Alternative Utilizations of Woody Biomass in Humboldt County

Prepared for: Redwood Coast Energy Authority

Humboldt State University

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Abbreviations & Acronyms

The following abbreviations and acronyms are used in this report:

AB	Assembly Bill
BDT	Bone Dry Ton
C	Carbon
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CEQA	California Environmental Quality Act
CEC	California Energy Commission
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPUC	California Public Utility Commission
CSL	California State Legislature
CRS	Congressional Research Services
CWA	Clean Water Act
CWC	California Water Code
DFW	Department of Fish and Wildlife
DFG	Department of Fish and Game
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
GHG	Greenhouse Gas
GIS	Geographic Information Systems
Gt	Green Ton
H_2	Hydrogen Gas
HRC	Humboldt Redwood Company
HWMA	Humboldt Waste Management Authority
IEA	International Energy Authority
JPA	Joint Power Agreement
Kg	Kilogram
kW	Kilo-Watt
MW	Mega-Watt
MWh	Mega-Watt Hour
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NCI	National Cancer Institute
NCRP	North Coast Resource Partnership
NCRWQCB	North Coast Regional Water Quality Control Board
NCUAQMD	North Coast Unified Air Quality Management District
NEPA	National Environmental Policy Act

NOx	Nitrogen Oxide Compounds
NPDES	National Pollutant Discharge Elimination System
NRPA	National Recreation and Park Association
O&M	Operation and Maintenance
O_3	Ozone
Pb	Lead
PBP	Payback Period
PDB	Polymer Database
PG&E	Pacific Gas and Electric
PM	Particulate Matter
Ppm	Parts Per Million
Ppt	Parts Per Thousand
RCEA	Redwood Coast Energy Authority
RPS	Renewable Portfolio Standard
SEI	Stockholm Environmental Institute
SB	Senate Bill
SO_x	Sulfur Oxides
SO_2	Sulfur Dioxide
SQL	Structured Query Language
SWRCB	State Water Resources Control Board
UF	Urea Formaldehyde
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USSEC	United States Securities and Exchange Commission
VOC	Volatile Organic Carbon
WBPI	Wood Based Panel International
WDR	Waste Discharge Requirements

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Executive Summary

The Redwood Coast Energy Authority (RCEA) was interested in alternative utilizations of waste woody biomass due to the questionable community support from the two existing combustion biomass powerplants in Humboldt County. Decreases in energy production resulting from implementation of an alternative was not required to be analyzed in this report.

Design Process

The project design process began with examining different utilizations of waste woody biomass. Alternative utilizations were subject to two key constraints, to follow regulatory guidelines and to provide at least the same amount of employment opportunities that are currently present at the existing combustion biomass plants. The client weighted criteria considered for each alternative included: Aesthetics, Community Support, Payback Period, Employment Opportunities, Project Implementation, Air Quality, and Carbon Sequestration. The four alternatives considered were a biomass Densification Facility, Particleboard Facility, Distribution Network, and Community-Scale Gasification Facilities. The Delphi and Pugh methods were then used in the Decision Analysis to examine how the alternatives were expected to perform.

Key Results

The results of the Decision Analysis determined that the preferred alternative would be a combination of the Community-Scale Gasification Facilities and Distribution Network alternatives. The combined alternative would dedicate 84% of the woody biomass waste to the gasification facilities, and the other 16% to the Distribution Network. Gasification facility placement would be within three Humboldt County cities, each city having two 5 MW gasification units. Optimum locations for the gasification facilities were determined by minimizing the travel distance of the woody biomass. This resulted in Garberville, Fortuna, and McKinleyville as the locations for the facilities. The gasification component helps RCEA meet their local 2030 renewable energy goals. The Distribution Network consists of one facility for storage and distribution of the biomass material. It also consists of an onsite community garden that could be up to 150 acres and consume some of the biomass itself as mulch. The most centralized location for the distribution network is in Rio Dell, but this can be altered to maximize population exposure to the community garden.

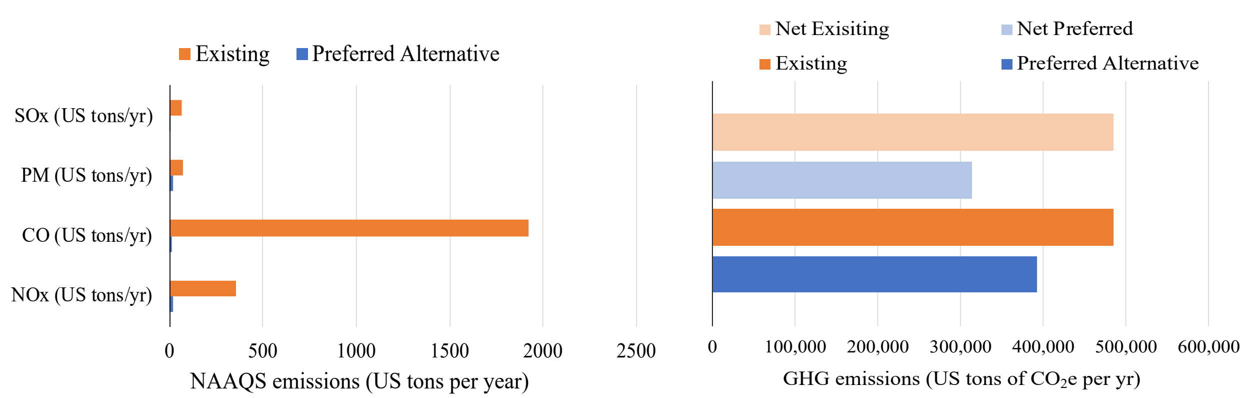

Figure ES-1: The GHG emissions and NAAQS emissions for both the business as usual and preferred alternative (CARB 2020).

Figure ES-1 describes the anticipated emissions from the preferred alternative in comparison to business as usual emissions from the current biomass facilities (CARB 2020). Note that gasification is considered carbon neutral in California and biochar production from gasification contributes to carbon sequestration (CEC 2020a). The total capital cost for the preferred alternative is 105 million dollars with a present net worth benefit of 238 million dollars. Sensitivity analyses were performed on energy demand in Humboldt County as well as consumer electricity cost. Figure ES-2 shows the results of the sensitivity analyses.

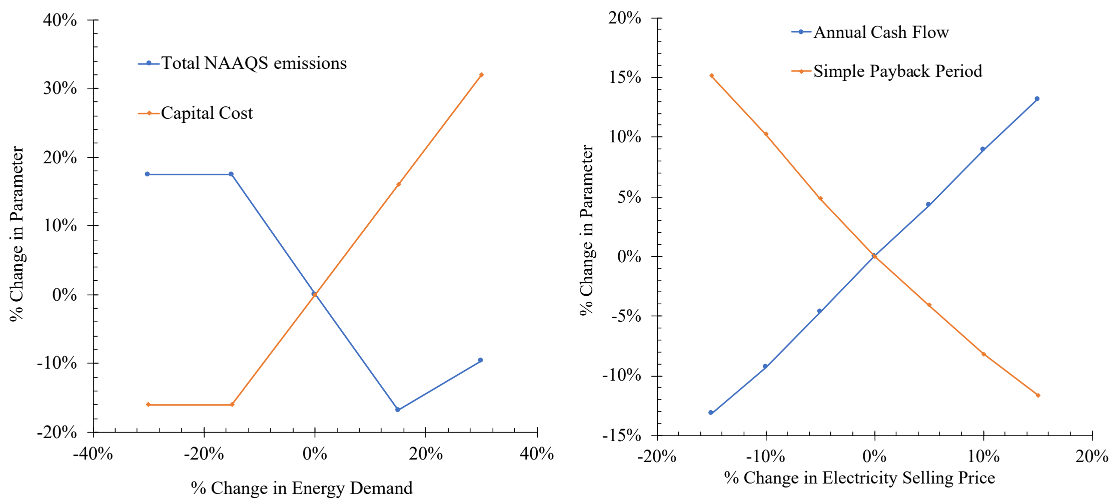

Figure ES-2: The sensitivity analyses conducted on total energy demand and consumer electricity cost.

Limitations and Recommendations for Future Work

The preferred alternative is heavily dependent on having a reliable stream of waste woody biomass. With capital costs reaching more than 100 million, this investment should be backed with a reliable relationship between the local sawmills and facility operators to ensure a steady stream of woody biomass to the preferred alternative. It is recommended that the preferred alternative is implemented as a combination of the Distribution Network and Community-Scale Gasification alternatives, this way the Distribution Network can act as a flow equalization basin for the gasification facilities. Excess biomass can be stored and distributed, and the community garden can still act as a community benefit if no biomass is coming in. For future work, it is recommended that the client investigate the potential for the gasification facilities to be funded through State grant money since gasification makes up a majority of the capital cost, and is considered a renewable energy resource in California (CEC 2020a). Another recommendation for future work is to investigate a potential partnership for the community garden aspect of the Distribution Network. Local city and county parks may be interested in a partnership as well as local universities looking for research space.

1. Introduction

Today, 3 million cubic yards of woody biomass is utilized annually to generate electricity in Humboldt County, Figure 1 (RCEA 2020). This waste woody biomass is sourced from logging and sawmill activities in Humboldt County. The 3 million cubic yards estimate was found by using information from the client for the estimated tons of biomass consumed by the current biomass powerplants, and the density of the incoming material. Of that annual value, only 15-40% leaves Humboldt County to be utilized elsewhere (RCEA 2020). Over the last two centuries, the main local uses of woody biomass have changed from being burned in teepee burners as a waste product, processed in pulp mills to generate paper, to now currently being utilized as feedstock to generate electricity (NCRP 2017).

Our client, the Redwood Coast Energy Authority (RCEA) is a joint powers agency that purchases and sells renewable sources of electricity to the communities of Humboldt County. RCEA purchases energy from many sources with the intent to promote sustainable and efficient energy production and use in Humboldt County. Biomass energy production is considered a renewable energy resource in the State of California, but residents of Humboldt County are divided on whether or not to continue to support this practice (RCEA 2020). RCEA conducted a survey to quantify the public support for the biomass powerplants and found an approval of about 50% (RCEA 2019). This mixed support from the public has prompted RCEA to look at alternative utilizations for the biomass in Humboldt County.

Figure 1: Project setting in relation to California (Adapted from: RCEA 2020 & Humboldt GIS 2020).

1.1 Objective

The objective of this project is to propose alternative utilizations of woody biomass in Humboldt County.

1.2 Scope

The project is focused on finding viable alternative utilizations of woody biomass. Decreases in energy production resulting from a chosen alternative is not required to be analyzed in this report.

1.3 Constraints

Implementation of each project alternative will be limited by existing regulations and employment opportunities. A detailed description for each project constraint can be viewed in Table 1.

Table 1: Constraints for the proposed alternatives.

Constraints	Description
Regulations	Alternatives analyzed must meet all local, state, and federal regulations.
Employment Opportunities	Jobs provided by alternatives must be equal to or more than current jobs provided by the existing biomass energy facilities.

1.4 Criteria

A list of criteria was developed through collaboration with the client. These criteria will be utilized to determine which alternative best meets the project objective and satisfies the client’s interests. The criteria were divided into three categories: Social, Economic, and Environmental. Each criterion under these categories has a basic description and quantifiable indicator (Table 2).

Table 2: Criteria for the proposed alternatives.

Criteria	Description	Quantification
Social		
Aesthetics	Minimize change in visual effects to surrounding environment	Volume of unnatural structures (ft^3)
Community Support	Maximize public approval	The percentage of the people who approve the project (%)
Economic		
Payback Period	Minimize time until a project begins making a profit	The number of years before a project begins to make a profit (years)
Employment Opportunities	Maximize job opportunities	Number of job opportunities that the project would produce or preserve (#)
Project Implementation	Maximize ability for implementation of project at the federal, state, and local level	Time required from approval to beginning operation of alternative (months)
Environmental		
Air Quality	Minimize air quality impacts	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)
Carbon Sequestration	Maximize sequestration of carbon	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)

2. Background

The Background Section offers information that will provide additional context on the project objective and the proposed solutions. This section of the document explores the setting of the project, discusses past and modern utilizations for woody biomass, and characterizes the regulatory setting for the existing biomass powerplants in Humboldt County.

2.1 Setting

RCEA currently procures energy from two biomass energy sources in Humboldt County (Figure 2). The two existing plants are DG Fairhaven in Samoa, California and Humboldt Redwood Company in Scotia, California. Together these plants generate almost one fourth of RCEA's energy portfolio (RCEA 2020). Despite the energy production and job opportunities the two power plants offer, local perception of biomass energy through combustion is not favorable throughout the communities of Humboldt County. The process emissions for each existing plant can be viewed in Table 3. With the uncertainty of the biomass power plants' futures, an opportunity to explore reutilizations of woody biomass produced in Humboldt County has presented itself.

Figure 2: Map of Humboldt County and locations of biomass power plants (Adapted from: RCEA 2020 & Humboldt GIS 2020).

The quantity of NAAQS emissions and employment values for each plant can be viewed below in Table 3 (CARB 2020). Direct employment is described as the number employees who work physically at the plant, whereas indirect employees is the number of employees who provide direct services to the plant so that it can remain in operation (i.e. truck drivers who deliver biomass to the plant). A breakdown of the current employment and power rating of the existing facilities is given in Table 4.

Table 3: The process GHG and NAAQS emissions for DG Fairhaven and HRC Scotia (CBEA 2020b, CBEA 2020c, PG&E 2020).

Facility	CO_2 (US tons CO_2e/yr)	NO_x (US tons/yr)	PM_{10} (US tons/yr)	CO (US tons/yr)	SO_x (US tons/yr)
HRC Scotia	258,042	171	37	785	32
DG Fairhaven	176,738	152	30	1139	28

Table 4: The power ratings and direct/indirect employment opportunities for HRC Scotia and DG Fairhaven (RCEA 2020).

Facility	Power Rating (MW)	Direct	Indirect	Total
HRC Scotia	18	22	19	41
DG Fairhaven	28	25	30	25

2.1.1 Project Stakeholders

There are many stakeholders who may have interests in the future of woody biomass. A list of potential stakeholders for the reutilization of woody biomass are depicted in Table 5.

Table 5: A list of stakeholders who have may have interests in the future of woody biomass in Humboldt County.

Stakeholder	Description/Mission	Local, State, or Federal, JPA, Other
Cities of Humboldt County	The incorporated cities of Humboldt County (i.e. Arcata, Eureka, etc.)	Local
Communities of Humboldt County	The communities of Humboldt County (McKinleyville, Garberville, Willow Creek etc.)	Local
North Coast Unified Air Quality Management District	Tasked with managing the air quality in Humboldt County.	Local
Department of Fish and Wildlife	Protects fish, wildlife, and plant resources in Humboldt County.	State
California Air Resources Board	Protects the air quality of California.	State
State Water Resources Control Board	Responsible for preserving and enhancing the quality of California's water.	State
California Department of Transportation	Responsible for improving and maintaining California's roadways.	State
California Public Utilities Commission	Creates policies and makes decisions on how California gets its utilities (i.e. water, energy).	State
United States Forest Service	Responsible for sustaining health, diversity, and productivity of our nation's forests.	Federal
United States Environmental Protection Agency	Responsible for protecting the human and environmental health of the nation.	Federal
Redwood Coast Energy Authority	Mission is to advance the use of clean, efficient, and renewable energy resources in Humboldt County.	JPA
Humboldt Waste Management Authority	Responsible for the transportation and disposal of Humboldt County's solid waste.	JPA
Pacific Gas and Electric	Mission is to power large areas of California through the use of clean and renewable energy.	Other
Humboldt County Farm Bureau	A network of farmers who educate on legislation that could affect the local farming industry.	Other

2.1.2 Defining Biomass

Biomass has always been a means for humans to produce useful materials and energy. In the context of the project, the term biomass is used to define materials of organic and biological origin. These materials can be utilized for energy generation, and in the production of other goods (Bioenergy Basics 2020). Biomass can be derived from the waste of industrial, agricultural, or timber processes. Examples of biomass include forest residues from wildfire suppression operations, orchid and crop trimmings, byproducts of lumber production, organic material in garbage, and waste from livestock and humans (Bioenergy Basics 2020). The composition of biomass can vary with the age of the collected material, how decomposed it is, and its location.

While there are discrepancies in biomass make-up, it is primarily composed of cellulose, hemicellulose, lignin, lipids, proteins, sugars, starch, water, and hydrocarbons (Jenkins et al. 1998). The elemental composition can vary as well, with 30%-40% of the dry weight in the form of oxygen, 30%-60% carbon, 5%-6% hydrogen, and less than 1% of nitrogen, sulfur, and chlorine (Jenkins et al. 1998). The density of biomass utilized this paper for quantitative analyses is 247 kg/m^3, which is characterized by a mixture of saw dust and green waste (Marino 2020).

