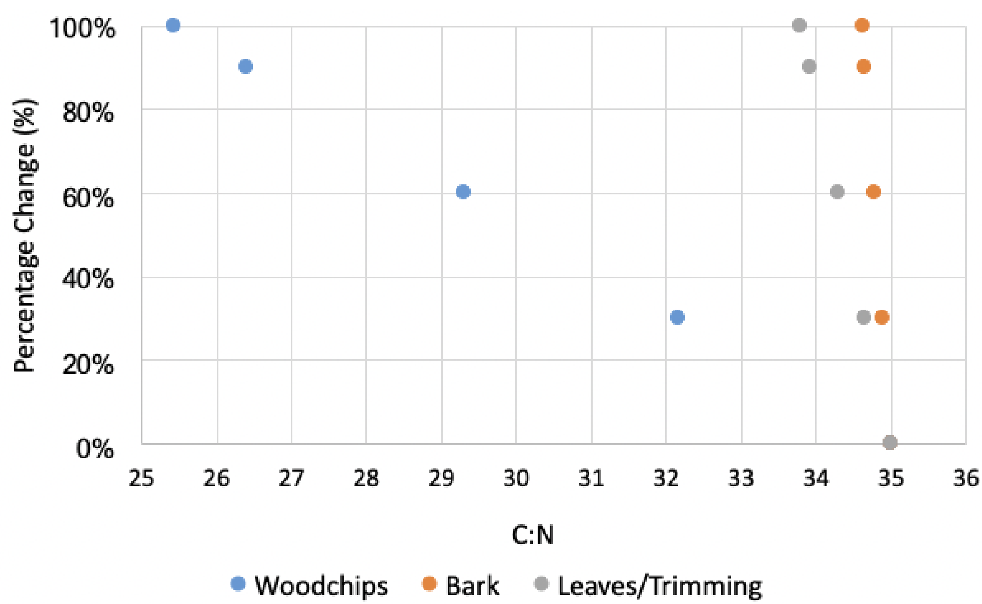

Figure 19. The sensitivity analysis for carbon-to-nitrogen ratio when the following biomass inputs change in moisture content: woodchips, bark, and leaves/trimming. The woody biomass clearly shows that it is more sensitive than bark and leaves/trimming.

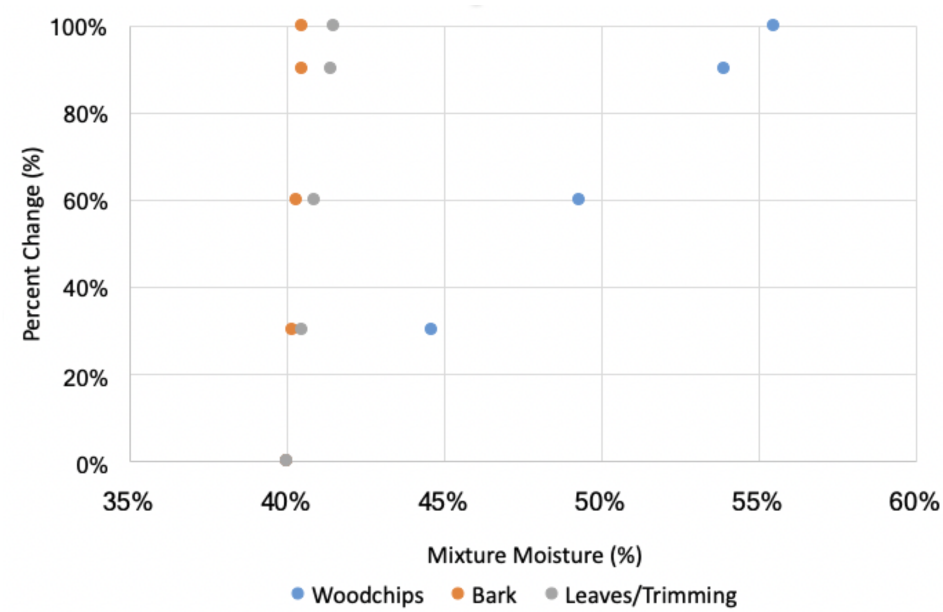

Figure 20 shows the effects of the moisture content of the individual material inputs to the compost mix's moisture content. The woodchips are more likely to change the moisture content from 40 to 53.9 percent with 90% increase of moisture; with this amount of moisture, the compost mix still lies between the parameter constraints, 40 and 60 percent.

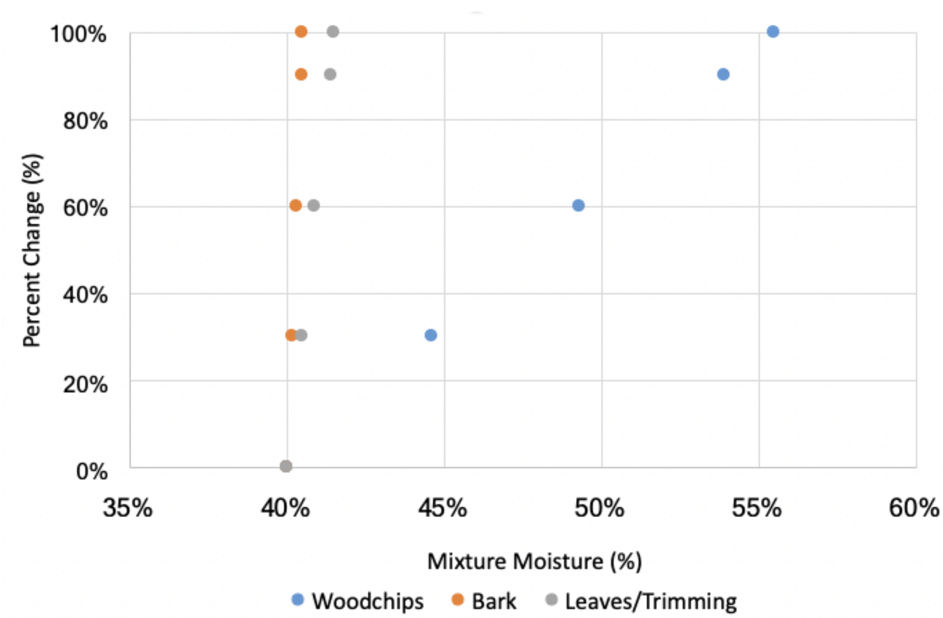

Figure 20. The sensitivity analysis for the mixture moisture content of the following biomass inputs: woodchips, bark, and leaves/trimming.

The sensitivity analysis ensures that the biomass moisture content of each material can increase from its assumed base state, in Table 29, by 100% and maintain an optimal compost mix. As stated above, the hay material in the compost maintains the stability in the compost mix to be between the set constraints.