One of the world's biggest problems is addressing energy security while combating GHG emissions produced from non-renewable fossil fuels. Biomass has received attention globally because of its use in green technology, and its ability to provide a source of renewable energy (Li et al. 2020). According to data gathered by the International Energy Authority, biomass waste utilized for energy production accounted for 3.3% of the world’s total energy in 2018, an increase of over 100% since the year 2000 (IEA 2019).

2.1.3 History of Biomass in Humboldt County

Humboldt County is known for its rugged coast and old-growth redwood forests. The County is covered with approximately 1.5 million acres of forested lands, with 990,000 acres of these lands designated as Timber Production Zones (Humboldt County 2017). Timber operations have been active in the area since 1850, which has coincided with the construction of sawmills and lumber processing (Palais and Roberts 1950). There are enormous amounts of waste associated with lumber production. In the past, it was reported that up to an excess of 15 billion tons of wood waste could be produced a year from lumber production in the United States alone (Harkin 1969). If there was no market for the waste, the saw mills frequently disposed of it in open burns called teepee burners, which emitted a significant amount of smoke and pollutants into the air (Furniss 2019).

2.1.4 Current Utilization of Biomass

As of the year 2020, woody biomass generated in Humboldt County goes to one of four locations: 1) the HRC biomass powerplant in Scotia, CA, 2) the DG Fairhaven biomass powerplant in Fairhaven, CA, 3) exported out of Humboldt County, or 4) is utilized for other local uses (Furniss 2020). A schematic displaying the volume of Humboldt County’s biomass being transported each day to one of the listed locations is shown in Figure 3 (RCEA 2020).

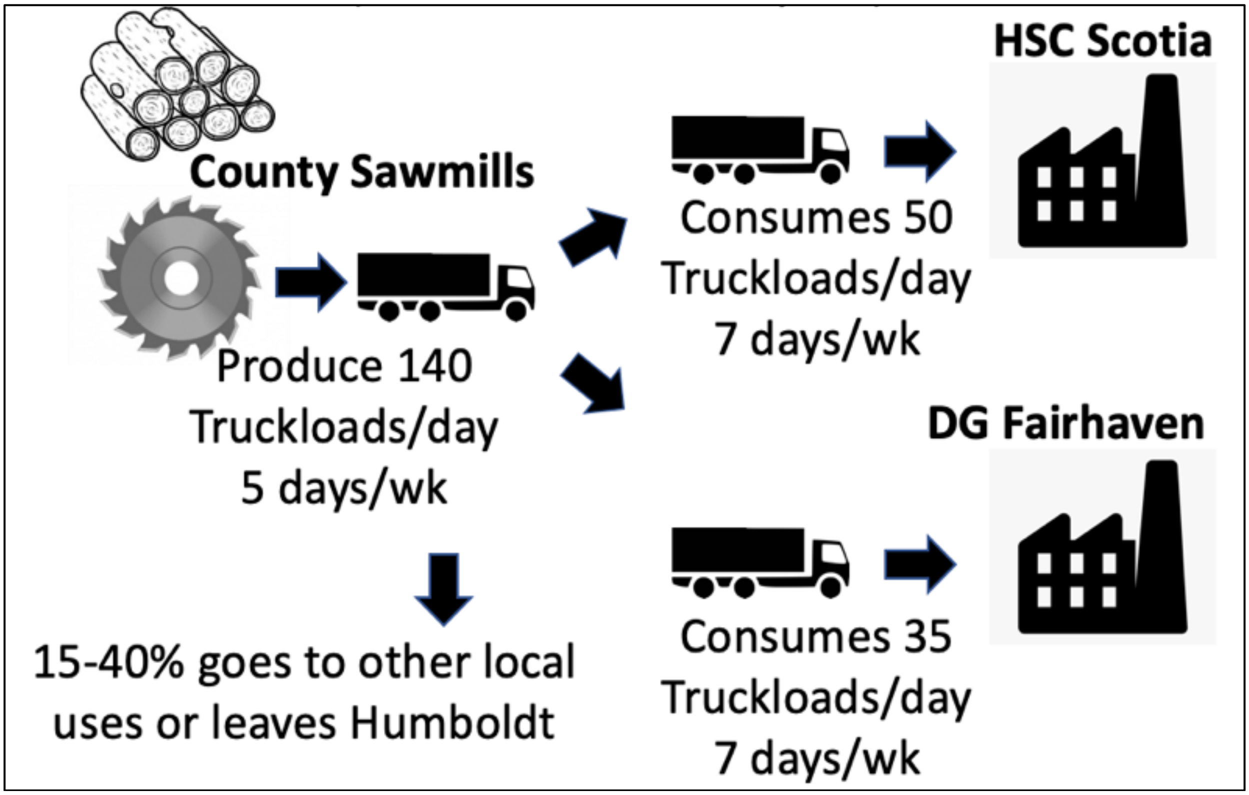

Figure 3: Volume of biomass in Humboldt County being transported daily (Image source: RCEA 2020).

One of the most common domestic uses of woody biomass is thermal heating in a home fireplace or wood burning stove. In Humboldt County, firewood is a common source of fuel for thermal energy in many homes and buildings. The market for woody biomass being used as thermal fuel is also quite high, selling from anywhere between $15-$30/Gt (NCRP 2017). If unregulated burning of firewood for thermal heating occurs, emissions can be of concern. The USEPA regulates woodstoves, which are now commonly equipped with catalytic converters to reduce emissions (CRS 2018). Other local uses of biomass in Humboldt County include erosion control, fertilizer, and activated carbon production (RCEA 2020). Additionally, woody biomass also leaves Humboldt County by either shipping it overseas or to nearby States to provide similar domestic and local uses (Furniss 2020).

Energy generation from biomass makes up for around 22% of the total electricity production in Humboldt County (RCEA 2019). Figure 4 is a breakdown of different ways electricity is generated for Humboldt County.

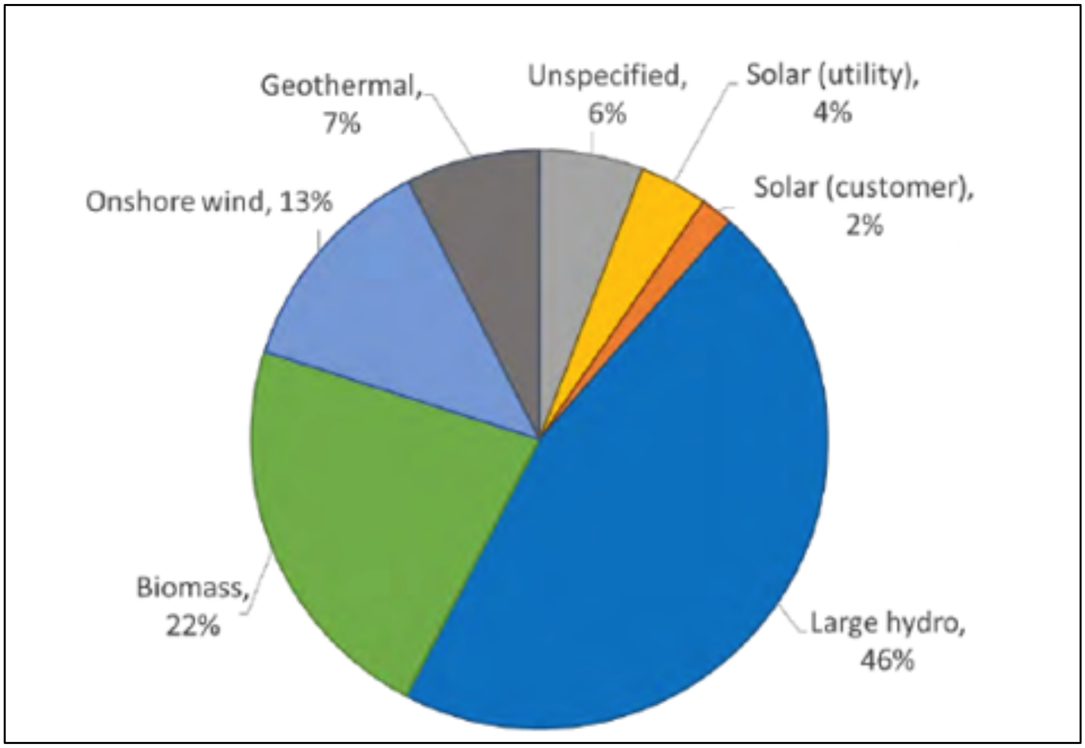

Figure 4: Breakdown of how Humboldt County's electricity is generated (Image source: RCEA 2019).

2.1.5 DG Fairhaven Biomass Plant

The DG Fairhaven biomass powerplant operates by combusting woody biomass to produce steam which powers a turbine (Furniss 2020). The plant utilizes one biomass/natural gas fueled boiler which produces 180,000 lb. of steam per hour (NCUAQMD 2019). The plant overall has a nameplate capacity of 18 MW, but typically operates at 13.25 MW, and has a year-to-year contract with RCEA (RCEA 2020). No future development plans for the plant are known.

2.1.6 HRC Scotia Biomass Plant

The HRC Scotia biomass powerplant operates by burning woody biomass to produce steam which powers a turbine (Furniss 2020). The plant utilizes three biomass fueled boilers each producing 150,000 lb. of steam per hour (NCUAQMD 2017). The plant overall is rated at 30 MW and has a 5-year contract with RCEA (RCEA 2020, Furniss 2020). Future development plans for the plant include the installation of a fourth natural gas fueled boiler to help meet future electricity demands (NCUAQMD 2017).

2.1.7 Regional and Local Perception of Biomass Energy

California produces an enormous amount of waste from agricultural production and forest residues. Part of the solution to managing the waste is to convert some of it to energy and other goods for the benefit of society. The current utilization of biomass in the State is driven by legislative policies that aim to establish biomass energy as a green and sustainable resource. Biomass is categorized as a renewable energy resource by the California Energy Commission and promotes its benefits as reducing carbon and other harmful emissions that would otherwise come from wildfires or landfills (CEC 2020a). The Renewable Portfolio Standard was established in 2002 with the passing of Senate Bill 1078 which targeted 20% of electricity sales generated from renewables by 2017, 60% by 2030, with the goal of 100% carbon free energy by 2045 (CPUC 2020). The year of 2006 saw the implementation of Executive Order S-06-06 which designated the minimum use of biomass for energy in California to 20% by the year 2010, 40% by 2020, and 75% by 2050 (Executive Order S-06-06 2006). Under Executive Order S-21-09, the California Air Resources Board was to adopt regulations that would help meet the 33% renewable energy target set in Executive Order S-14-08 by 2010 (Executive Order S-14-08 2008 & Executive Order S-21-09 2009).

Despite the implementation of many policies that aim to maximize the potential and public opinion of biomass energy, there are many problems associated with meeting these targets. Studies done on different forms of biomass energy show that certain data is not always accounted for in carbon accounting. The reasoning behind labeling biomass as a carbon neutral energy source is that all carbon released during energy production is assumed to be captured by the next generation of plants. However, some practitioners of life cycle assessments do not see this as true. There are those in the scientific community that argue that removing trees reduces carbon storage enough that it leads to an overestimate of the amount of carbon sequestered (Johnson 2009). The controversy of biomass as a true renewable energy source is also prevalent in Humboldt County. Air quality has always been a concern in Humboldt County history, dating back to the peak of the timber industry where teepee burners were operating. A recent poll performed by RCEA on combustion of biomass for energy revealed that the opinions of the communities of Humboldt County are split, with 48% in support of utilization, 29% who want to minimize its usage, and 24% who are against the current utilization (RCEA 2020). Figure 5 shows results of a public opinion survey on different energy sources in Humboldt County (RCEA 2020).

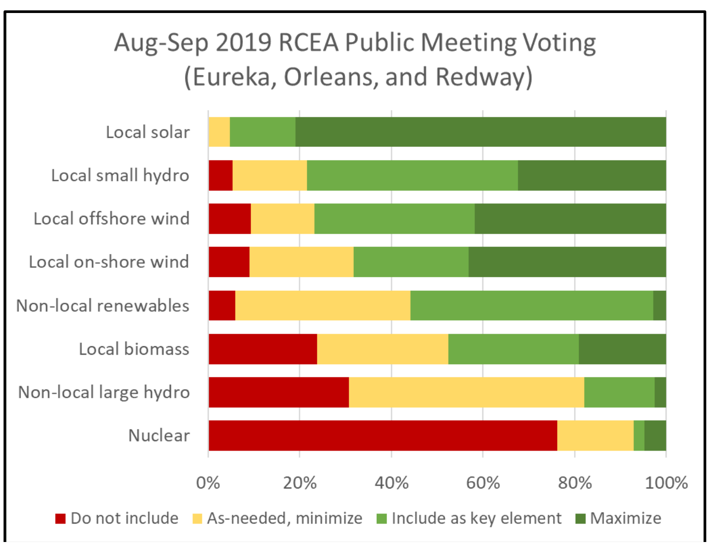

Figure 5: Public opinion of different sources of energy in Humboldt County (Image source: RCEA 2020).

This source of division is of great importance to the development of a solution that satisfies both Humboldt County's desire for renewable local energy and enhancing the quality of life for its citizens.

2.1.8 Climate Change Policies

Several pieces of legislation have been passed within the last 20 years that address climate change. One of the most notable pieces of legislation was Assembly Bill 32, which was titled the California Global Warming Solutions Act (AB32 2006). This 2006 bill recognized the threat global warming posed for the future of California, and would require that GHG emissions from the State be reduced by 15% by 2020 (CARB 2014). Furthermore, the bill set a goal to reduce the GHG emissions an additional 80% by the year 2050.

Like AB32, Senate Bill 100 will play a vital role in reducing the GHG footprint for the State of California. Senate Bill 100, passed in 2018, focused on energy procurement in the State, and sets an aggressive goal of meeting the consumer energy demand with 100% renewables by 2045 (CSL 2020). The development of clean energy will be instrumental in reducing GHG emissions because it addresses one of the bigger sources in the State, the use of fossil fuels in power generation.

2.1.9 Air Quality Policies

Humboldt County has a 2025 energy general plan that discusses the role of woody biomass utilization in reducing air quality pollutants (SERC 2005). It is recognized that the combustion of the biomass in a controlled facility is better for air quality than burning on site or for residential use (SERC 2005). Open burning releases more than triple the amount of particulate matter, CO_2 and NO_x per ton of biomass than burning in a biomass energy plant (NCRP 2017). Humboldt County is considered an attainment area for all the NAAQS pollutants, except for PM_{10} (Humboldt County 2012). Although with recent research showing that PM_{10} is much less of a lung health concern than finer particulate matter, the federal and state standards have been adjusted accordingly (Humboldt County 2012). It is also important to note that the largest identified source of PM_{10} in Humboldt County is unpaved road dust, contributing to 58% of PM_{10}, while all forms of biomass utilization accounts for approximately 20% of PM_{10} (Humboldt County 2012). These percentages do not consider PM_{10} from forest fires, just direct anthropogenic sources. It is recognized that any major source of PM_{10} would have a significant and unavoidable impacts on the area and would therefore be subject to CEQA (Humboldt County 2012). Any major source of any NAAQS pollutant is subject to a Title V permit, which sets limits on air quality emissions.

2.1.10 Wildfire Policies

Wildfires are annually prevalent in California and cause damage to resources and property. In addition, wildfires release massive amounts of carbon and particulate matter into the air which is of concern to public health. The State has implemented policies which aim to reduce the negative and adverse effects of wildfires by utilizing woody biomass for energy; this biomass would otherwise be left in the forest which could potentially help feed and sustain these fires. Senate Bill 1122, also called the Bioenergy Feed-in Tariff Program was established in 2012 to accelerate the State's investments in small scale bioenergy production which utilizes woody biomass from forest management and high fire risk areas to help meet RPS targets (Bill Text - SB-1122 Energy: Renewable Bioenergy Projects 2012).

2.2 Other Utilizations of Woody Biomass

The biomass utilizations examined in this section include: pyrolysis, gasification, biomass products, biomass use in building materials, and hydrolysis. This background knowledge is important in considering what solutions can be implemented within Humboldt County.

2.2.1 Pyrolysis

Pyrolysis is the process of thermally decomposing organic matter at high temperatures in the absence of oxygen. Pyrolysis produces a mixture of hydrocarbons called bio-oil and biochar (Ringer et al. 2006). Pyrolysis can be undertaken in many different forms. Multiple temperatures, scales, and pyrolysis techniques can be used resulting in different qualities and quantities of product (Ringer et al. 2006). Here it is aimed to discuss different pyrolysis techniques, the quantity and quality of products produced, as well as the emissions associated with the process.