5.5.3 Salability of Compost

The payback period for the WWTP and composting solution shows that it is a very lucrative investment for potential investors; however, this solution was formulated under two primary economic assumptions, that regional compost demand will meet the supply from the composting facility without changing the market price of compost and that potential changes in capital costs will not significantly impact this solution's financial benefit.

The first economic sensitivity analysis was performed on the local sales price of compost to determine how sensitive the payback period is to changes in compost sales price. The minimum feasible price for local compost sales is $38 per cubic yard, which is $7 less than potential competitors (Wes Green Landscape Materials 2020). Increasing the price charged showed a power curve relationship with substantial decreases in payback period with small increases in sales price (Figure 21).

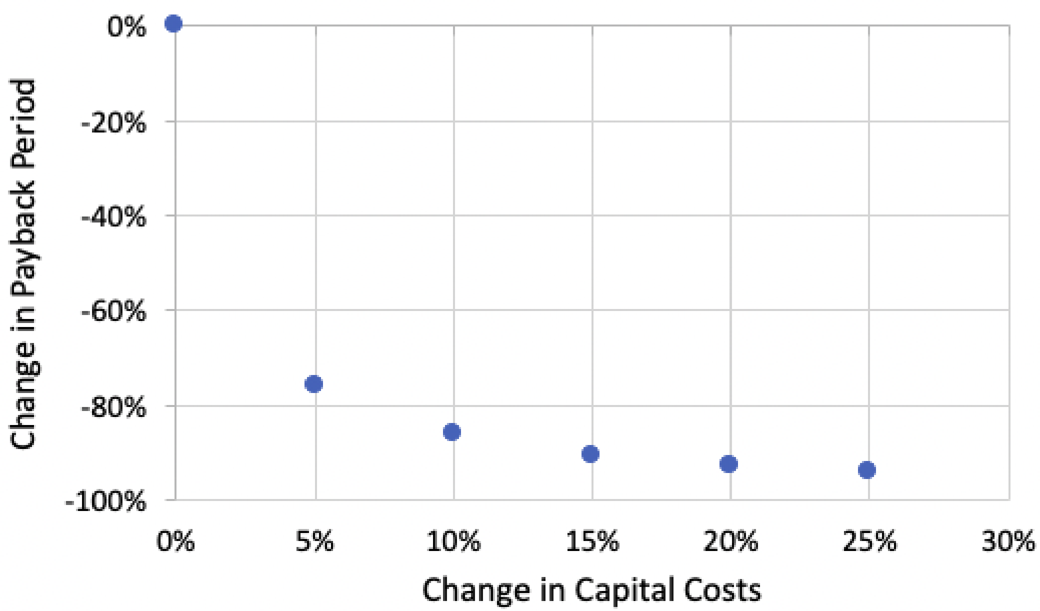

Figure 21. Sensitivity of payback period, in years, to the change of sales of compost in volume sold.

The second economic sensitivity analysis explored the effect that capital cost changes would have on the payback period. Besides the cost of land, all other cost variables were estimated for present worth based on Tchobanoglous and Kreith's 2002 Handbook of Solid Waste Management. In evaluating the sensitivity of payback period to changes in this variable, a linear trend was observed, where a 25% increase in capital costs causes a proportional 25% increase in payback period (Figure 22).

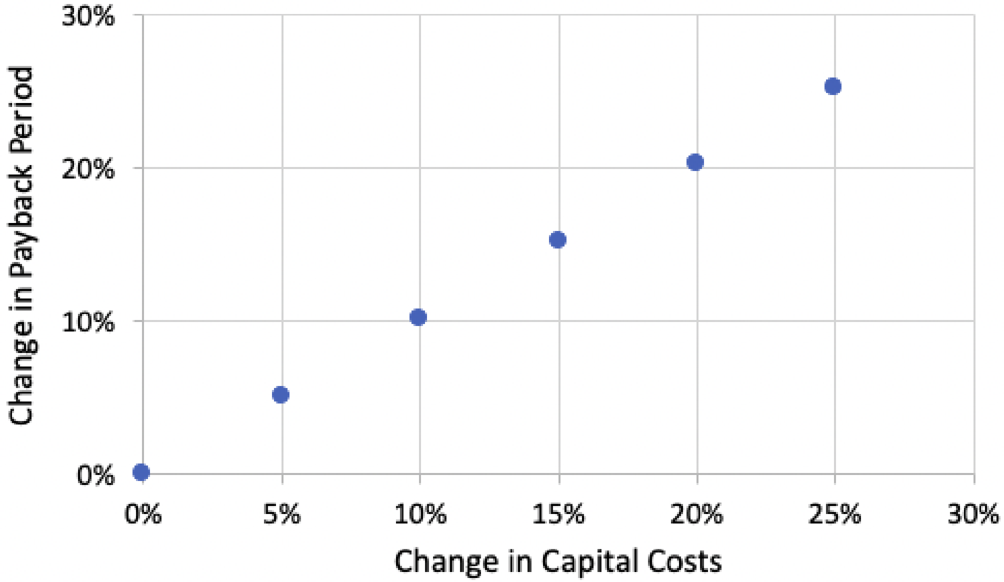

Figure 22. Sensitivity of payback period to change in capital costs of project.

6 Conclusion

After thorough analysis of four different alternatives, one alternative performed best when considering necessary social, economic, and environmental criteria. The composting with local WWTP utilization alternative was focused upon and improved to achieve the highest possibility of success due to its high carbon sequestration properties (approximately 583,000 tons carbon per year) and low payback period of 2.8 years. Approximately 98% of the biomass utilized was composted with windrow piles at a commercial-scale facility, while the remaining was implemented at four local WWTPs to produce Class A biosolids, replace trickling filter media, and replace odor control media. It is proposed that half of the compost would be sold locally for $38 per cubic yard, while the other half is trucked to Santa Rosa to various distribution centers and sold for $20 per cubic yard. Sensitivity analyses were conducted to understand the effects that different parameters imposed on the outcome.

6.1 Limitations and Recommendations

There are several limitations that are important to note when moving forward with implementation of the WWTP and composting alternative. In order to meet a reasonable C:N ratio and moisture level, it was necessary to account for a very large mass of cow manure. As most cattle in Humboldt County are dairy cattle, the manure would be more difficult to obtain, possibly resulting in the solution incurring additional logistic, financial, and supply chain burdens. Another limitation of this design is the demand for compost. Economic sensitivity analysis showed that the payback period has little sensitivity to changes in capital costs, and even if the price were to double, the payback period would double as well, bringing it to approximate 5.6 years, which is reasonable for the project. As the sensitivity of the projections for sales price of compost indicate, the payback period would increase exponentially if the local sales price had to be lowered beyond its already competitive price of $38/yd^3$; if there is insufficient demand at the regional level, this could cause the composting with WWTP solution to become infeasible so a market study is recommended to determine the true demand and estimated sales prices in Humboldt and Sonoma Counties to determine the feasibility of the proposed design.

Eighty percent of the biomass waste from the sawmills is used under this alternative, leaving twenty percent unaccounted for. Recommendations for this twenty percent include the following possible uses, which would require further investigation and scoping:

- Animal bedding
- Firewood for Humboldt County residents to use in existing woodstoves
- Flooding and corrosion control

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8 Appendices

Appendix A: Frequently Asked Questions

This section discusses the six frequently asked questions proposed by RCEA. Five of the six are quantifiable and can be used as an alternative assessment.

Table 31. The questions and responses from the Humboldt County community (RECEA 2020b).

Questions	Response
"How many trees are being cut down for electricity production at the local biomass plants?"	"The plants utilize waste from local lumber mills, not whole trees, as their primary fuel source (according to local forest products industry sources, some whole trees from operations such as roadside vegetation management may be sent directly to the biomass plants). In the absence of the plants, the material would otherwise need to be disposed of by an alternative means, most likely trucking it to more distant power plants, thus increasing total emissions. The local mill waste stream is more than sufficient to allow the plants to fulfill their RCEA power contracts without harvesting trees specifically for feedstock."
"The mill waste should be used for compost instead of electricity production."	"Potential alternatives for local use of the mill waste include composting or production of durable goods. However, to our knowledge no one is currently positioned to implement these solutions locally at the needed scale. There are significant permitting and social acceptance hurdles for a startup commercial composting facility to overcome. From a greenhouse gas perspective, rigorous analysis is needed to determine the emissions implications of composting the biomass instead of using it for electricity generation. RCEA recognizes the value of such analysis, but it is outside our organization's mission and technical expertise to perform."

“Is the biomass power RCEA is buying more expensive than other renewables?”	“Biomass power is typically more costly than other forms of renewable energy, mainly because it is more labor-intensive to produce. For Humboldt County, this can mean higher power costs, but also means skilled local jobs that help strengthen our economy. RCEA originally contracted its biomass procurement at the lowest price offered to us under a competitive solicitation for biomass power. This was substantially higher than what we were paying for renewable power from other, non-local sources. However, we have since renegotiated this contract to a lower price and entered a second biomass contract at a comparable price that, inclusive of all power products in the contracts, is approximately at parity with our other renewable resources. RCEA’s current effort to contract for long-term renewables is expected to bring us contracts at prices below what we currently pay for biomass power, as we strive to maintain an affordable power mix.”
“We should source 100% of our electricity from zero greenhouse gas sources such as solar and wind instead of biomass.”	“RCEA includes substantial amounts of solar and wind power in our portfolio and is striving to develop these resources locally. Biomass is a “baseload” resource, meaning it can be used to serve electricity demand at any time of day or night to balance out the production from intermittent renewables. Wind and solar are not baseload resources, and thus are not available on-demand. Battery storage can alleviate this issue but is not yet cost-effective to deploy at the scale that would be needed to replace biomass’s baseload function in the local power mix.”
“Can improvements be made to the biomass plants to modernize them and reduce their greenhouse gas and particulate emissions?”	“RCEA’s current contracts call for power producers to comply with all laws and regulations, including emissions limits. Beyond this, we do not dictate what equipment is to be used to control emissions. Some plant improvements have been made since RCEA

	began contracting for biomass power, and data to become available to the public in the future through the California Air Resources Board and the California Energy Commission, will show whether this is resulting in lower emissions per unit of energy produced. Further improvements in the plants are possible, but the operators are unlikely to make these investments unless they are ordered to by regulators or offered a higher price for power with plant improvements as a contractual condition.”
“Clarifications”	“**Biomass vs. vehicle emissions:** The local biomass power plants together emit less greenhouse gasses than from on-road vehicles in Humboldt County. The comparison referenced in some of the submitted comments only accounted for emissions from vehicles in the unincorporated county and excluded emissions from vehicles in the seven incorporated cities. **Biomass contract length:** RCEA is not in a long-term contract with either of the biomass plants. We are in a five-year contract with Humboldt Redwood Company and a one-year contract (with option to renew each year) with DG Fairhaven. Long-term contracts are ten-year and above, as defined by the state for compliance with SB 350 (the law requiring us and load-serving entities to procure at least 65% of our state-mandated renewable energy under long-term contracts starting in 2021).”

Appendix B: Biomass Greenhouse Gas Emissions in Humboldt County

In 2016, there were three facilities that produced electricity from biomass in Humboldt County: DG Fairhaven, Humboldt Redwood Company, and PG&E Bay Generating Station in Blue Lake. Each facility has a footprint of greenhouse gas emission that are listed in Figure 23.

Year	Facility	Total GHG	Non-Biomass GHG	Biomass CO2
2016	DG Fairhaven Power LLC	87,243	6,158	81,085
2016	Humboldt Sawmill Company	231,566	6,132	225,435
2016	PG&E Humboldt Bay Generating Station	171,847	171,847	0

Year	Facility	CO2	CH4	N2O	VOC	NOx
2016	DG Fairhaven Power LLC	85,532	27.75	3.64	8.9	74.8
2016	Humboldt Sawmill Company	226,819	76.95	10.1	36.9	174.8
2016	PG&E Humboldt Bay Generating Station	171,676	3.26	0.33	15.9	24.9

Year	Facility	SOx	PM10	PM2.5	Diesel PM	Formaldehyde	Hydrochloric Acid
2016	DG Fairhaven Power LLC	12.7	14.3	13.3	8.63	4,457	19,222
2016	Humboldt Sawmill Company	34.6	37.4	34.5	56.6	12,376	442
2016	PG&E Humboldt Bay Generating Station	1.2	5.2	5.2	129	1,933	

Figure 23. The biomass facilities in Humboldt county and the total green house and non-biomass greenhouse gas and carbon dioxide (Furniss 2020).

Technologies to filter Particulate Matter (PM)

Cyclones

The following characteristics in cyclones will increase the efficiency in filtering particulate matter: the size and density of PM, air inflow velocity, cyclone length, gas revolutions, ratio of the diameters for the cyclone and gas outflow, age, and maintenance. The efficiency of cyclones decreases when the gas viscosity, diameter of the cyclone, and gas outflow increases (EPA & NSCEP 2003).

Appendix C: Air Quality Regulations for DG Fairhaven

This section shows the air quality regulations for DG Fairhaven, as displayed by their Title V permit. These emission limits are used to compare the environmental criteria of alternatives.