The first major variable to consider in different pyrolysis techniques is temperature. Different components of woody biomass will break down at different temperature ranges as listed in Table 6 (Demirbas 2000). Different methods take advantage of these temperatures and heating rates to produce specific products as seen in Table 7 (Pandy 2008). The most common equipment used for these methods are either fixed bed reactors or fluid bed reactors which can both involve the use of catalysts (Gollakota et al. 2016). Currently, pyrolysis as a means of making bio-oils has been studied for small scale prototypes (NCRP 2017). It has also been studied in large scale applications (Ringer et al. 2006).

Table 6: Degradation temperatures of woody biomass components (Demirbas 2000).

Woody Biomass Component	Degradation Temperature Range (K)
Hemicellulose	470-530
Cellulose	510-620
Lignin	550-770

Table 7: Pyrolysis methods with their parameters and products (Pandey 2008).

Method	Residence Time	Temperature (K)	Heating Rate (BTU)	Products
Carbonization	Days	675	Very Low	Charcoal
Conventional	5-30 min	875	Low	Oil, gas, char
Fast	0.5-5 s	925	High	Bio-oil
Flash-liquid	<1s	<925	Very high	Bio-oil
Flash-gas	<1s	<925	Very high	Chemicals, gas
Hydro-pyrolysis	<10s	<775	High	Bio-oil

As stated previously, the quality and quantity of products produced in pyrolysis are heavily dependent upon technique and feedstock. Almost any organic material can be used as a feedstock but when using a consistent feedstock material, the products become more consistent, making them easier to process and manage. Some studies have compiled a list of case studies with specific feedstocks and pyrolysis methods, and the respective quality of bio-oil produced (Gollakota et al. 2016). In the case of bio-oil, the product is a crude mixture of oils that would need to be refined for any conventional use as a biofuel (Gollakota et al. 2016). Without refinement, the bio-oil may be utilized for heating or energy production through steam production, but the crude will burn less efficiently and dirtier than a refined product (Ringer et al. 2006). Use of crude bio-oil in a conventional internal combustion engine used in transportation would be infeasible. Through the separation and refinement of different oils present in the bio-oil, specific products can be made. These include: fuels for energy and transportation, resins, chemicals, binders, and wood preservatives (Gollakota et al. 2016). It is important to note that the combined energy inputs required to create bio-oils through pyrolysis and refine the crude mixture is significantly larger than the energy requirements needed to collect and refine fossil fuels into similar products (Gollakota et al. 2016). Providing a consistent feedstock and scaling up the process could result in significant reductions in this energy cost (Ringer et al. 2006).

Just as in the case of bio-oils, there are studies that have looked into biochar qualities resulting from specific pyrolysis techniques and feedstock combinations (Spokas et al. 2012). Biochar is a charcoal-like substance high in carbon, ash content, minerals, and nutrients. Biochar has many utilizations and the most notable are: as a soil amendment, applied as odor reducer in landfills, chemical adsorption and clean up, livestock feed supplement, cosmetics, filters, etc. While the uses of biochar seem endless, it is important to note that the quality of biochar produced may be best suited for only a few applications. Biochar has recently been studied extensively for its soil amendment properties. These include increased water retention, nutrient retention, porosity, increased pH, long term reduction of soil erosion, increased habitat and surface area for beneficial microorganisms, and high nutrient content on initial application (Li et al. 2018). With soil erosion and water management being large concerns in global agricultural, biochar shows potential as a possible solution. Some studies have compiled the resulting effects on crops after the use of biochar in amending the soil (Beesley et al. 2011). The coarseness of the feedstock directly effects the coarseness of the biochar since the biochar is a residue of the feedstock.

Pyrolysis air emissions, other than greenhouse gasses, vary depending on the method used. The emissions generated by refining bio-oil into biofuel and combusting for energy would be similar to other biofuel production methods. Use as a transportation fuel would result in higher emissions in comparison to an energy plant where the exhaust can be treated as a point source. Biochar itself is heavy in soot and handling the product in large quantities can produce large quantities of particulate matter if the material is dry. Also, higher moisture content leads to more CO emissions which explains seasonal emission regulations that are more relaxed in the wet season (NCUAQMD 2019).

The use of pyrolysis in order to make biochar and biofuels results in net CO_2 emissions of 91-360 kg CO_2 per MWh without considering carbon sequestration from biochar utilization (Gaunt and Lehmann 2008). Another consideration is that wet biomass produces bio-oils with higher moisture and a lower heating value in comparison to dry biomass products (Gallakota et al. 2016). This means that the amount of CO_2 emitted per MWh or gallon of refined biofuel is higher for biomass higher in moisture. Drying or preventing the biomass from getting wet can reduce this effect and the associated CO emissions, but this may require more energy or capital investment. The amount of GHG offset due to biochar use in agriculture is significant and variable considering the total carbon content in the char, the amount of N_2O emissions reduced, the displaced fertilizer, and preservation of soil (Gaunt and Lehmann 2008). It is difficult to quantify the amount of GHG emissions that would be reduced by using the biochar product due to all these factors, but they are significant and worth considering. Figure 6 shows the complex relationships between biochar, the soil, and greenhouse gases (Li et al. 2018).

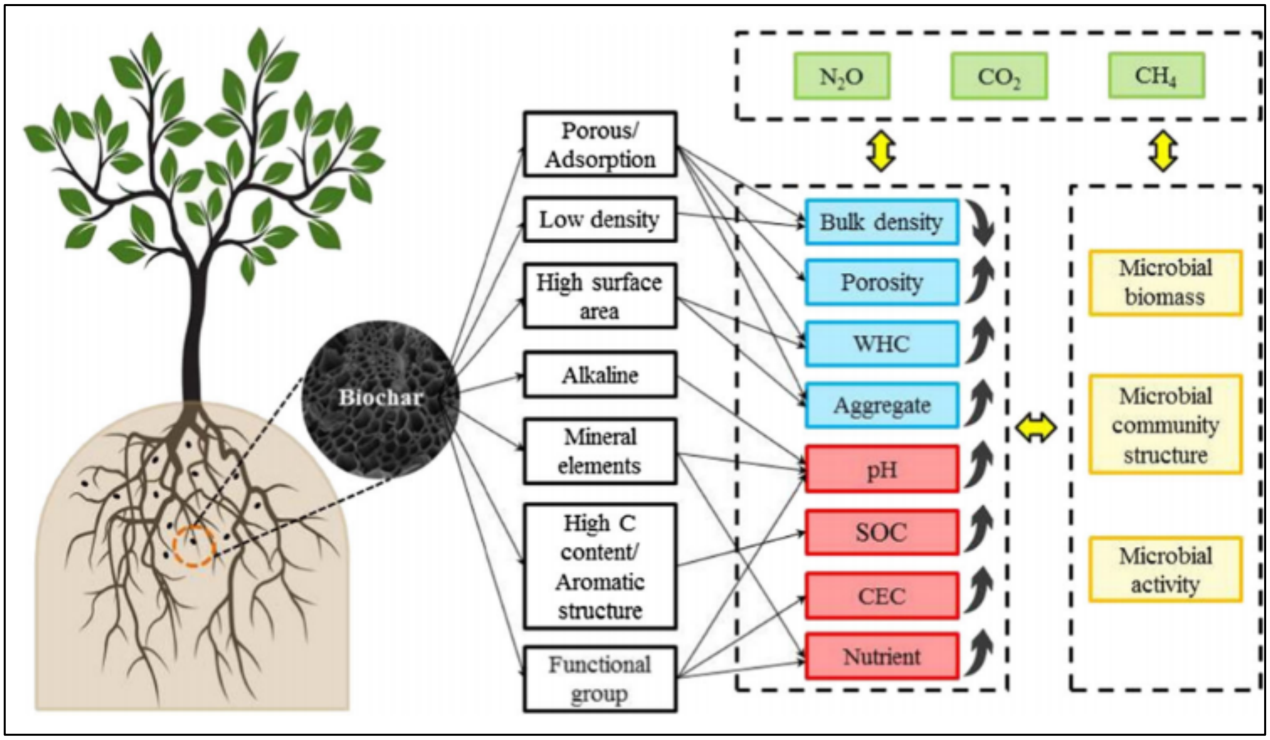

Figure 6: Biochar, soil properties, and their relationship with greenhouse gasses (Image source: Li et al. 2019).

2.2.2 Gasification

Gasification is the thermal decomposition of organic matter into CO_2, CO, H_2, methane, and biochar with a controlled amount of oxygen or steam (Kumar et al. 2009). Gasification, like pyrolysis, requires energy inputs and has some advantages over conventional combustion. Here we aim to discuss the products produced through gasification as well as the associated emissions. A general gasification process is outlined in Figure 7 (Kumar et al. 2009).

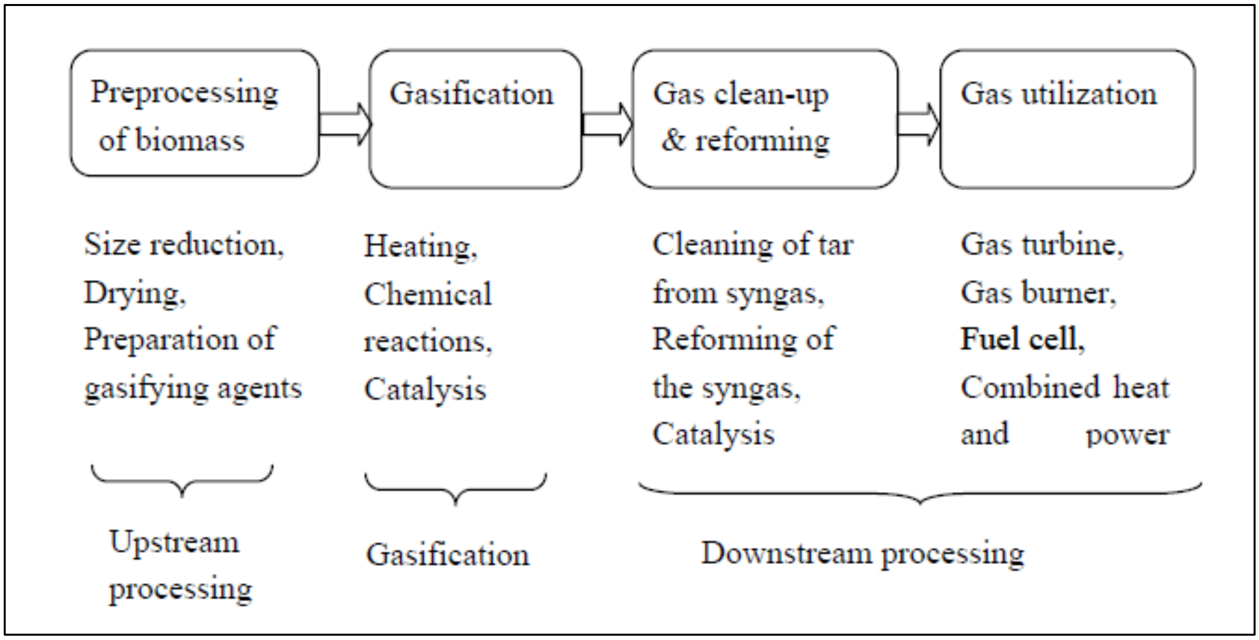

Figure 7: Flow diagram of general gasification process (Image source: Kumar et al. 2009).

Carbon monoxide and hydrogen gas are two fuel sources that can be utilized in combustion or in fuel cell technology for energy production. Unlike pyrolysis, little refinement is needed to purify these fuels into a useable product. Some small-scale gasifiers can produce 50% to 60% hydrogen, 10% to 20% carbon monoxide, and the remainder CO_2 by volume (SERC 2016). Small amounts of methane gas can be produced as well (Son et al. 2011). Studies have looked at how feeding rates, compositions, and temperatures can result in a different distribution of syngas products (Son et al. 2011). It is also common for gasification systems to fully gasify the char as part of the gasification process at high temperatures to maximize the amount of carbon monoxide and methane in the syngas product and minimize char, ash, and tar products (Son et al. 2011).

A benefit to using a fuel cell is that hydrogen gas can be stored indefinitely serving as a battery. Hydrogen can also be purified and sold for petroleum refinement, creating synthetic fertilizer, and other industrial or academic applications.

Biochar is a byproduct of gasification and potential utilizations have been discussed in the previous section. It is not clear whether the properties of biochar change drastically between different methods. Biochar can be made from multiple feedstocks and through many different methods and there has yet to be a study that holds feedstock constant while varying the fundamental production method. In addition to the syngas mixture and resulting biochar, a significant amount of tar will result in the gasification system. The tar has few utilizations and must be cleaned out occasionally to keep the efficiency of the system up. Tar removal is one of the more challenging aspects for the long-term use of gasification systems (Kumar et al. 2009).

The associated emissions of gasification in comparison to biomass combustion would be significantly lower. This is because the combustion of pure hydrogen gas and carbon monoxide results in steam and carbon dioxide with no intermediates. Although, through the gasification process small amounts of hydrocarbons, particulate matter, carbon monoxide, and nitrous oxide species will escape the gasification system's exhaust due to imperfect separation of syngas and incomplete gasification of the biomass (Son et al. 2011). Some systems have been tested for emissions and have shown that hydrocarbon emissions in exhaust from burning syngas can be limited to less than 200 ppm for hydrocarbons, 40 ppm for NO_x, and 250 ppt for CO using a 5-kW syngas engine (Son et al. 2011). Cyclone separators, wet scrubbers, filters, and electrostatic precipitators can be utilized to remove particulate matter, ash, and fine char from both the waste stream and exhaust (Kumar et al. 2009). The use of these components does require energy input. Resulting biochar will also produce particulate matter if disturbed in its dry state.

GHG emissions depend on how the gasification process is carried out. At certain temperatures and production methods, more biochar would be produced lowering the amount of carbon emitted instantly. Other production methods may significantly decrease the amount of biochar produced maxing out the amount of carbon dioxide and carbon monoxide produced. The production of outputs is variable and dependent on the system (SERC 2016). The amount of carbon sequestered, and emissions offset by biochar are variable depending upon use and biochar quality. Just as in pyrolysis or incineration the efficiency of the system will decrease with higher moisture in the feedstock causing increased GHG emissions per unit of energy produced.

2.2.3 Biomass Products in Erosion Control, Mulching, and Animal Bedding

Erosion, deforestation, and unsustainable agriculture are the major contributors to desertification of soil. Erosion is the loss of soil that results in low nutrient content and infiltration rates of water. This contributes to high runoff flow rates in rain events as well as instable surfaces with few plants capable of revegetating the soil (Zuazo et al. 2008). Woody biomass can be used as a mulch to reduce erosion and provide other beneficial attributes for the soil and plants. Mulching as a way of erosion control and sustainable soil development (Lal 2007). Woody biomass can also be utilized for animal bedding to reduce smell, reduce exposure of animals to fecal matter, and for the capture of nutrients present in the animal's fecal matter.

Woody biomass is a common component of forest soils and can act to reduce erosion, weeds, compaction, and help to retain water and an environment for soil organisms. The quality of the woody biomass is important to consider. Sawdust-like material can easily compact, be a fire hazard if completely dry, and degrade much faster than a coarser woodchip-like biomass (Chalker & Scott 2015). Woody biomass creates a home and coverage for microorganisms, worms, and fungi (Chalker & Scott 2015). Fungal hyphae can thrive in woody biomass mulch and act as a sponge for water as well as effectively allocate water and nutrients to plants through mycorrhizal associations. The slow breakdown of cellulose, hemicellulose, and lignin by fungi results in a fungal dominant soil that outcompetes pathogenic bacteria (Chalker & Scott 2015). Dead fungal material also contributes to soil nutrient content. Woody biomass reduces erosion by acting as an obstacle to the flow of water resulting in increased infiltration rather than runoff. Also, the biomass blocks sunlight, reducing evaporation of the water from the soil's surface and subsurface. The effects of wood chips and other mulches and their beneficial effects on erosion have been studied extensively (Tyner et al. 2011). Biochar can also act as an effective mulch. Like other woody biomass, coarser biochar is better for reducing compaction and increasing infiltration. There are concerns as well that woody biomass can tie up nitrogen in the soil, but this can be avoided by not tilling the biomass into the soil and by directly planting or seeding into the soil and not the mulch itself (Chalker-Scott 2015).