Table 4.0 Device S-1 (Boiler) - Seasonal Tier Carbon Monoxide Emission Limits

Tier	June 1st to October 31st (Dry Season) Lb CO/MMBTU 24-Hour Average	November 1st to May 31st (Wet Season) Lb CO/MMBTU 24 Hour Average	Allowable Frequency in Each Tier for Each Month
1	1.8	2.5	CO emissions may not exceed the Tier 1 limit except as noted below for Tier 2 and Tier 3.
2	1.8 < x ≤ 2.3	2.5 < x ≤ 3.3	CO emissions shall not occur in the Tier 2 *and* Tier 3 ranges for more than eight (8) 24 hour averages each month.
3	2.3 < x ≤ 3.0	3.3 < x ≤ 4.0	CO emissions shall not occur in the Tier 3 range for more than three (3) 24 hour averages each month.

Figure 24. The emission limit regulations for each tier and season (NCUAQMD 2019a).

Table 4.1 Device S-1 (Boiler) - Seasonal Tier Nitrogen Oxides Emission Limits

Tier	Lb NOx/MMBTU 24-Hour Average	Allowable Frequency in Each Tier for Each Month
1	0.16	NOx emissions may not exceed the Tier 1 limit except as noted below for Tier 2 and Tier 3.
2	0.16 < x ≤ 0.18	NOx emissions shall not occur in the Tier 2 *and* Tier 3 ranges for more than eight (8) 24 hour averages each month.
3	0.18 < x ≤ 0.23	NOx emissions shall not occur in the Tier 3 range for more than three (3) 24 hour averages each month.

Figure 25. The emission limit regulations for each tier on 24-hour basis (NCUAQMD 2019a).

Table 4.2 – Release Point E-1 (Main Stack) Emission Limits

Pollutant	Emission Rate	
	lb/hr	tons/year
PM_{10}	12.6	55.4
$PM_{2.5}$	12.6	55.4
NOx	154.8	236
VOC	5.37	23.5
CO	1,264	3,316
SOx	7.9	34.6

Figure 26. The emission limit regulations for the emission rate for each pollutant (NCUAQMD 2019a).

Appendix D: Gasification Alternative Costs

These are projected costs for the implementation of a 3 MW modular gasification system estimated by West Biofuels. Included are capital and O&M for equipment that have been boiled down to respective dollars per kW. These factors were scaled up to the appropriate MW power generation and used to estimate costs for this project.

Table 32. Gasification system capital cost summary (Summers et al. 2016).

Item	Unit Cost ($000)
Truck unloading/fuel yard equip	200
Feedstock sizing equipment	350
Metering and conveyance	200
Feedstock dryer	600
Rotary gasifier	2500
Thermal oil heater	2600
3 Mwe ORC generator	4000
Interconnection gear cost	300
Site improvement costs	500
Total System	11,250
Construction/Installation, 30%	3,375
Contingency, 20%	2,250
Grand Total Capital Cost	16,875
Cost per kW ($/kW)	5,625

Table 33. Gasification alternative fixed operations cost summary (Summers et al. 2016).

Item	Unit Cost ($000)
Manager-Level Staff	280
Labor-Level Staff	420
Insurance	75
Property Taxes	50
Utilities	60
Administration	40
Total System	925
Construction/Insallation, 30%	278
Contingency, 20%	185
Grand Total Fixed Operations	1,388
Cost per kW ($/kW)	463

Table 34. Gasification alternative fixed maintenance costs (Summers et al. 2016).

Item	Unit Cost ($000)
Feedstock Handling	68
Conversion System	255
ORC Generator	80
Other	40
Total System	443
Construction/Insallation, 30%	133
Contingency, 20%	89
Grand Total Fixed Operations	664
Cost per kW ($/kW)	221

Table 35. Gasification alternative total fixed O&M summary (Summers et al. 2016).

Item	Unit Cost ($000)
Fixed Operations	11,388
Fixed Maintenance	664
Total	2,052
Cost per kW ($/kW)	684

Appendix E: Gasification Alternative Emissions

The third column in this table, representing next-generation thermochemical conversion power plants, provides emission factors used to estimate the expected annual criteria pollutant emissions as well as the GHG emissions.

Table 36. Next-generation thermochemical conversion power plant characteristics (Carreras-Sospedra et al. 2016)

Characteristic	Current-Generation Biomass Combustion Power Plant	Current-Generation Integrated Gasification/Combustion Power Plant	Next-Generation Thermochemical Conversion Power Plant	Next-Generation Thermochemical Conversion Bioalcohol and Power Plant
Plant size (BDT/day)	450	450	450	450
Electricity (kWhr/BDT)	1000	1200	1400	550
Alcohol fuel (gallons/BDT)	—	—	—	80
Diesel fuel	—	—	—	50
Average net energy efficiency	20%	22%	28%	50%
Emissions (lb/MMBTU output)				
NO_x	0.329	0.067	0.008	0.005
SO_x	0.125	0.010	0.002	0.001
PM	0.269	0.030	0.032	0.018
CO	0.897	0.070	0.042	0.023
VOC	0.085	0.018	0.003	0.002
CO_2	972	884	694	389

Appendix F: Freight Quote

This section shows the freight quote to truck biochar briquettes from Eureka to Santa Rosa for $1,317.20 per truck load.