Animal bedding can serve to relatively increase the living standard for livestock animals, reduce odors, prevent the spread of fecal pathogens, and help capture nutrients in the livestock's feces. Once the bedding has been used, the mixture can be applied in compost or used for biomass energy. Few published materials were found comparing the effectiveness of different materials as animal bedding. Although, common knowledge and experience can help in understanding the benefits of certain types over others. The use of coarser material requires a deeper application to ensure the capture of fecal material. Finer material, like sawdust, will capture material with a smaller depth of application, but then requires more frequent applications. Layers of woody biomass can be added on top of each other as space permits. The high labor costs for applying or removing bedding and monoculture techniques are usually the main reasons why commercial farmers do not use animal bedding. With regards to labor, it is more cost effective to wash away or shovel the waste directly rather than move a whole layer of bedding. Also, since there is usually no vegetable farming or orchards being maintained by the same livestock farmer, there is little incentive to collect used bedding for mulch application.

Upon application of wood chips or sawdust, there is a significant quantity of particulate matter in the air. This can be reduced by first wetting the material. The particulate matter can also cause allergies in persons that are sensitive to such material. Use of animal bedding reduces volatile organic matter in the air that is associated with smell. After application, the associated air quality attributed to the material would be approximately the same as that of a forest floor covered with woody organic matter.

The coverage of soil with woody biomass can help retain vegetation and soil microbial life. This results in vastly different effects on greenhouse gas emissions depending on the environment and vegetation profile that the mulch supports. While all the biomass will eventually decompose, the carbon will be sequestered in the soil much longer than if burned for energy. Although, after time much of the carbon in woody mulch will be released as methane which is a more potent greenhouse gas (Whittaker et al. 2016). Decomposition into methane also occurs during long term storage of the material for any other usages (Whittaker et al. 2016). Anerobic and wetter conditions promote degradation of the woody biomass into methane. The revegetation and stabilization of an eroded soil may outweigh the negative effects of the methane with regards to greenhouse gasses. Although, it is difficult to study such complex interactions that vary widely depending on the setting.

2.2.4 Use in Building Materials

Woody Biomass can be used in several different ways including construction materials. The use of biomass in building materials is a sustainable means of repurposing sawmill waste. Some items that can be created using wood residuals include "wood-crete" and particleboard. These two materials offer a cost-effective means of constructing sustainable furniture, and construction materials.

Wood-crete is a relatively new building material that focuses on the use of lignin-rich wood residuals as an aggregate in cement (Aigbomian 2014). The composition of the wood-crete is completely up to the maker and can be adapted to the composition of wood wastes readily available. This makes wood-crete an extremely versatile material in that it can use any regionally available wood sources. The different factors affecting the final compressive strength of the material include its composition, and different chemical or thermal treatments (Aigbomian 2014).

Particleboard is one of the most common building materials in use today (Rivela 2006). It serves as a cost-effective means of repurposing wood residues into usable building materials. The most common uses for particleboard include their use in construction of buildings and furniture, as well as serving as a material for carpentry and art (Rivela 2006). The general process to produce particleboard is that woody waste arrives at a facility for processing, is then mixed with a binding compound, and then is compressed under high load before going through final finishing steps (Rivela 2006). The particleboard then is transported to end consumers and is put into use. The end of life destination of the particleboard is dependent on its composition; however, it will typically go to either a landfill, or a resource recovery facility (Rivela 2006). Within the resource recovery system, it will either be broken down into new raw materials or will be incinerated with the intention of capturing its remaining energy value.

2.2.5 Teepee Burners

Teepee burners are devices that open burn sawmill wastes within an open conical vessel. Teepee burners generally have no air pollution mitigation device; however, attempts have been made to cap them to reduce some of the escaping ash (Wilson 2002). These attempts, while in good intention, do not address concerns with escaping greenhouse gases and fine particulate matter. The general goal of these devices is to reduce the space that sawmill waste consumes before its final disposal. The USEPA has banned their use in the Code of Federal Regulation (CFR 2019).

Humboldt County has a rich history with its logging industry dating back to the 1850's when the first northern Californian settlers saw the value in the redwood forests (Wilson 2002). The logging boom really took off with the construction of railroads in 1915, that would later connect central and northern California to make up the Northwestern Pacific Railway. This infrastructure would eventually lead to the logging boom in Humboldt County during the late 1940's and early 1950's. With logging activities and wood mills operating at capacity, the need for wood waste disposal was growing (Wilson 2002).

The logging boom set the stage for the wide use of teepee burners to simply burn the wood waste and reduce its size to make it more manageable. According to historical newspapers, and interviews with Humboldt County residents, the air pollution from the teepee burners was so bad that people could not use their clotheslines without all their clothes becoming caked in falling ash. Public concern with the logging pollution would prompt the development of alternative uses, and pollution mitigation strategies associated with the residual woody biomass (Wilson 2002).

There are a wide variety of chemicals that are produced during the open combustion of woody biomass. The largest amount of emissions from the burning of woody biomass are carbon dioxide, carbon monoxide, and particulate matter (Andreae 2001).

The USEPA has stipulated six criteria air pollutants that are regulated nationally. These air pollutants include carbon monoxide, lead, nitrous oxide, ozone, particulate matter, and sulfur dioxide (USEPA 2020). Wood burning directly produces all these chemicals with the exception of ozone; however, nitrogen oxide compounds can produce ozone depending on conditions in the atmosphere (CCAC 2020).

2.2.6 Hydrolysis for Ethanol Production

Additional uses for biomass include their use for biofuel production. One method for converting woody residuals into usable fuel is through hydrolysis. Hydrolysis is the use of water to chemically decompose a substance down into simpler components (Britannica 2020). There are several different ways of carrying out hydrolysis to break down compounds, typically using water and the addition of another substance or heat. The most common types of hydrolysis strategies include the use of either acids, bases, salts and heat to break down compounds (Yu et. al. 2008). There are also biological forms of hydrolysis that make use of bacteria, fungi, and enzymes (Lee 1997). The hydrolysis strategy used will be highly dependent on the compound that is being decomposed. This makes it essential to know the chemical properties of the substance that is being decomposed so that the best hydrolysis strategy can be utilized.

Woody biomass is a difficult substance to break down compared to other biomass forms due to the strong bonds between the lignin in the wood and other carbohydrate polymers (Lee 1997). Different types of hydrolysis strategies have varying ability to break down lignin, and each of which will have their own respective yields with respect to woody sugars (Zhu & Pan 2010). The pretreatment strategy employed is an important consideration because it will dictate the amount of sugar that is available to be fermented by microbes.

The process of converting woody biomass into bioethanol is comprised of 3 key steps: delignification, depolymerization of carbohydrates, and fermentation of woody sugars (Lee 1997). The delignification step is the controlled decomposition of lignin in the biomass; this allows for the processing of woody carbohydrates. This process can be done physically, chemically, or biologically. Depolymerization uses different processes to break down the carbohydrates, some examples include the uses of heat and enzymes. The final fermentation step utilizes bacteria or fungi that will consume the fermentable sugars and produce bioethanol (Lee 1997). There are discrepancies on the exact microbes to use due to variances in the composition of the biomass. Bacteria generally have a more difficult time processing woody sugars, particularly xylose (Zhu & Pan 2010). This has prompted research into either developing bacteria that will be able to ferment the sugars more effectively or to try and convert the sugars into glucose.

2.3 Regulatory Setting for Existing Biomass Energy Production

The quality of air and water can become negatively impacted by a nearby combustion biomass powerplant if not properly regulated. The Air Quality Management District and Regional Water Quality Board for the North Coast are responsible for regulating the discharge of pollutants coming from the two-existing biomass powerplants in Humboldt County. This section will cover overlying regulatory agencies, permits, and air quality standards that the existing biomass powerplants must satisfy in order to remain in operation and to protect the health and safety of the nearby public and environment.

2.3.1 Air Quality

Air quality regulations and permit requirements for the North Coast region's two existing biomass powerplants ensure operating compliance at the district, state, and federal levels through the issuing of a Title V Federal Operating Permit (NCUAQMD 2017; NCUAQMD 2019). Title V permits are issued by the North Coast Unified Air Quality Management District. The NCUAQMD issues a Permit to Operate in pursuant of United States Environmental Protection Agency's 40 CFR Part 70, which additionally satisfies the State's operating permit program requirements (NCUAQMD 2019). A Title V permit shall be renewed for each existing site every 5 years (NCUAQMD 2017; NCUAQMD 2019).

While it is estimated that the two-existing biomass powerplants in Humboldt County emit approximately 320,000 lb. of carbon dioxide annually, the State of California considers emissions from biomass as carbon neutral (Furniss 2020). The identification of biomass as a renewable energy source is justified by the State on the basis that biomass energy is different than fossil fuel derived energy. Fossil fuel derived energy results in the emissions of once deeply sequestered carbon, whereas biomass energy results in emissions of carbon that is already part of the carbon cycle (Furniss 2020). Additionally, carbon emissions from biomass energy generation could be justified as offsetting emissions that would instead result from an uncontrolled wildfire (NCRP 2017). As a result, emission limitations for biomass energy are focused on air quality parameters rather than carbon emissions at the two-existing biomass powerplants in Humboldt County.

2.3.2 Existing Biomass Powerplant Emission Limitations

Annual emission limitations for each powerplant can be found in Table 8 (NCUAQMD 2019; NCUAQMD 2017). The active Title V permits for both the Fairhaven and Scotia powerplants mainly regulate for air pollutants such as particulate matter, carbon monoxide, nitrous oxides, sulfur oxides, and volatile organic carbons. Annual emissions for the Scotia plant were calculated using the Base limits for each air pollutant, as this limit had to be reached the majority of the time throughout the year (NCUAQMD 2017). No regulatory standards were set on SO_x or VOCs emissions at the Scotia plant, except for when discussing the on-site asphalt plant and the proposed natural gas boiler. The SO_x and VOCs emission limitations for Scotia are strictly the emission limitations for the proposed natural gas boiler, and do not account for emissions from the other three biomass fueled boilers on-site (NCUAQMD 2017).

Table 8: Total emission limitations for both the Scotia and Fairhaven biomass powerplants (NCUAQMD 2019; NCUAQMD 2017).

	PM [tons/year]	**CO [tons/year]**	**NO_x [tons/year]**	**SO_x [tons/year]**	**VOCs [tons/year]**
Scotia	125.1	3,302.4	643.4	0.1	0.6
Fairhaven	55.5	3,316	237	34.7	23.5

The Fairhaven biomass powerplant is equipped with the capability to burn natural gas as a source of fuel for energy generation (NCUAQMD 2019). With natural gas being considered a non-renewable fossil fuel, the Title V permit for the Fairhaven powerplant sets a cap on how much natural gas can be burned annually (NCUAQMD 2019). The Scotia powerplant is not equipped with the capabilities to burn natural gas, but is authorized to install and operate a natural gas boiler with certain annual emission limitations (NCUAQMD 2017).

Table 9: Limitations set on the existing plants' fossil fuel derived energy sources (NCUAQMD 2019; NCUAQMD 2017).

Equipment	Location	Limitation	Active
Natural Gas Boiler	Scotia	12,597 tons CO_2/year	No
Natural Gas Boiler	Fairhaven	16,850 tons CO_2/year	Yes

Limitations set on natural gas use for both the Fairhaven and Scotia biomass powerplants can be viewed in Table 9. Limitations shown in Table 9 are critical to display, as they provide a ceiling amount for the quantity of fossil fuel emissions that can be produced annually. Limitations on fossil fuel emissions at the two-existing biomass powerplants prevent a plant from claiming to be a biomass powerplant, when in actuality the plant could be producing most of its emissions using an alternative fossil fuel source. The emission limitation for the Fairhaven powerplant was calculated based on the maximum amount of natural gas that can be utilized annually (Furniss 2020; NCUAQMD 2019).

2.3.3 Water Quality

Water quality discharge regulations for the North Coast region's two existing biomass powerplants allow operating compliance at the region, state, and federal levels through the issuing of a National Pollutant Discharge Elimination System permit. A NPDES permit is issued on behalf of the North Coast Regional Water Quality Control Board in order to meet water discharge requirements (WDR) specific to Division 7 of the California Water Code, which are in pursuant of the Federal Clean Water Act (NCRWQCB 2012; NCRWQCB 2018). A NPDES permit shall be renewed for each existing site every five years (NCRWQCB 2012; NCRWQCB 2018).

As of today, municipal water is utilized at both the Fairhaven and Scotia biomass powerplants to generate steam for the turbines. Prior to entering the turbines, the water is treated with reverse osmosis to prevent mineral scaling (NCRWQCB 2012; NCRWQCB 2018). The water utilized at each of the biomass power plants are discharged once a day, as the water is recycled throughout the day until discharge (NCRWQCB 2012; NCRWQCB 2018). At the Scotia plant, the wastewater goes to the Scotia wastewater treatment plant, whereas at the Fairhaven plant the wastewater is discharged to the ocean one and a half miles off the coast (NCRWQCB 2012; NCRWQCB 2018). No treatment is done onsite before discharging the wastewater from either plant (NCRWQCB 2012; NCRWQCB 2018).

No known WDR regarding the application of biochar or fly ash to agricultural fields as a soil amendment are known of, just as long as the feedstock does not contain lead-based paint or wood preservatives (SWRCB 2015). However, biochar and fly ash do have effects on alkalinity and can increase concentrations of important biogenic compounds such as phosphorous, potassium, magnesium, and nitrogen in soils and runoff (Saletnik et al. 2018).

2.3.4. Compliance

In regard to air quality, only the Scotia biomass powerplant has violated their Title V permit requirements (NCUAQMD 2020a). In 2017, there was a settlement agreement for excess emissions of carbon monoxide and fine particulates from the Scotia biomass powerplant (NCUAQMD 2020b). The issue has now been resolved, and the NCUAQMD is still monitoring the plant's emissions to ensure the safety of the public.

For water quality, the DG Fairhaven plant violated their WDR back in 2007 through six unauthorized discharges that resulted in approximately 12,000 gallons of wash water entering the Pacific Ocean. These unauthorized discharges resulted in the plant receiving a total fine of $165,000 (NCRWQCB 2008). Since then, the issue has been resolved and the NCRWQCB still monitors water quality from the plant to ensure it is meeting its set standards. There have been no recorded water quality violations for the Scotia biomass plant (NCRWQCB 2012).

3. Alternatives

The Alternatives Section reviews each proposed alternative through an alternative description, constraints and criteria analysis, alternative analysis, and a list of advantages and disadvantages. The four considered alternatives are the Biomass Densification Facility, the Particleboard Facility, the Distribution Network, and the Community-Scale Biomass Gasification Facilities. For all alternatives, they were sized so that 2.4 million cubic yards of woody biomass could be consumed annually; 80% of the total 3 million cubic yards produced annually.

3.1 Alternative 1 | Biomass Densification Facility

This section provides a detailed analysis of the Biomass Densification Facility alternative. The social, economic, and environmental criteria for this analysis are touched upon with respect to the project criteria.

3.1.1 Alternative Description

The Biomass Densification Facility could be implemented as a means to utilize the wood waste produced from the sawmills. The waste would be condensed from its raw bulk density into briquettes, pellets, and other high-density wood products. These would have a higher retail value, broader utilizations, better combustion and improved transport properties as a fuel source when compared to sawdust alone (Clarke & Preto 2019). Briquettes can be made to specific sizes and densities for use in certain applications, the most traditional being fuel (Figure 8).

Figure 8: Finished Briquettes (Image source: C.F. Nielsen 2020).

Most densification occurs by high-pressure compression through the use of a piston press or screw extrusion technologies (Jha & Yadav 2011). The main components of a briquetting machine include conveyor belts and associated machinery, metal hoppers, motors, and a mechanism that drives the piston or screw press. A general schematic of a piston press briquetting machine is given below in Figure 9.