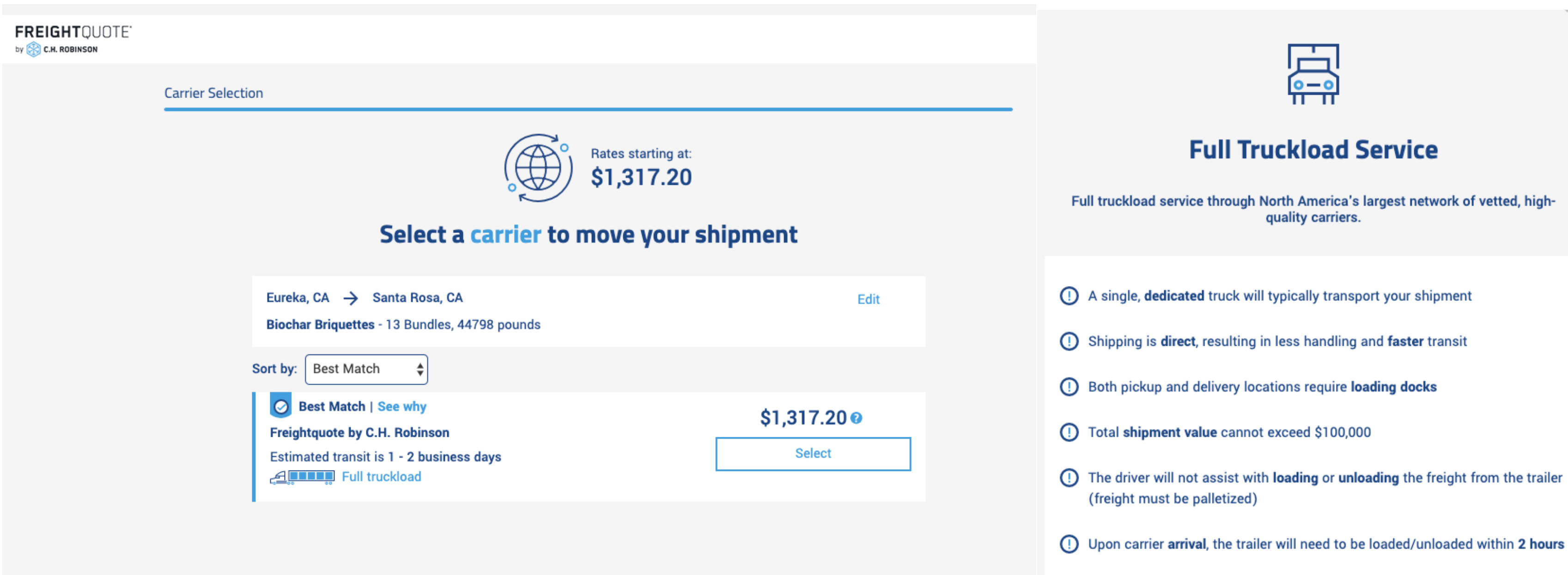

Figure 27. Freight quote for the transportation of biochar and compost (C.H. Robinson 2020)

Appendix G: Available CDI Property used to Assess Site Cost

The following Humboldt County multiple listing service report shows details for the site that was used to determine an approximate cost for Samoa peninsula CDI land of $76,000 per acre (Humboldt County MLS 2020).

3/28/2020 865 New Navy Base Road, Samoa Peninsula, CA 95564 (MLS# 254645) |

865 New Navy Base Road
Samoa Peninsula, CA 95564
MLS# 254645

$1,740,000

Property Description

One of a kind real estate opportunity: Oyster Beach, a beautiful, relaxed resort home plus 4 rustic-chic cabins on 22 bayfront acres. This gated, secluded beachfront property feels miles away from everything but is located just minutes from Arcata and Eureka. After a long day, unwind and take in the view of the Humboldt Bay from the beach, the outdoor bathhouse or one of the private decks. The current owners operate the property as a vacation rental resort to create the quintessential Humboldt experience and are working to expand available lodging to include "glamping" and RV sites. This is an ideal property for buyers looking to continue the profitable business or own a private, stylish retreat for friends and family. This property is situated in a federally approved Opportunity Zone.

Listing Information

Status: Active **List Date:** 2019-08-12

https://www.humboldtlistings.com/idx/865-New-Navy-Base-Road-Samoa-Peninsula-CA-95564-mls_254645/?SavedSearch=20200128152525392491000000&Proper... 1/3

List Price: 1740000 **Current Price:** 1740000

Property Description

Type of Property: Commercial	**Realtor.com Type:** Commercial
Construction Status: Existing	**Lot Size:** 20 - 39.99 Acres
Lot Acres: 22.7	**Flood Zone:** Yes

Location, Legal and Taxes

Area: South Bay	**House Number:** 865
Street Name: New Navy Base	**Street Suffix:** Road
Sub-Area: Samoa Peninsula	**State:** CA
Zip Code: 95564	**Cross Street:** Hwy 255
APN: 401-141-003	

Building Description

Year Built: 1860	**# Units:** 4
SqFt: 3670	**Condition:** Very Good

Square Footages

Total Building SqFt: 3670

Business

Real Estate Included: Yes

Property Features

Zoning: Commercial; Industrial; Coastal; Flood; Other

Income & Expenses: Financials Available

Type of Use: Amusement; Bed and Breakfast; Lodging; Recreation; Other-Spec in Remark

Existing Use: Other

Location: Rural

Sale Includes: Land & Building

Possession: At Close of Escrow

Financing Terms: Cash; Conventional; Exchange

Last Updated: February - 17 - 2020

Broker Reciprocity

Saturday 28th of March 2020 11:20 PM

Appendix H: Costs for Biochar Production Alternative

The following table details the costs associated with the biochar production alternative (Table 37). All machine estimates were provided by B. Hao of Beston in personal communication (2020).

Table 37. Costs for biochar production alternative.

Cost Item	100% of biomass	80% of biomass
Price per machine (Beston 2020)	$204,491	$204,491
Metric ton biomass	702,005	561,600
Hourly Capacity per machine (tons/hour)	3	3
Daily Capacity per machine (tons/day)	72	72
Days in year	365	365
Hours in Day	24	24
# machines needed	27	22
Price for all machines needed	$5,462,431	4,369,945
Annual machine maintenance cost ($)	$267,659	$214,127
Electricity required, no co-gen (kWh)	145.9	146
Total Electricity Needed (kW)	1278084	1,278,084
Electricity, industrial ($/kWh)	$0.1775	$0.1775
Power required (kWh)	3897	3,118
Annual electricity cost ($)	$6,059,957	$4,847,965
Area required for one machine (m2)	7500	7,500
Total Area Required (acres)	24.8	19.8
Cost per acre industrial facility in Humboldt ($) (Humboldt MLS 2020)	$252,384	$252,384
Cost to build a structure/cover	$154,133,439	$123,306,751
Cost of land for new facility	$1,881,215	$1,504,972
Cost of annual tax on land (assume 20% sales)	$18,812	$15,050
Annual water to facility ($)	$1,000	$1,000
Employment Costs (assume 8.25 FTE)	$525,600	$525,600
Distribution center percentage	$15,795,000	$12,636,000
Corporate Taxes (assume 20% of sales)	$22,113,000	$17,690,400
Mass biochar produced (ton)	210,600	168,480.00
Selling price biochar ($/ton)	$500	$500
Annual Biomass Sales ($)	$105,300,000.00	$84,240,000
Price to ship biochar ($/yr) (Appendix F)	$13,651,652	$10,921,322

Appendix I: Beston Carbonization BST-30 Emissions Report

This section shows the emissions report for Beston Carbonization BST-30 (B. Hao. Personal Communication, 2020).

SGS

Page 1 of 3

TEST REPORT

CLIENT DETAILS		LABORATORY DETAILS	
Contact	Henry He	Manager	SGS-CSTC
Client	Beston (Henan) Machinery Co., Ltd.	Laboratory	Shanghai Environmental Services
Address	9th Floor, E-Business center of Central China, South third ring & Zhengping Road, Erqi District, Zhengzhou , Henan , China.	Address	2/F, 3RD BUILDING NO. 889, YISHAN ROAD, XUHUI DISTRICT, SHANGHAI, CHINA
Telephone	-	Telephone	+86 (21) 6140 2666-2002
Facsimile	-	Facsimile	+86 (21) 6115 2164
Email	-	Email	REPORT.ENV @SGS.COM
Order Number	-	Report Number	SHE17-02663 R0
Samples	Exhaust Gas(1)	SGS Reference	0000068725
Project	-	Date Reported	2017/05/25

COMMENTS

1.This test document cannot be reproduced in any way, except in full content, without prior approval in writing by the laboratory.
2.The results shown in this test report refer only to the sampling and the sample(s) tested unless otherwise stated.