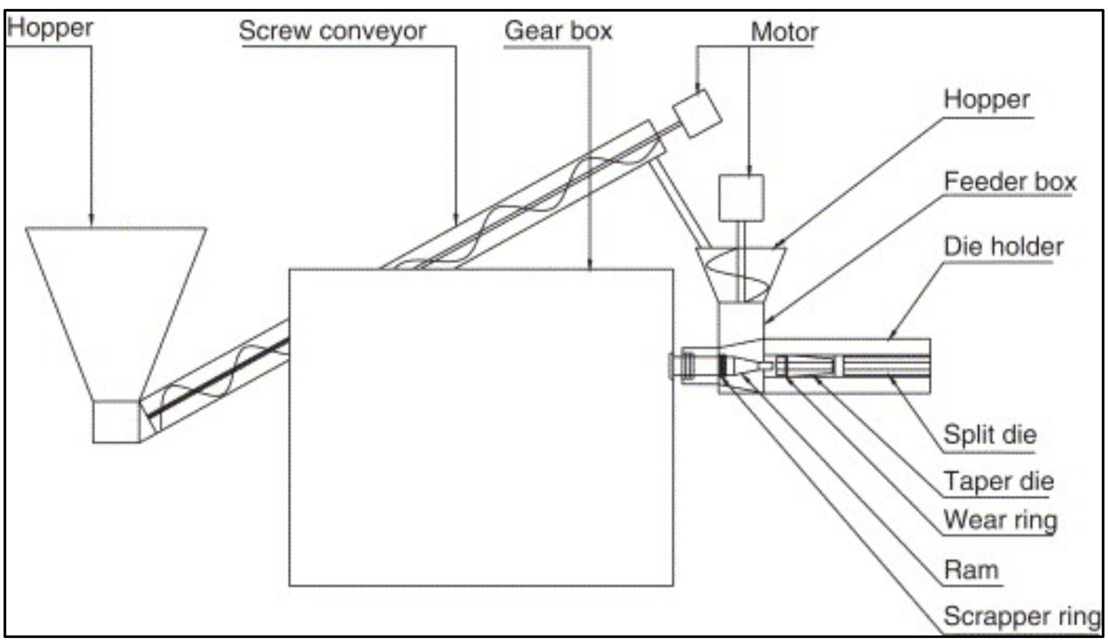

Figure 9: Piston press briquetting machine (Image source: Singh et al. 2007).

Densification processes would begin with the transportation of the woody biomass from the sawmill to the facility, which would involve emissions from vehicles and the need for labor. Once the biomass has arrived at the facility, it would ideally be stockpiled in an area that would limit its exposure to the elements before being sent to the briquetting machine. The holding area requires infrastructure and a woody biomass drying unit. The drying unit is an important part of the process as it reduces the moisture content in the biomass for optimal combustion but requires fuel to operate. There is potential for the release of volatile gases during this drying process. After drying, the biomass is loaded onto a conveyor belt or manually fed into a hopper. Raw sawdust and other forms of biomass are generally briquetted with the addition of a binding agent. These binding agents can be of organic, inorganic, or a composite of several other binding agents. The mixed sawdust is then fed into the unit, which houses the piston or screw compress, and forms the material into briquettes (Jha & Yadav 2011). The finished product is stockpiled again in an ideal environment before being distributed to consumers. A flow diagram of the processes and respective inputs and outputs associated with densification is provided in Figure 10 below.

The facility could be large scale, meaning it would ideally be large enough to receive all the woody biomass at one location, or could be implemented as several smaller facilities optimally placed near or at sawmills and timber sites to reduce transportation costs. With respect to the reference case, utilization of 80% of the annually produced woody biomass is assumed to be completely achievable for this project. Given a bulk density of 247 kg/m^2 for the biomass, the total mass that is produced per year can then be scaled down to a production rate of briquettes given in mass of densified wood per unit of time (Ciolkosz 2010). The production rate of some of the world's largest briquetting capacities reach 15 tons per hour, so this project will need to be produce well over this rate (C.F. Nielsen 2020). However, a case study at an Ohio wood product manufacturing facility has successfully been able to implement a system that outputs 40 to 42 tons of briquettes a day with only two custom made briquetters, so there is some feasibility to this alternative given an increase in the number of units needed to utilize 80% of the biomass produced in Humboldt County annually (RUF Briquetting Systems 2020b).

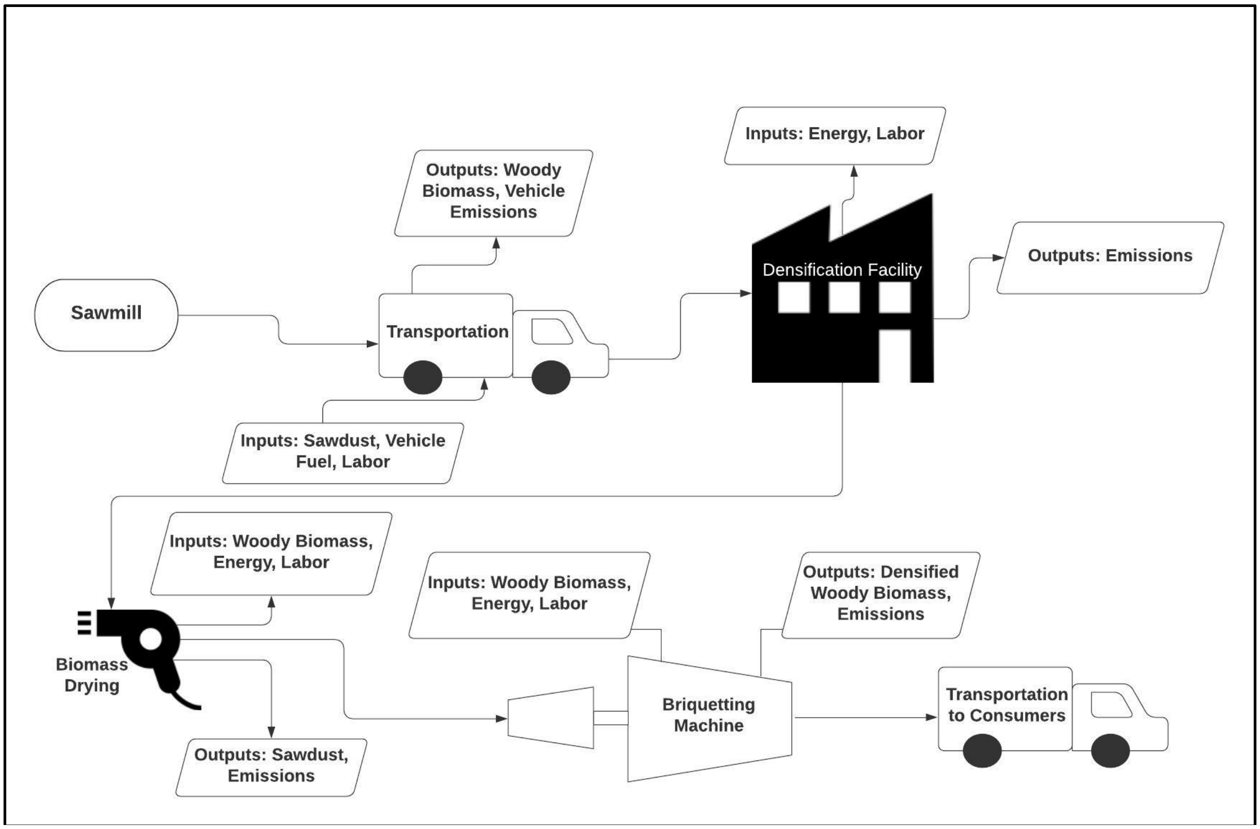

Figure 10: Flow chart depicting processes from bulk woody biomass to densified products.

3.1.2 Constraints Analysis

The Biomass Densification Facility could meet the constraints set forth for the project alternatives. Regarding meeting local, state, and federal regulations, the facility would meet regulations by implementing proper safety procedures and equipment. The protection of employees and the monitoring for every constituent emitted during production would be done as to not violate any permits associated with components of the facility; these components would include the infrastructure, machinery, and waste or wastewater discharge.

The employment opportunities generated from this alternative will be presented in values given the need for planning and construction of the facility, operation, and maintenance, and need for full-time employees. The alternative would most likely encourage economic growth around the industry, given others can implement their own ideas and creativity to expand the market and commercial use of briquets.

3.1.3 Social Criteria Analysis

This section outlines how the Densification Facility performs with regards to the aesthetics and community support criteria set forth for the project.

Aesthetics

Considering the large quantity of woody biomass to be utilized, the volume of housing units might be quite large. There is also the preservation of habitats and the natural environment to consider. In terms of how the buildings look might also depend on the permittable size needed to hold the volume of woody biomass and densified products at any given time. This could potentially be a drawback to the alternative if the volume required to house all processes safely at peak production is significantly larger than the other alternatives.

Community Support

The community would ideally appreciate the efforts made to reduce local emissions, increase efficiency, and create jobs in response to their attitudes towards bioenergy production. There is still the issue of the material being used for energy production by combustion of the briquets, but given the enhanced transportability and combustion properties of the densified wood the products could be sent away to a different biomass plant or for other uses other than combustion for fuel.

3.1.4 Economic Criteria Analysis

The performance of the alternative with respect to economics such as payback period, employment opportunities, and project implementation are discussed in this section.

Payback Period

Payback period will be an issue considering what the market price of briquets are and their demand beyond the traditional use as biofuels, assuming that biomass is no longer given for free to biomass plants. Measures to mitigate this could be to focus on the quality of the briquets and expand sales to other parts of the Country, State, or world at a higher price to increase the profit margin. An initial estimate of the payback period is provided below in Eqn. 1.

$$PBP = \frac{C_i}{N_t C_t - N_e C_e - C_{OM}} \quad \text{Eqn. 1}$$

<u>Where:</u>

PBP	=	years needed to regain capital investment and start profiting (year)
C_i	=	Initial cost of facility ($)
C_t	=	Average cost of briquets per mass ($/mass)
N_t	=	Average number of briquets sold per year (mass/year)
C_e	=	Average annual salary of employees ($/employee-year)
N_e	=	Average number of employees
C_{OM}	=	Average annual operation and maintenance costs ($/year)

Employment Opportunities

As previously mentioned, the implementation of a Biomass Densification Facility is expected to create jobs at multiple skill levels during every aspect of its lifecycle. Some jobs will be temporary like construction, and others will be required full-time positions like management, engineering, operation and maintenance, and transportation. The number of jobs is expected to increase with the development of more than one facility as mentioned earlier. In summary, this alternative is expected to create a significant number of employment opportunities.

Project Implementation

The exact specifications of project implementation are not currently known, but at a glance they should not meet or exceed the amount of time or permitting required for a biomass power plant. Briquetting can begin as soon as all the components of the process are assembled, assuming that there are customers expecting to order shipments.

3.1.5 Environmental Criteria Analysis

This section outlines how the alternative performs with regards to air quality and carbon sequestration criteria set forth for the project.

Air Quality

Both outdoor and indoor air quality can be affected by daily operations at the facility, but mostly due to the abundance of biomass particulate matter. The GHGs and emissions produced during briquet production would probably come in relatively small or insignificant concentrations during the drying phase or fuel combustion for mechanical parts. As mentioned before, precautions can be taken such as requiring employees to use masks to reduce their risk of exposure.

Carbon Sequestration

The use of densified woody biomass in biomass energy applications is considered a renewable and neutral energy source with regards to carbon emissions. This alternative could potentially meet carbon sequestration criteria assuming that the briquets and other products are utilized in other non-combusting industries that returns the material to the soil. An analysis will need to be done on the implementation of these biomass byproducts and their widescale application in order to effectively quantify how much carbon is released during production as opposed to how much is stored after utilization.

3.1.6 Quantitative Alternative Analysis

Table 10 contains the results of the criteria analysis for the Biomass Densification Facility alternative. Criteria calculations for this alternative and assumptions used can be referred to in Appendix A section of this report.

Table 10: Criteria analysis for Biomass Densification Facility.

Criteria	Quantification	Value
Social Criteria		
Aesthetics	Volume of unnatural structures (ft^3)	3,750,000
Community Support	The percentage of the people who approve the project (%)	70
Economic		
Payback Period	The number of years before a project begins to make a profit (years)	1.1
Employment Opportunities	Number of job opportunities that the project would produce or preserve (#)	115
Project Implementation	Time required from approval to beginning operation of alternative (months)	42
Environmental		
Air Quality	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)	Table 11
Carbon Sequestration	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)	-100,203,280

Table 11: Table of the NAAQS annual emissions.

Pollutant	US tons/year
PM_{10}	111
NO_x	394
SO_x	45
CO	6,043

The total area of the facility is based on the current area occupied by the sawdust at DG Fairhaven and an additional 125,000 square feet. This value comes from a wood product manufacturer facility which implemented briquetting machines as a way to add an extra source of revenue (RUF Briquetting Systems 2020b). The total volume calculated for the briquetting facility is based on 30-foot-tall warehouse. Public perception was calculated using the average approval rating for two different case studies: one regarding the implementation of a wood briquetting factory in Kenya, and another survey regarding public perception of woody biomass as a renewable resource. In Kenya, 68% of participants were in favor of implementing briquetting facility in the community, and 71% of participants in Alachua County, Florida were in favor of forest waste as opposed to feedstock for fuel (Plate et al. 2010, Omwenga 2018).

The payback period was calculated using Equation 1. The initial cost of the facility was assumed to consist of the capital needed for a briquetting facility including buildings and equipment. The cost of the facility was based on a construction price of $250 per square foot (Garcia 2020). The main equipment needed at the facility would be 30 RUF 1500 Briquetting Machines operating at their rated horsepower of 125 hp at a production rate of 3,000 lbs per hour ($275,000), 30 Flexible Screw Conveyors ($199,800) and 2 commercial dryers from Norris Thermal Technologies

($550,000) (Flexicon 2020; Norris 2020; RUF Briquetting Systems 2020a). The average price for a ton of briquettes was estimated at $160.00 (RUF Briquetting Systems 2020a). The average retail cost for the finished briquettes was determined to be $636.5 per ton based on prices of similar products (Ace Hardware 2020, Lowe's 2020, TrueValue.com 2020) which creates an alternative payback period of 0.02 years. Annual operations assumed annual use of electricity and water to operate the briquetters and dryers (EIA 2018, Food and Agriculture Organization of the United Nations 2014). An annual maintenance cost of 10% the total initial cost was assumed. Employees were given an average salary of $80,000 per year (Sahoo et. al 2019).

Since briquetting is a highly automated process, each briquetting machine is always assumed to have two employees. Two employees will be needed at each machine, one to operate the machine and the other to transport raw material and finished briquettes (RUF Briquetting Systems 2020). 27 screw conveyors and briquetters are assumed to operational at all times, with three of each being on standby for redundancy. The finished briquettes are assumed to be distributed between 5 different markets; San Francisco, California and Portland, Oregon will each receive 25% of the total mass produced per day while Sacramento, California and Reno, Nevada will each receive 20% of the daily production load, leaving the final 10% to be distributed among Humboldt County. The time needed to implement the project was assumed to account for the average time it would take for each part of the permitting process to be completed (CEC 2019). Markets receiving 25% will need 7 truckloads a day, markets receiving 20% will need 5 truckloads per day, and Humboldt County will require 3 truckloads a day with each truckload having a total capacity of 25 metric tons.

The air quality criterion was assessed by calculating the emissions generated from transportation and the end use of the sawdust briquettes which was assumed to entirely be combusted for commercial and industrial heating. Using the assumptions made for transportation above and assuming an energy density of 17.99 MJ/kg of briquettes combined with an 80% combustion efficiency, the total amount of NAAQS pollutants (US Tons/year) emitted were found to be 111, 394, 45, and 6,043 for PM_{10}, NO_x, SO_x, CO respectively (Alanya-Rosenbaum et al. 2018). Pollutants were also accounted for during electricity generation for briquette and dryer consumption (EIA 2018).

Since all the briquettes that are produced were assumed to be combusted, there is no carbon sequestration taking place for this alternative. Total U.S. Tons of CO_2 equivalent produced over a 20-year time span was calculated using emissions produced from transportation, sawdust drying, briquetting, and the final use phase which resulted in a net 20-year carbon output of 100,203,280 U.S. Tons (Alanya-Rosenbaum et al. 2018, Eriksson et al. 1996; SEI 2010).

3.1.7 Alternative Advantages and Disadvantages

The advantages and disadvantages of the Woody Biomass Densification Facility are presented below in Table 12. One great advantage of the alternative is that it could be implemented at an existing site where the sawdust is currently being transported to at no cost. From the case studies reviewed, the majority of people from two different parts of the world seem to mostly approve of wood waste fuels and the economic and environmental benefits created from their production. The number of jobs produced would also be appealing in a rural community. However, the production, transportation, and end use of the briquettes would still produce a significant amount of emissions that would not appeal to the community. Since Humboldt County is so remote, there is also the possibility that the marketable range of the briquettes would not be large enough to justify or support operations or the payback period.

Table 12: The alternative advantages and disadvantages.

Advantages	Disadvantages
- Utilizes Existing Site	- Emissions Intensive
- High Approval Rating	- No Carbon Sequestering
- High Job Production	- Questionable Regional Market
- Short Payback Period	-Energy Intensive

3.2 Alternative 2 | Particleboard Facility

This section describes the Particleboard Facility alternative and contains a constraints analysis, criteria analysis, and a list of potential advantages and disadvantages from implementing the alternative. The alternative's design criteria assessment will examine the social, economic, and environmental impacts of the proposed facility.

3.2.1 Alternative Description

A Particleboard Facility is one potential project alternative for the utilization of woody biomass. In this proposed alternative it is assumed 80% of Humboldt County's waste woody biomass would be used for particleboard production. This alternative would provide a means of repurposing the lower grade biomass material into a more valuable product. The facility itself would take the woody biomass as a feedstock, and then process it to make a particleboard material. The specific processes that occur include mixing the woody material with a binding agent and then thermally compressing the mixture into wood sheets. The board material would then be allowed to cure, and finish procedures would smooth out the material prior to being distributed for sale. Figure 11 describes the process to create particleboard, beginning from a sawmill and ending at distribution. A facility like the proposed alternative is also depicted in Figure 12.

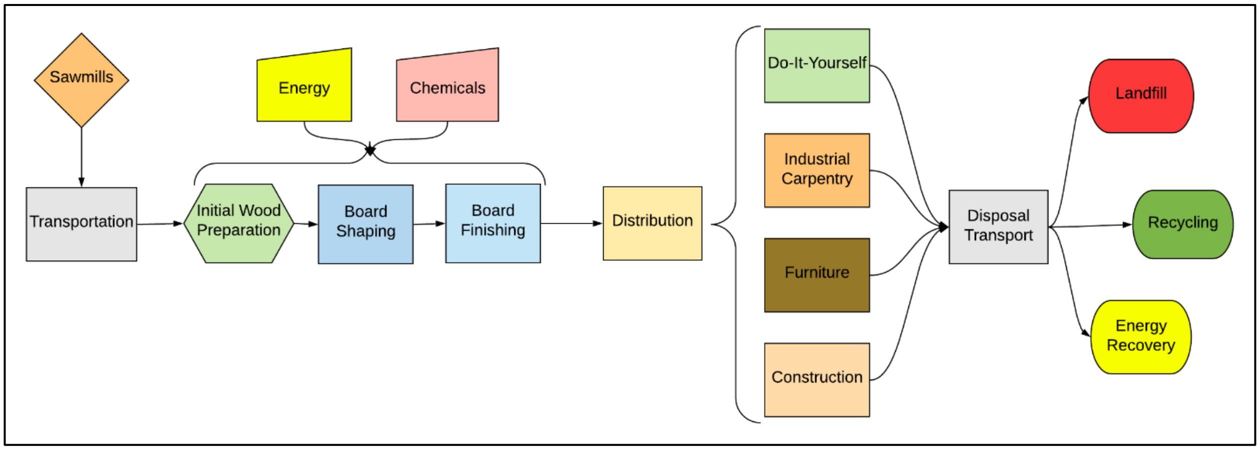

Figure 11: This flowchart describes the simplified process of the particleboard lifecycle (Rivela 2006).

Figure 12: The inside of a particleboard facility (Image source: WBPI 2020).

From a preliminary reference case assessment using 80% of woody biomass produced in Humboldt County, the amount of production capacity that would be needed to process this amount of woody biomass is roughly 440,000 cubic yards of finished board per annum (Rivela 2006). Using information from the USDA, typical production capacities for similar facilities ranged from 200,000 – 400,000 cubic yards per year; this figure is relatively dated however and the report acknowledges that facility capacity is generally increases each year (USDA 1994). The upper estimate was therefore used to estimate that it would take 1 larger particleboard facility to meet the biomass utilization reference case.

3.2.2 Constraints Analysis

The constraints of this project will offer a baseline to evaluate whether this specific alternative is feasible. The main constraints guiding the alternative analysis includes following regulations in place and creating new jobs, or preserving jobs, within Humboldt County. With respect to following regulations, the facility would likely be being constructed to code, and operate within in regulatory standards. Therefore, this constraint should be met during the facility construction.

The new particleboard facility would also provide entry-level labor jobs within the region, which should garner support from Humboldt County's surrounding community. Regarding biomass usage, the alternative should be able to process the entirety of the sawmill waste. The biomass utilization goal will govern several design parameters for the facility. Design parameters that the biomass usage constraint will affect include facility size, production capacity, necessary storage, rate of distribution, and employees needed.

3.2.3 Social Criteria Analysis

This section discusses how the Particleboard Facility alternative will fit in with the social criteria of this project. Social criteria that are considered in this analysis include the effects on the aesthetics of the alternative and community support. Consideration of these social criteria will assist in the determination of whether to proceed with this project alternative.

Aesthetics

The aesthetics of this project would not be the most appealing to the community of Humboldt County. The region generally is not excited about new industrial facilities. It is possible to manage the discontent with the facility's appearance by potentially planting trees and shrubs around the perimeter of the facility to make it more appealing.

Community Support

Community support for this alternative would likely be mixed due to the social climate within Humboldt County. There are likely to be several different factors affecting how the community would respond to this facility. Two of the biggest things that the community would likely respond to in this alternative implementation is of the laborer jobs that would be created, and the public health and environmental concerns with the alternative's pollutants. Assuming the facility is operating within regulations, any negative impacts would likely be minimized. This can be conveyed to the community to potentially ease any worries of implementing the alternative.

3.2.4 Economic Criteria Analysis

This section discusses how the Particleboard Facility alternative will fit in with the economic criteria of this project. Economic criteria that are considered in this analysis include the payback period, the employment opportunities that would be generated, and the ease of implementing the project. Consideration of these economic criteria will assist in the determination of whether to proceed with this project alternative.

Payback Period

The payback period for the facility will be highly dependent on the final sizing of the facility and other design parameters. The facility design will directly dictate the initial expense of the facility, operational costs, maintenance costs, and potential profit the facility would generate. These expenses and profits would then affect the respective payback period of the facility. Below in Eqn. 2 shows a payback period equation for the Particleboard Facility alternative.

$$PBP = \frac{C_i}{V_p C_p - C_{OM}} \quad \text{Eqn. 2}$$

Where:

PBP	=	Payback period (yr)
C_i	=	Capital cost ($)
V_p	=	Volume of particle produced per year (ft^3/year)
C_p	=	Cost of particleboard ($/$ft^3$)
C_{OM}	=	Average annual O & M costs ($/year)

Employment Opportunities

The employment opportunities that would be generated by the facility will be dependent on the size of the facility, amount of raw materials that are being resourced and the amount of particleboard that is being distributed. This preliminary analysis is unable to quantify the amount of new jobs that would be created, however it expected to be numerable.

Project Implementation

The implementation of this alternative is likely to take a large amount of time and needs to go through several regulatory committees, community support hearings, and other entities prior to starting the facility's construction. It is also possible that permitting or regulatory authorities in the region would outright deny the construction of the facility. This makes the alternative's ease of implementation relatively mixed.

3.2.5 Environmental Criteria Analysis

This section discusses how the Particleboard Facility alternative will fit in with the environmental criteria of this project. Environmental criteria that are considered in this analysis include the alternative's effect on air quality, and the amount of carbon that will be sequestered through its implementation. Consideration of these environmental criteria will assist in the determination of whether to proceed with this project alternative.

Air Quality

The negative impacts of particleboard production on the public is expected to be moderate and would be mostly isolated to those working in the facility and the surrounding area. The construction of particleboard requires several different compounds; these compounds include the use of urea-formaldehyde resins, paraffin, and ammonium bisulfate (Rivela 2006). The most concerning of these compounds is the use of UF resins which is generally stable, but may release some amounts of formaldehyde as particleboard begins to slowly breaks down over time (PDB 2020). Formaldehyde is a concern for public health both during the production of particleboard, and in its use for consumers. Processed woods, such as the particleboard used in furniture and housing, impose a significant source of formaldehyde in homes which is related to both short-term and long-term health effects (NCI 2020). This has prompted the development of low-formaldehyde emitting resins that can take place of UF resins in modern production; these low emitting UF resins would likely be used exclusively in the facility, unless a better binding agent was found (PDB 2020). With respect to the disposal of any hazardous waste, the expectation is that it would be disposed of properly; this expectation is directly based on the constraint of staying within regulatory guidelines.

This alternative would provide large scale emissions since several industrial processes occur during the manufacturing processes. The biggest pollutants of concern to NAAQS are natural gas based drying processes and offsite transportation. While this is a concern, the amount of cost savings this material offers in furniture and building materials will still make it a viable option for use.

Carbon Sequestration

This alternative does not have a means of long-term carbon storage. Though controversial, the argument can be made that the biomass that is used in its production would be stored until the particleboard is finally discarded or salvaged. This would therefore preserve the carbon within the woody biomass and defer its emissions until a later date. This is not a sustainable means of carbon storage and it is likely that it introduces new lifetime emissions through its production, and final disposal. Carbon sequestration is measured in the amount of GHG's that will be emitted through its operation, distribution needs, and decomposition.

3.2.6 Quantitative Alternative Analysis

This section of the document analyzes the Particleboard Facility alternative. Each of the criteria was analyzed with respect to the project criteria. The quantified values of the criteria were calculated using computations and background research. The quantified value for each criterion is depicted in Table 13 and Table 14.

Table 13: The Particleboard Facility criteria quantified.

Criteria	Quantification	Value
Social Criteria		
Aesthetics	Volume of unnatural structures (ft^3)	8,060,000
Community Support	Maximize public approval (%)	11
Economic		
Payback period	Minimize time until a project begins making a profit (years)	11.4
Employment Opportunities	Maximize job opportunities (jobs)	196
Project Implementation	Maximize ability for implementation of project at the federal, state, and local level (months)	22
Environmental		
Air Quality	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)	Table 14
Carbon Sequestration	Maximize sequestration of carbon (US Ton eq. CO_2 per year)	-42,000

Table 14: Table of the NAAQS annual emissions.

Pollutant	US Tons/year
NO_x	144
CO	498
SO_x	3.1
PM_{10}	79

Each of the criterion required a means of standard quantification so that the alternatives could be compared; the criteria quantified consider social, economic, and environmental factors. The aesthetics criterion was determined by examining other particleboard facilities and comparing their production capacity to the square footage of the facility (Arauco 2020). The facility area per production capacity was then scaled for the anticipated production capacity of the alternative. The resulting facility area assumed an average facility height of two stories to find a facility volume. The community support criterion was determined by examining case studies related to particle board facilities and wood waste usage preferences (Grosskopf 2006, Kunttu 2020).

The payback period was found by using operating expenses data for particleboard facilities, and facility cost data to compute the capital costs, annual expenses and annual profit (Spelter 1994). For the capital cost, it was assumed that the technology for particleboard production had been mostly developed since the 1990's; this assumption was supported by facility cost data showing that the capital costs had reached a distinct plateau during this decade. A value of $19.2 per foot cubed of production capacity was used for the capital costs analysis. For the operating costs and annual profit, the raw data was plotted and used a linear regression fit to predict the annual expenses and profit for the year 2020, these prices were based on dollar per cubic foot of production capacity. The operating costs included to power, fuel, labor, management, binding agents, and other miscellaneous expenses. The annual profit was based on the wholesale value of the finished particleboard. These predicted values for the capital, operation expenses and profit were then scaled with the production capacity of the proposed facility; this production capacity is based on the reference case where the facility would need to process 80% of Humboldt County's annually produced woody biomass. All expenses and profits were computed on an annual basis; Eqn. 2 was then used to compute the payback period in years. A summary table of the expenses and profits per year are depicted in Figure 30 (Appendix B).

The anticipated employment opportunities were found by examining the number of employees at different particleboard facilities comparing it to the production capacity of the respective facility (US SEC 2005, Lapastora 2016, BizJournal 2002, Arauco 2020). The employee per facility production capacity ratio was then used to anticipate the amount of jobs the Particleboard Facility alternative would offer. Implementation time was found in a similar way to the employment opportunities; an existing particleboard facility of similar capacity was used to anticipate the implementation time that the alternative would take (Johnson 2019, Arauco 2020).

Air quality and carbon sequestration was found by examining different emissions that are produced during facility operation, transportation, and disposal. The transportation emissions assumed that trucks responsible for delivering incoming feedstock will travel 33 miles a day and product distribution trucks will travel an average 500 miles a day. It was assumed each truck would hold 25 tons of incoming feedstock and hold 91.8 cubic meters of finished products. The alternative's emissions from each source were determined from particleboard production data (Rivela 2006, Wilson 2010, Eriksson 1996, SEI 2010). The air quality criterion focused on criteria air pollutants stipulated by the EPA (EPA 2016). The carbon sequestration criterion focused on greenhouse gas emissions and their relative carbon equivalence (Pachauri 2015). Supporting information on the quantitative analysis of this alternative can be found in Appendix B of this document.

3.2.7 Alternative Advantages and Disadvantages

The advantages and disadvantages of implementing the Particleboard Facility are depicted in Table 15.

Table 15: The summarized advantages and disadvantages of the Particleboard Facility Alternative.

Advantages	Disadvantages
- Provides a useful resource from wood waste - Provides substantial employment opportunities	- Large capital investment for multiple facilities - Emissions - Relatively long payback period - Large unnatural volume

3.3 Alternative 3 | Distribution Network

Woody biomass utilization in energy and materials applications has no issue with using the large quantities of the waste woody biomass material present in Humboldt County. Although, uses such as mulch, erosion control, animal bedding, and environmental restoration do not use enough of the biomass alone to meet the supply of the material at a county scale. While there is potential for all the material to be used in soil amendment applications in Humboldt County, farmers do not widely practice woody mulch application. By creating a distribution center and network for woody biomass, this alternative aims to make the material available for these uses at a large enough scale to meet the supply of the material.

3.3.1 Alternative Description

In this proposed alternative, waste woody biomass would be transported by truck to a distribution center located on the grounds of a community garden. Mills will not be charged for dumping the waste at the facility and the distribution facility will not pay for the material either. The incentive for the mills is that they will not have to pay for the material to be landfilled. This distribution center will be responsible for allocating the woody biomass into three separate categories depending on demand. As shown in Figure 13, these three categories are primary use, secondary use, and excess. Ideally, biomass distribution priority will be in the stated order, but can be adjusted as relationships and demand from consumers changes.

The primary objective is to maximize the local use of the material. This will consist of delivery or pick up of the material to local landscapers, environmental restoration sites, construction sites, farmers, and residents. They may use this material for landscaping, farming mulch, erosion control, restoration work, animal bedding, and other non-combustion uses. Local universities can also use the material for research work on biomass utilization including as an energy source, although this would be an expectably tiny fraction of the total material. Ideally, most of the biomass will eventually follow this path. Initially, demand will be low, and it will be the responsibility of the distribution center to reach out to potential consumers and build long term relationships. The main incentive for the local consumer is that the material is free. Although, if the local consumer requires drop off, they will be charged to cover the cost of transportation.

The secondary priority for the material is uses in other areas of California. While local cost for the material is free, uses outside of Humboldt County will include transportation costs as well as a flat rate cost per cubic yard of the material. Adjusting for the change in density of the material and associated change in transportation cost will be accounted for with varying wet and dry season costs. Demand for this material in Central and Southern California is expected to be high due to the relatively low supply of the material in these areas. A distribution center and community garden facility will be located in Central or Southern California to more efficiently distribute the product. While the material can be used the same way as in local uses, there is potential for another source of demand. This is in helping communities reduce their carbon footprint and meet climate change goals. Many cities and counties have general plans that involve reducing emissions or even becoming carbon neutral. By purchasing and applying woody biomass in public parks and landscaping, they could figure out an appropriate carbon accrediting system.

The last category is excess. The excess biomass will be used as a thick mulch in two large community gardens. These gardens will be a centered where community members can recreate, garden, drop off organic food waste, drop off landscape waste, and learn about sustainable food development in workshops and tours. Employees will be responsible for managing and allocating space to community members as well as guiding workshops and tours. Allowing compost drop off will greatly increase the ability of the garden to build up nitrogen in the soil organically without synthetic fertilizers. This will help reduce runoff and nitrous oxide emissions associated with conventional fertilizer application. Animals will also help with the buildup in nitrogen. Sustainable food production will be the major educational component of the community garden. There will also be potential for education about woody biomass utilization and water management. The design of the garden will depend on location and topography. The garden will act as a live example of many sustainable practices: pairing vegetable growth with animals, composting, mulching, natural irrigation, permaculture, etc. Areas of the garden can be dedicated to native plants to educate community members about local flora. There are a variety of opportunities in a large community garden for woody biomass utilization and community benefits (Figure 13).