SIGNATORIES

Mingyue JIANG	Charles ZHENG	Eddy SHEN
Reported by	Reviewed by	Lab Manager

3rd Building, No.889 Yishan Road, Xuhui District, Shanghai, China 200233 t (86–21) 61072828 f (86–21) 61152164 www.sgsgroup.com.cn
中国・上海・徐汇区宜山路889号3号楼 邮编: 200233 t (86–21) 61072828 f (86–21) 61152164 e sgs.china@sgs.com

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SGS

TEST REPORT

SHE17-02663 R0

Parameter	Method	Units	LOR	Sample Number: 17-02663.001 Sample Matrix: Exhaust Gas Sample Description: -
Sampling Date	-	-	-	2017/5/16
Sampling location	-	-	-	Biomass Cabonization Plant Chimney
Sampling Time(PM)	-	-	-	10:01-11:01
Sampling Time(Hg)	-	-	-	10:00-10:45
Sampling Time(H_2S)	-	-	-	10:00-10:30
Sampling Time(Others)	-	-	-	09:57-10:42
Sampling Time(blackness)	-	-	-	10:00-10:30
Atmospheric Pressure	-	kPa	-	99.0
Gas Temp	-	℃	-	35.0
Stack gas velocity	-	m/s	-	8.6
Sec.ar.	-	m^2	-	0.0707
Oxygen	-	%	-	10.8
Moisture Content	-	%	-	3.0
Dry Stardard Flowrate	-	m^3/h	-	1.83×10^3
Exhaust Height	-	m	-	5
Static Pressure	-	kPa	-	0.07
Particulate matter (Emission conc.)	GB/T 16157	mg/m^3	0.1	**18.4**
Sulphur dioxide (Emission conc.)	HJ/T 57	mg/m^3	3	<3
Nitrogen oxides (Emission conc.)	HJ 693	mg/m^3	2	**170**
Mercury(Emission conc.)	HJ 543	mg/m^3	0.006	<0.006
Fume blackness	SEPA 2003	grade	1	<1
Carbon monoxide (Emission conc.)	SEPA 2003	mg/m^3	1	**161**
Hydrogen Sulfide (Emission conc.)	SEPA 2003	mg/m^3	0.02	**0.21**

Remark:
Sampling Address:Xingminan Road Xingyang City Henan Province
Equipment manufacturers:Beston (Henan) Machinery Co., Ltd.
Equipment name:biomass carbonization plant

*** End of Report ***

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中国・上海・徐汇区宜山路889号3号楼 邮编: 200233 t (86–21) 61072828 f (86–21) 61152164 e sgs.china@sgs.com

SHE17-02663 R0

Method List

GB/T 16157-1996 Examination of particulate matter and air pollution sampling method
HJ/T 57-2000 Determination of sulphur dioxide from exhausted gas of stationary source
HJ 693-2014 Stationary source emission-Determination of nitrogen oxides Fixed potential by electrolysis method
HJ 543-2009 Stationary source emission. Determination of mercury. Cold atomic absorption spe
SEPA 2003 Analytical Method for Monitoring of Ambient Air and Exhausted Air(4th ed.,SEPA,China,2003)5.3.3
SEPA 2003 Analytical Method for Monitoring of Ambient Air and Exhausted Air(4th ed.,SEPA,China,2003)5.4.10(3)

3rd Building, No.889 Yishan Road, Xuhui District, Shanghai, China 200233 t (86–21) 61072828 f (86–21) 61152164 www.sgsgroup.com.cn
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Appendix J: Area of Interest for all Alternatives

The map below, Figure 28, illustrates the general area of interest for all alternatives.