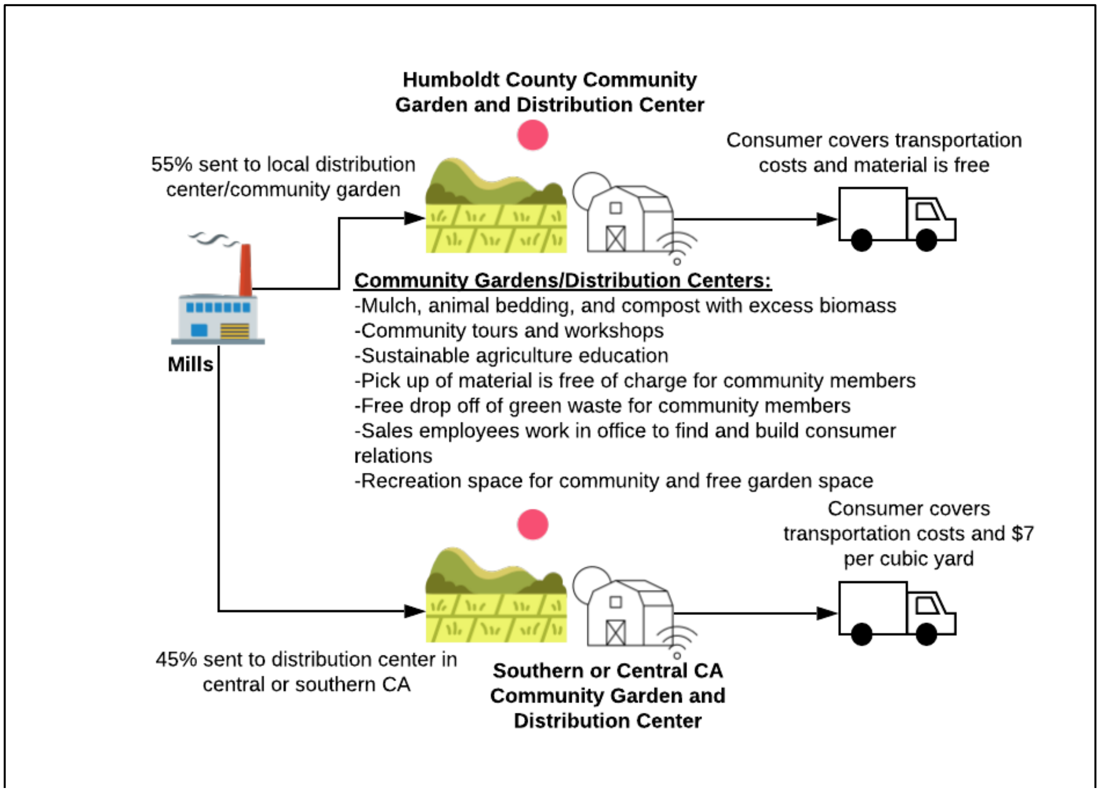

Figure 13: Flow chart of proposed Distribution Network of woody biomass.

3.3.2 Constraints Analysis

This alternative is assumed to meet all constraints. While an environmental impact report and permits may have to be completed for the distribution and community garden center, it is unlikely that such a facility would break any regulations related to air, water, or soil quality. One possible concern is if animals are implemented in the food forest, their waste must be managed properly. Although with excess mulch, erosion control, and bedding material it would be feasible to protect waterways from the animal waste. Fertilizer application will be limited to organic waste produced onsite from animal waste and onsite generated compost. This way nutrient runoff will be minimized, and the entire garden can be considered organic. A downside to this is that soil nutrient content will start low depending on the site. Although, after about a year of application and decomposition of the woody material, compost collection, and animal manure collection soil nutrients will start to build up.

With regards to employment, there are many opportunities to create jobs. The transportation of woody biomass will most likely be outsourced. Although, the transportation of roughly 2-3 million cubic yards of woody biomass a year in Humboldt County and potentially many regions of California would cause an increase of employment in the transportation sector. Assuming 120 cubic yards per truck, there is potential for more than 33,000 separate deliveries per year over varying distances. This could theoretically require up to 100 workers just for transportation assuming an average of 2 deliveries a day per worker. Although, this is all assuming demand is high enough for the material and that a significant number of consumers would like the material delivered. Another consideration is that all the truck drivers that use to deliver to the biomass plants could fill a large portion of these new jobs. With increased travel distance to other regions of California, there will still be a net increase in transportation jobs. If the consumer covers the transportation cost and the service is outsourced, the cost for creating these jobs would be covered by the consumer. It is assumed that as relationships with consumers develops, the amount of jobs created due to transportation will slowly increase. At the community garden it is expected that two to three full time employees will be onsite to manage the community food garden by taking care of animals, assisting community members, compositing, applying woodchips when necessary as well as watering and irrigation in the dry season if needed. These employees will also be responsible for giving tours to community members, educational workshops, and outreach about sustainable food development. The number of these employees will be highly dependent upon the acreage and number of animals in the garden. Another full-time employee would be needed for finding consumers for the biomass. They will also be responsible for allocating the biomass appropriately once demand meets supply. Initially it would be best to have two or more of these employees to ramp up the initial demand for the material and build relationships with consumers. A couple employees will also be needed for management and administrative tasks. Overall, the expected number of jobs created by this project varies greatly depending on site location and varying demand with time. It is expected that approximately 50-100 jobs will be indirectly created or conserved in the transportation sector. Approximately 30 jobs will be directly created at the distribution and community garden center.

3.3.3 Social Criteria Analysis

This section will analyze how the Distribution Network system will perform with regards to the social criteria established in this project, which include aesthetics and community support.

Aesthetics

Depending on the location of the site, it could be argued that community aesthetics could increase due to this project. The only negative aesthetic impacts expected are the barren grounds after the initial application of the material, the large piles of the material, and a small office and tool shed for workers. After time, the development of perennial vegetation and rich soil will positively impact the aesthetics of this alternative. Although, to compare alternative designs the volume of unnatural structures will be used to quantify aesthetics.

Community Support

Communities generally react positively towards the creation of recreation spaces in their community. Sustainable food development and the opportunity to garden may be of interest to many community members who do not have their own land. It is expected that a solid majority of community members would have a favorable opinion of this alternative.

3.3.4 Economic Criteria Analysis

This section will analyze the economic criteria with respect to the Distribution Network alternative. This will include payback period, employment opportunities, and project implementation time.

Payback Period

The payback period for this alternative can be calculated based on the annual cash flow calculation shown in Eqn. 3. Note that transportation cost is not included since any deliveries will be covered by the consumer and deliveries will be outsourced. The two sources of income are from distribution to consumers outside of Humboldt County as well as charging for personalized workshops or tours in the community gardens. All values are averages since the expected number of consumers will change with time and pricing may be adjusted as well.

$$PBP = \frac{C_i}{N_t C_t + N_b C_b - C_{OM}} \qquad \text{Eqn. 3}$$

Where:

PBP	=	years needed to regain capital investment and start profiting (yr)
C_i	=	Initial cost of distribution and community garden center ($)
C_t	=	Average tour cost ($)
N_t	=	Average number of tours provided each year
C_{OM}	=	Average annual operation and maintenance cost ($/yr)
C_b	=	Cost per cubic yard of biomass ($/yd^3)
N_b	=	Average cubic yards of biomass sold outside of Humboldt County (yd^3)

Employment Opportunities

As stated in the constraints section of this alternative analysis, the employment opportunities for the distribution and community garden center are promising. It is estimated that employment will increase with time. Net indirect employment through outsourced transportation could range from 50-100 employees. Direct employment at the garden and facility is estimated to be 30 full time employees. This consist of one manager, four sales employees, and 30 employees for managing the grounds of the facility and assisting with drop-offs and tours.

Project Implementation

Project implementation would be fairly feasible. In comparison to an energy production facility, the amount of permitting needed to make the facility and community garden would be insignificant. Although, to be conservative for such a large park, it is expected that it will take at least a year for the project to get approved and permitting to be completed if needed. Water harvesting, from rain, is an important component of the facility that may require permitting. After buying property for the distribution and community center, woodchips should be applied immediately to start the degradation process. Planting directly after application of the mulch would be infeasible unless the soil of the property was fertile. Initially implementing a community composting center and introducing animals will also help build up soil fertility. After six months to a year it would be more reasonable to allow community members in. During this time an office, animal shelters, and tool sheds could be built. The project can start within a few months of buying the product, but community involvement and tours will most likely take a year or more to be fully implemented. With permitting, purchasing, soil restoration, and revegetation, it is estimated the project could take 2.5 years to implement.

3.3.5 Environmental Criteria Analysis

This section will discuss how the Distribution Network alternative performs with regards to the environmental criteria established for this project. This will consider air quality and carbon sequestration.

Air Quality

The pollutant associated with this alternative is mainly particulate matter during brief application of the material. Again, the main concern would be triggering allergies of individuals that are in close proximity to the community garden during these brief application periods. This can be reduced by slowly applying the material on a day to day basis as needed rather than applying everywhere twice a year. That would greatly minimize particulate matter and associated allergies.

Carbon Sequestration

Carbon sequestration is difficult to quantify with this alternative. The woody biomass will decompose partially in the long term into CO_2 and CH_4 while much of the carbon will remain in the soil. Although, the rate of decomposition and distribution of CO_2 to CH_4 is highly dependent upon a variety of properties such as moisture, native soil properties, microorganisms, etc. These complex relationships in the context of greenhouse gasses are represented in Figure 14 (Thangarajan et al. 2013). Another consideration is that the amount of vegetation that the mulch will eventually support. With time and especially the development of perennials, supported plant life can significantly contribute to amount of carbon sequestered.

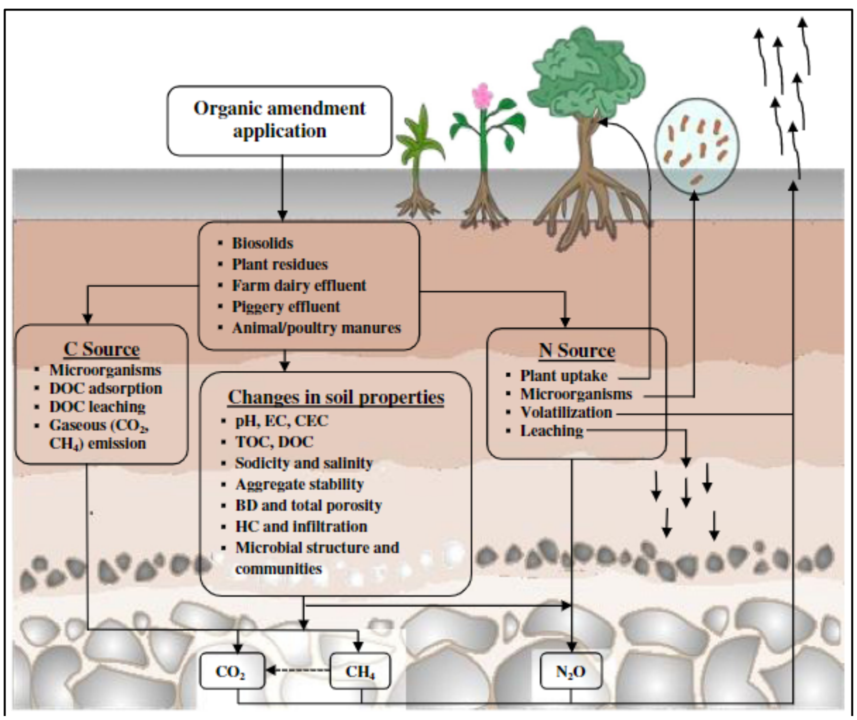

Figure 14: Complex relationship between soil properties and mulch that contributes to GHG emissions (Image source: Thangarajan et al. 2013).

3.3.6 Quantitative Alternative Analysis

To eventually score and compare alternatives, criteria must be analyzed in a quantifiable manner. Table 16 is a summary of quantified values associated with each constraint. Capital costs was determined by estimating the cost of constructing two small 6-person office buildings, equipment for landscaping, initial landscaping, and the cost of 300 acres total assuming a $10,000/acre average land cost in California. Payback period was calculated using Equation 3 with initial capital costs at about 7 million dollars and an average net annual cash flow around 4 million dollars. This assumes biomass is sold at $7 per cubic yard and includes approximated operation and maintenance costs. A low price for the material was used in order to increase the demand for the product since the supply of the material will most likely outweigh the demand in the early stages of implementation. Four sales people will be working full time to ensure sales are meeting the supply. A 5% safety factor was used in calculations to account for issues with demand. Most demand for this material is expected to come from consumers such as; Cal Trans, contractors, landscapers, small farmers, and public parks. It is assumed that in California these consumers have the potential to use 45% of the product, although the challenge is convincing them to use this product rather than others. It is important to note that consumers will pick up the cost for deliveries in all cases. Some of the environmental criteria need additional details for how they were calculated. For these calculations, an average moisture content of 50% by weight was used for the woody biomass. It was also assumed that 10% of the material stayed onsite in the community garden, 45% was transported an average of 35.1 miles locally, and 45% was transported an average of 517 miles throughout California through the second distribution center. In terms of sequestered carbon, hog fuel emissions per dry weight of woody biomass were subtracted from transportation emissions and decomposition emissions using literature source conversion values (SEI 2010, Eriksson et al. 1996). Refer to Appendix C or calculations used to quantify criteria.

Table 16: Distribution Network criteria quantified.

Criteria	Quantification	Value
Social Criteria		
Aesthetics	Volume of unnatural structures (ft^3)	30,000
Community Support	The percentage of the people who approve the project (%)	85%
Economic		
Payback period	The number of years before a project begins to make a profit (years)	1.7
Employment Opportunities	Number of job opportunities that the project would produce or preserve (#)	80-130
Project Implementation	Time required from approval to beginning operation of alternative (months)	30
Environmental		
Air Quality	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)	Table 17
Carbon Sequestration	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)	-392,000

Table 17: Breakdown of the NAAQS pollutants resulting from Distribution Network alternative.

Pollutant	US tons/yr
NO_x	95.4
CO	40.8
PM_{10}	5.7
SO_x	1.3

3.3.7 Alternative Advantages and Disadvantages

After the quantitative analysis of the criteria it is clear what advantages and disadvantages this alternative. There are quite a few considerable advantages. This includes aesthetics, large community support, low NAAQS pollutant emissions, and the supply of a remediation material at a low cost. Disadvantages include a relatively low increase in jobs, long implementation period, and high GHG emissions from the decomposition process. Another consideration that could be a disadvantage is robustness. The success of this alternative heavily weighs on the employees' abilities to build consumer relations fast. This is why four full time employees will be hired to work directly at the facility to ensure consumer relations are built. Also, this is why the cost of the material is much lower than the average market price for woody mulches. Without employee success the payback period could be significantly impacted especially during the initial implementation of this alternative. This becomes more relevant as the quantity of biomass handled by the network increases. It is important to note that the NAAQS pollutants mainly come from diesel truck transportation and not the distribution facility itself so the facility would not be considered a major source with regards to air pollutants. Table 18 is a summary of the advantages and disadvantages of this alternative.

Table 18: Advantages and disadvantages of Distribution Network alternative.

Advantages	Disadvantages
- Large benefits for the community in terms of aesthetics, recreation, and education	- Financial success heavily dependent upon sales team
- Unique community garden will generate tourism	- Labor intensive jobs
- Low NAAQS pollutant emissions	- No energy production
- Supply and use of environmental remediation material at a low cost	- High GHG emissions from decomposition

3.4 Alternative 4 | Community-Scale Biomass Gasification Facilities

This section describes the Community-Scale Biomass Gasification Facilities alternative. A constraints and criteria analysis, quantitative alternative analysis, and a list of potential advantages and disadvantages that could result from implementing the proposed alternative are included in this section.

3.4.1 Alternative Description

The installation of a number of Community-Scale Biomass Gasification Facilities throughout the County of Humboldt is one project alternative that could be implemented to replace one or both of the two existing combustion biomass powerplants. As stated in California Senate Bill 1122, and later amended by California Assembly Bill 1923, a community-scale biomass gasification facility would not be authorized to produce a net amount of power more than 5 MW and would be designed to provide for a community with a maximum energy load of 3 MW (CPUC 2012, Wood 2016). Use of such a facility in a community would support local fire management practices and be suitable for multiple small communities throughout the County.