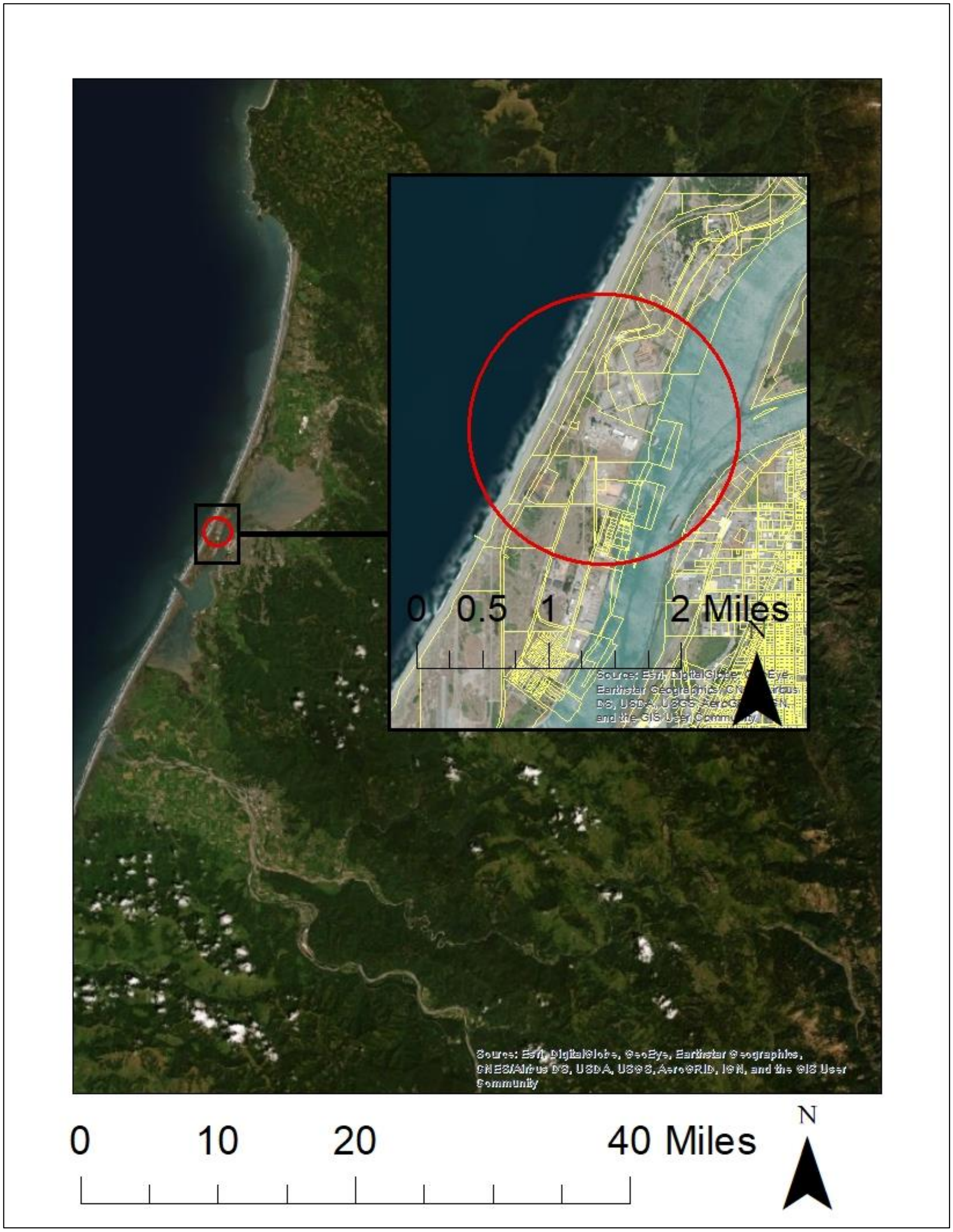

Figure 28. Area of interest for four alternative uses for the biomass generated by sawmills in Humboldt County. (Burke 2020)

Appendix K: Construction Materials Alternative Data

The figures, Figure 29 to Figure 31 below, show the data used to support the OSB materials alternative. The raw data consists of material, and amount of electricity that was inputted to produce one cubic meter of OSB. The outputs consist of emissions, and co-products. The processes for the OSB facility are represented in Figure 31. The cost of the material, and product can be found in Table 38. Table 40 was the multiplier for each component to produce the final results, which can be found in Table 42.

Materials[1]	Unit	Quantity per m^3	Mills Reporting a Value (n)	CVw[3] (%)
Roundwood (26% hardwood, 74% softwood)	m^3	1.52E+00		
	kg	8.04E+02	8	10
Bark	kg	1.10E+02	8	32
Phenol-formaldehyde resin	kg	1.21E+01	8	30
Methylene diphenyl diisocyanate resin	kg	5.95E+00	7	56
Wax	kg	3.76E+00	8	39

Figure 29. The input materials to make a cubic meter of an oriented strand board (OSB) (Puettmann, et al. 2017).

Inputs - Water		
Water, process, surface	3.10E-01	kg
Water, process, well	2.40E-01	kg
Water, municipal, process, surface	7.90E-01	kg
Water, municipal, process, well	2.40E-01	kg
Outputs – Products and Co-Products		
CORRIM Wood Combusted, at boiler, at mill, kg, RNA	1.00E+00	kg
CORRIM Wood ash, at boiler, at mill, kg, RNA	2.00E-02	kg
Outputs - Emissions to air		
Acetaldehyde	1.05E-06	kg
Acrolein	8.07E-07	kg
Benzene	1.69E-07	kg
Carbon monoxide, biogenic	3.23E-03	kg
Carbon dioxide, biogenic	1.76E+00	kg
Wood (dust)	5.62E-04	kg
Formaldehyde	1.26E-05	kg
HAPs	6.27E-06	kg

Figure 30. The water inputs and emission outputs for Oriented Strand Boards (Puettmann, et al. 2017).

Production Step	Description	Inputs	Outputs
Debarking	Includes log yard storage, sorting on the log yard; bucking (cutting logs to shorter *bolts*) and debarking.	Roundwood Diesel (log handlers) Electricity	Debarked bolts Bark and wood waste
Stranding	Bolts are cut parallel to the grain using an electrically-powered, multi-knife ring flaker to produce thin (mm) *strands* about 6 inches long and 1 inch wide.	Debarked bolts Electricity	Green (undried) strands
Drying	Green strands are passed through rotating driers heated with wood combustion exhaust and possibly natural gas to 4-8% moisture content.	Green strands Wood fuel (bark, screen fines, trimmings) Natural gas	Dry strands Air emissions, including particulates and volatile organic compounds (VOC)
Screening	*Fines,* wood pieces that are too small for OSB production, pass the screen and removed for use as fuel. Strands retained on the screen are used for OSB production.	Dry flakes Electricity	Dry strands of appropriate dimensions Fines
Blending	Stands are mechanically mixed with resins (adhesives) and wax to create the *furnish.*	Dry, screened strands Resins (MDI, PF) Wax Electricity	Blended furnish
Forming	The furnish is deposited in three, perpendicular layers to form a thick *mat.*	Blended furnish Electricity	Formed mat Air emissions, including VOC and hazardous air pollutants (HAP)
Pressing	The formed mat is heated and compressed in a (multiple-opening or continuous) press to achieve the final thickness and to cure the resin.	Formed mat Thermal energy (press) Electricity	Rough OSB Air emissions (VOC and HAP)
Finishing	Rough OSB sheets are trimmed, cooled, cut to size, stamped, stacked and packaged for shipment.	Rough OSB Electricity Fuel for forklifts Packaging materials	Packaged OSB Wood waste (trimmings) Air emissions (VOC and HAP)

Figure 31. The production steps for oriented strand boards. Note that the biomass that are mentioned to be used as fuel are not quantified in this report (Puettmann, et al. 2017).

Table 38. The positive and negative costs for an OSB facility in California (The Beck Group 2015).

Table 6.3 – Relative Economics of California Based and AR-LA-TX OSB Producers

$ per MSF (3/8" basis)	N. CA	AR-LA-TX
Delivered panel value (Southern Cal)	$240.00	$240.00
Transportation to market	$15.00	$40.00
FOB mill sales value	**$225.00**	**$200.00**
Wood ($/ton)	$35.00	$30.00
Recovery (M3/8 per ton)	0.62	0.62
Wood (panel basis)	$56.45	$48.39
Wax, resin	$30.61	$30.61
Manufacturing costs	$106.25	$96.25
Total costs	**$193.31**	**$175.25**
Pretax profit	**$31.69**	**$24.75**

Table 39. The carbon sequestration data to find the total amount of carbon dioxide equivalence is stored in the OSB from the biomass supplied from the mills (Puettmann, et al. 2017).

Carbon Sequestration

Carbon balance per 1 m3 of OSB

Carbon Balance	Value	
Released during manufacture	182	kg/m3
Stored in product	1150	kg/m3
Difference	968	kg/m3
Amount of m3 of OSB using just the biomass	587,033	m3/yr
Carbon sequestered	744,157	tons CO2 equivalent
Carbon released	174,431.37	tons CO2 equivalent
Net Carbon	569,725	tons CO2 equivalent

Table 40. The amount of cubic meter OSB produced in a medium/large facility annually (Puettmann, et al. 2017).

Facility(s)	Quantity	Unit
1	575000	m3/year
Individual facilities were studied and had an average amount of one cubic meter of OSB produced (Puetmann).		

Table 41. The quantity of inputs and outputs of material and outputs of emission for one facility.

For 1 Facility		
Input (one cubic meter of OSB)		
Materials	Quantity	units
Total Wood (26% hardwood, 74% softwood)	509597.91	tons/year
Hardwood	132495.46	tons/year
Softwood	301682.03	tons/year
Bark	69721.11	tons/year
Phenol-formaldehyde Resin	7669.32	tons/year
Methylene diphenyl diisocyanate Resin	3771.28	tons/year
Wax	2383.19	tons/year
Electricity (CO2 emission)	18915.78	tons/year
Electricity (NO2 emission)	30.82	tons/year
Output:	Quantity	Units
OSB	387269.06	tons/year
Air Emissions	Quantity	units
Acetaldehyde	4.43	tons/year
Acetone	1.34	tons/year
Acrolein	1.30	tons/year
CO	182.54	tons/year
CO2 (biogenic)	20979.72	tons/year
Formaldehyde	10.20	tons/year
MDI	0.06	tons/year

Methanol	20.09	tons/year
Nox	157.82	tons/year
Particulate PM2.5	45.95	tons/year
Particulate PM10	76.06	tons/year
Phenol	1.69	tons/year
Propionaldehyde	0.71	tons/year
SO2	16.86	tons/year
VOC	161.63	tons/year
CO2 from electricity	18915.78	tons/year
NO2 from electricity	30.82	tons/year

Table 42. The final values for each criterion for OSB production.

Criteria Analysis

Number of FAQs addressed	1
Height of facility (ft)	40
Population density impacted (people in 1-mile radius)	1000
Number of people employed (people)	169.00
Payback Period (years)	17.2
Number of permits required	3
Mass of GHG (tons/year)	60,657
Mass of criteria pollutants discharged (tons/year)	730
Mass of sequestered carbon (tons/year)	744,157
Mass of biomass utilized	80%

Capital Cost - Cost of Land	$ 6,000,000.00
Capital Cost - Cost of OSB Industrial Facility	$ 250,000,000.00
Annual Cost of Materials	$ 149,419,981.16

Annual Revenue	$ 164,361,979.28
Annual Profit	$ 14,941,998.12

Appendix L: RS Means Cost of Commercial Building

The cost of a commercial building was found utilizing the square footage cost estimator tool in RS Means. RS Means is a database of construction cost estimate and due to the free trial, the cost estimates that are provided are from 2011. The cost of a 2 story (12 feet each story) concrete frame new construction commercial building was costed out to be $142.95 per square foot. The cost estimate includes all the building material, labor, default contractor and architectural fees and equipment in the location of Eureka, California. Below show the general requirements by topic and letter, which replicates the Building Codes requirements for a commercial building (Gordian 2020).

Table 43. The general cost estimate for a commercial building described above (Gordian 2020).

		% of Total	Cost per SF	Description
A	Substructure	8.97	$9.68	Standard Foundation, Slab on Grade, Basement Excavation, Basement Walls.
B	Shell	39.86	$43.00	Floor, and Roof Construction, Exterior Walls, Windows, and Doors, Roof Coverings, Roof Openings
C	Interiors	8.78	$9.47	Partitions, Interior Doors, Fittings, Stair Construction, Wall, Floor, and Ceiling Finishes
D	Services	42.39	$45.73	Elevators and Lifts, Plumbing Fixtures, Domestic Water Distributions, Rainwater Drainage, Energy Supply, Cooling Generating Systems, Sprinklers, Standpipes, Lighting and Branch Wiring, Communications and

				Security, Other Electrical Systems
E	Equipment and Furnishings	0%	$-	Individual Cost Estimates
F	Special Construction	0%	$-	Individual Cost Estimates
G	Building Sitework	0%	$-	Individual Cost Estimates
	Subtotal	100	$107.89	All Above
	Contractor Fees	25	$26.97	GC, Overhead, Profit)
	Architectural Fees	6	$8.09	
	User Fees	0	$0	
	Total Building Cost	-	$142.95	

Appendix M: Pugh Method

Table 44 below shows the Pugh Method with the composting with WWTP utilization alternative as a baseline.

Table 44. Pugh Method with composting and WWTP utilization alternative as baseline.

	Compost/WWTP	Gasification	Biochar	OSB
Social				
Community Satisfaction	0	-	0	-
Aesthetics: Height	0	-	-	-
Aesthetics: Population Impacted	0	0	0	0
Economic				
Cost, Payback Period	0	-	-	-
Local Employment	0	-	-	-
Ease of Implementation	0	(+)	(+)	(+)
Environmental				
Air Quality, GHGs	0	(+)	(+)	(+)
Air Quality, Criteria Pollutants	0	-	(+)	-
Carbon Sequestration	0	-	-	(+)
Biomass Use	0	0	0	0
Sum all Positives		2	3	3
Sum all Negatives		6	4	5
Sum all Neutrals		2	3	2
Total		-4	-1	-2

Appendix N: Sensitivity Analysis

The tables below are the values that are represented in the figures in Section 5.5 Sensitivity Analysis for both the biomass and optimal compost mix.

Table 45. Sensitivity analyses of percent biomass utilized and effect on criteria pollutant emissions

Percent Biomass Used	Biomass Utilized (tons)	Criteria Pollutant Emissions (tons)	Percent Change
100%	702000	112.2	11%
95%	666900	109.3	8%
90%	631800	106.5	6%
85%	596700	103.7	3%
80%	561600	100.8	0%
75%	526500	98.0	-3%
70%	491400	95.2	-6%
65%	456300	92.3	-8%
60%	421200	89.5	-11%

Table 46. Sensitivity analysis data used to produce Figure 19 and Figure 20.

Percent Increase	Moisture of Woodchips	C:N	Mixture Moisture
0%	50%	35	40.0%
30%	65%	32.17	44.6%
60%	80%	29.3	49.3%
90%	95%	26.41	53.9%
100%	100%	25.44	55.5%
Percent Increase	Moisture of Bark	C:N	Mixture Moisture
0%	14%	35	40.0%
30%	18%	34.89	40.2%
60%	22%	34.78	40.3%
90%	27%	34.65	40.5%
100%	28%	34.62	40.5%
Percent Increase	Moisture of Leaves/Trimmings	C:N	Mixture Moisture
0%	40%	35	40.0%
30%	52%	34.65	40.5%
60%	64%	34.3	40.9%
90%	76%	33.93	41.4%
100%	80%	33.8	41.5%