Advances of gasification technologies in Europe over the beginning of the last century have been remarkable (Göteborg Energi 2020). In Europe, electricity is scarce and biomass is in abundance, promoting an innovative market for development in large-scale woody biomass gasification facilities that can generate 20 MW or more of energy (CEC 2019). However, these large-scale European facilities utilize high grade uniform woodchips as feedstock to produce a prime quality gas that can then be burned in an internal combustion engine (Alamia et al. 2017). In California, the quality of the feedstock is far from the uniform woodchips utilized in the European plants. Utilizing a more low-quality feedstock with differing moister contents and potentially non-consistent sources throughout the State results in the creation of a cruder gas to be burned for electricity production, resulting in more emissions. With California having much of its forested lands at risk of catastrophic wildfires, California is not focused on harvesting timber for high quality woody biomass, rather it is focused on removing vast amounts of woody biomass from multiple different forested locations throughout the State to prevent catastrophic wildfires (Wood 2016). With transportation being a large limiting factor throughout the State, there is a restriction as to how far biomass can be transported from the source to a large-scale gasification plant until the process becomes economically infeasible. All these reasons help to justify as to why using multiple community-scale biomass facilities throughout the County of Humboldt could be more beneficial to remove biomass at the source, rather than invest in one or two large-scale gasification facilities.

To recall from the Background section, biomass gasification is the thermal decomposition of organic matter into CO_2, CO, H_2, methane, and biochar with a controlled amount of oxygen or steam (Kumar et al. 2009). Biomass gasification can be more beneficial in comparison to combustion biomass powerplants because of the cleaner emissions that come from burning the syngas produced during the gasification process. Another benefit of gasification includes the ability for the syngas to be stored in a fuel cell, acting the same as a battery to be burned at a later time to produce energy.

Large-scale gasification plants have been designed to gasify the majority of the biochar (>50%) produced during the gasification process (Alamia et al. 2017). On the other hand, alternative gasification systems can be designed to harvest high quality biochar so as to be able to sell it to agriculture sectors as a soil amendment, and help decrease the cost to produce gas or electricity (Ahrenfeldt et al. 2013). Community-scale biomass gasification facilities are designed to harvest high quality biochar. High quality biochar can be sold for an estimated market value of $1 per Kg, which could decrease electricity generation prices to $40 per MWh (CEC 2019). Below in Figure 15 is a basic schematic showing biomass being transported from a sawmill to a community-scale gasification plant, and the outputs being high quality biochar, electricity, and emissions.

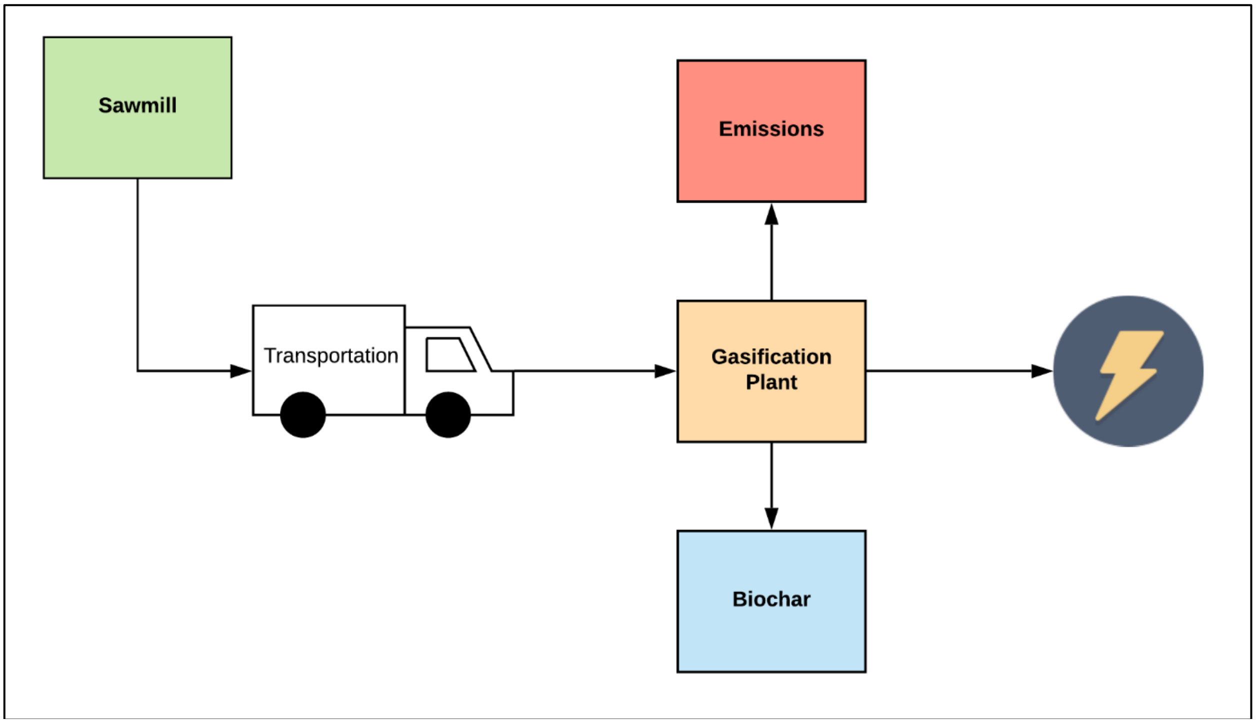

Figure 15: A basic schematic showing the inputs and outputs to a community-scale gasification facility.

A superior configuration for a modular gasification system can be viewed in Figure 16, which includes a feedstock meter, dryer, rotary gasifier, thermal oil heater, and Organic Rankine Cycle turbine (CEC 2019). The woody biomass enters the dryer from the metering bin, then the dryer reduces the moisture content in the woody biomass before entering the rotary gasifier. Once in the rotary gasifier, the woody biomass either becomes syngas or high-quality biochar through gasification. The product syngas is then combusted in a thermal oil heater, which utilizes the resulting hot oil in a heat exchanger to heat a working fluid inside an ORC generator and produce electricity. The configuration can be modified to include a gas scrubber and gas-engine in place of a thermal oil heater and ORC turbine, if desired.

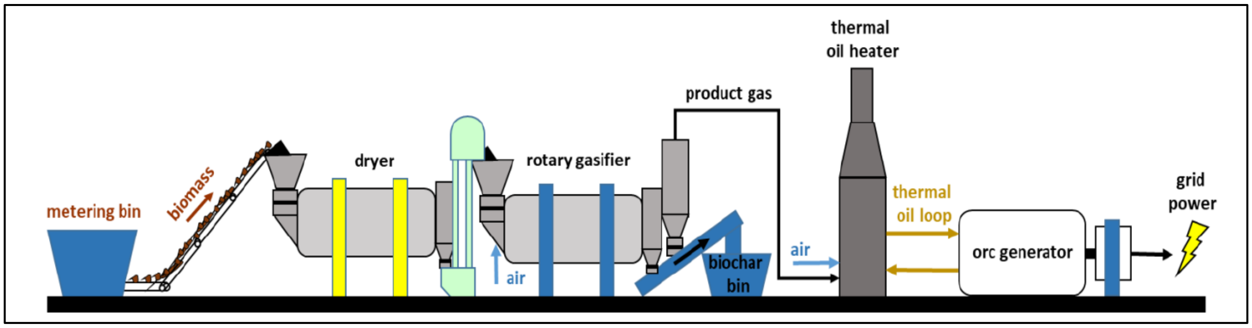

Figure 16: A flow diagram showing the configuration and process of a modular biomass gasification system (Image source: CEC 2019).

A downfall of biomass gasification is excessive tar build up that can appear in the system as a result of the thermal decomposition of woody biomass. However, gasification systems can utilize equipment such as gas scrubbers, rotary gasifiers, or other proprietary equipment to prevent excessive tar build up and blockage throughout the system (CEC 2019, Göteborg Energi 2020).

3.4.2 Constraints Analysis

With there being initiatives to promote small-scale biomass gasification plants throughout the State of California, a push to approve these projects at the local, state, and federal regulatory levels would be expected. Using an average bulk density of 247 kg/m^3 for saw dust and green woodchips, and knowing the annual biomass consumption of one community-scale biomass gasification plant to be 31,560 BDT/year, a little over 100,000 cubic yards can be consumed annually at each plant (Ciolkosz 2010, RCEA 2020). With the proposal being for multiple plants throughout the County of Humboldt, this could enable the alternative to replace the biomass being consumed annually at the two existing combustion biomass powerplants. Each community-scale biomass facility would support new jobs in rural communities at 5 renewable energy jobs per MW (CEC 2019).

3.4.3 Social Criteria Analysis

The Social Criteria Analysis evaluates the aesthetics and community support for the Community-Scale Biomass Gasification Facilities alternative.

Aesthetics

The small-scale gasification plants typically take up around 3 to 10 acres, with most of the parcel being used for onsite biomass storage piles (CEC 2019). These small-scale plants would also be regulated by SB 1122 to ensure facility equipment only makes up so much area of the parcel (CPUC 2012).

Community Support

With an increase in jobs in rural communities, the installation of infrastructure to allow communities to be more resilient in case of county wide power outages, and the use of a technology known to be more environmentally safe in comparison to biomass combustion, it is expected community members would be supportive of this alternative.

3.4.4 Economic Criteria Analysis

The Economic Criteria Analysis evaluates the payback period, employment opportunities, and project implementation for the Community-Scale Biomass Gasification Facilities alternative.

Payback Period

The payback period for the gasification facility alternative would account for the revenue generated from producing electricity, the average yearly O & M costs, and the amount of money gained from selling high quality biochar produced at the plant. Eqn. 4 could be utilized to calculate the payback period for a gasification facility that sells high quality biochar in addition to electricity.

$$PBP = \frac{C_i}{PtC_e + \dot{m}_b C_b - C_{OM}} \qquad \text{Eqn. 4}$$

Where:

PBP	=	Payback period in years (yr)
C_i	=	Total capital investment ($)
P	=	Average operational power output of the facility (MW)
t	=	Hours of facility operation per year (hr/yr)
C_e	=	Cost of electricity ($/MWh)
$\dot{m}_b$	=	Average mass of biochar produced per year (kg/yr)
C_b	=	Average cost of biochar per kg ($/kg)
C_{OM}	=	Average yearly operation and maintenance ($/yr)

Employment Opportunities

Employment opportunities would be 4.9 jobs per MW of the facility (CEC 2019). A typical facility would be 3 to 5 MW, indicating that 15 to 25 new jobs in rural areas would be needed as a result of the project.

Project Implementation

Depending on CEQA and NEPA requirements, approval for the project could take as long as 12 to 48 months to obtain an EIR or EIS if it were found that the proposed project site needed such documents certified. Construction time would be estimated to be no longer than a year, and could be started prior to meeting all permit requirements, depending on the permits still needed (CEC 2019).

3.4.5 Environmental Criteria Analysis

The Environmental Criteria Analysis evaluates the air quality and carbon sequestration for the Community-Scale Biomass Gasification facilities alternative.

Air Quality

Particulate matter would be less than 0.31 pounds per MWh of energy generated (CEC 2019). Air quality could be further improved through the use of additional facility equipment such as an electrostatic precipitator to reduce emissions of fine particulates.

Carbon Sequestration

Carbon sequestration would be done through the use of high-quality biochar produced from the gasification process. It should be noted that carbon sequestration could be done by quantifying the amount of carbon that would otherwise be pile burned or become rid of via mastication as well.

3.4.6 Quantitative Alternative Analysis

With the objective to score the Community-Scale Biomass Gasification Facilities alternative, Table 19 summarizes found scores for each criterion. This quantitative alternative analysis accounts for eight separate facilities being put online within Humboldt County. The number of facilities was found utilizing the calculation shown in Figure 49 of Appendix D.

Table 19: Community-Scale Biomass Gasification Facilities alternative quantified for each criterion; the values represent that of eight separate facilities combined.

Criteria	Quantification	Value
Social Criteria		
Aesthetics	Volume of unnatural structures (ft^3)	1,842,048
Community Support	The percentage of the people who approve the project (%)	33
Economic		
Payback Period	The number of years before a project begins to make a profit (years)	4
Employment Opportunities	Number of job opportunities that the project would produce or preserve (#)	150
Project Implementation	Time required from approval to beginning operation of alternative (months)	12 - 48
Environmental		
Air Quality	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)	Table 20
Carbon Sequestration	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)	105,600

Table 20: Table of the NAAQS annual emissions.

Pollutant	US tons/year
PM_{10}	22.9
NO_x	24.3
SO_x	0.3
CO	15.3

To calculate the aesthetics criterion, a known modular gasification plant's dimensions were utilized to discover its volume (Powermax 2020). For the community support criterion, three known case studies on biomass gasification were utilized to find an average percentage on public approval for the project (Plate et al. 2010, RCEA 2020, Roracher et al. 2015).

The payback period criterion was calculated using Eqn. 4. For the payback period criterion, it was assumed a biochar market was present and that the biochar could sell for a value of $0.50 per kg (CEC 2019). The payback period criterion also utilized an electricity rate of $156 per MWh (Electricity Local 2020). It was additionally assumed that the plant had a parasitic load of 1 MW, the plant was never operating at full capacity (1 MW less than its 5 MW rating), and had an average of 2 days of maintenance per month. The annual maintenance costs were priced at $2,052,000 per year, and construction costs were 30% of the capital cost with a 20% contingency also applied to the total capital cost in order to account for any variations in price (CEC 2019). The capital cost of one modular gasification facility was priced at $16,875,000 (CEC 2019).

The employment opportunities criterion was calculated based on the plant being assumed to be sized as a 5 MW plant, and assuming that the number of jobs be 5 jobs per MW (CEC 2019). The implementation criterion was determined to be based on how long the project could get through the CEQA or NEPA permitting process. It was determined that at most it would take 12 months to get through the CEQA process and 48 months to get through the NEPA process (West Biofuels 2020b).

The air quality criterion utilized the annual biomass consumption of 31,560 MT BDT per year for one 5 MW modular biomass gasification powerplant and the four truckloads per day to calculate the transportation NAAQS emissions (West Biofuels 2020a). For transportation emissions it was determined that 5.73 grams of NO_x, 0.08 grams of SO_x, 2.45 grams of CO, and 0.34 grams of PM_{10} were released per kilometer of travel (Eriksson et al. 1996). The distance each truckload had to travel was the distance from Piercy, California to Crescent City, California along Route 101, which turned out be 163 miles (Google Maps 2020a). For process emissions it was determined that 0.14 grams of PM_{10} was released per KWh of energy produced by the gasification facility. Likewise, it was determined that 0.032 grams of NO_x per KWh of energy and 0.045 grams of CO per KWh of energy were released from plant operations. Other NAAQS pollutants such as SO_x remained negligible during plant operations (West Biofuels 2020a, SEI 2010). It was assumed that with control technologies a 90% reduction would be achieved for these NAAQS pollutants (USEPA 2000).

For the carbon sequestration criterion, three things needed to be accounted for: 1) the GHG emissions generated during the construction of the plant and during the transportation of the biomass to the plant, 2) GHG emissions produced during operation of the plant, and 3) GHG emissions avoided through biochar sequestration. In terms of analyzing GHG emissions, only CO_2 emissions were analyzed. This lifecycle assessment did not account for the displaced emissions not released as a result of using the gasification plant alternative. Emissions were analyzed for a 20-year equivalence, and the distance the biomass was transported was assumed to be again the 163 miles from Piercy, California to Crescent City, California along Route 101 (Google Maps 2020a). Four truckloads of biomass would be needed to be transported to the plant each day to keep the plant fully operational, where each truckload was assumed to hold a volume of 120 cubic yards of biomass. The reported carbon sequestration emissions for the gasification alternative considered plant operation emissions as carbon neutral, and are excluded from the final reported total number in Table 19 as a result (CEC 2020). The operation emissions as well as a further explanation on how each criterion was quantified can be found in Appendix D.

3.4.7 Alternative Advantages and Disadvantages

The advantages and disadvantages for implementing eight new community-scale biomass gasification plants within Humboldt County can be viewed in Table 21.

Table 21. The alternative advantages and disadvantages.

Advantages	Disadvantages
- Helps meet RCEA 2030 goal of fully renewable	- Large capital investment for multiple facilities
- Small unnatural structures	- Questionable community support
- Carbon sequestration and low emissions	- New jobs require technical skills
- Provides a large number of new jobs for rural communities	
- Biochar market can help offset electricity costs	
- Offers a more robust electrical grid for rural communities	

4. Decision Analysis

This section conducts a Delphi method analysis and Pugh method analysis to determine the preferred alternative. For the Delphi method, both the criteria weights given by the client and each of the criteria scores were utilized to find the alternative with highest overall weighted score. This highest scoring alternative was then used as the base case for the Pugh Method before coming to a final preferred alternative.

4.1 Delphi Method

To produce a score for each alternative, the Delphi Method was applied. RCEA was sent a memo to weigh the criteria for this analysis, which were then utilized in the Delphi Matrix. A scoring rubric was developed that encompassed values determined for each alternative. The total score for each alternative is the sum of the weighted scores for each criterion.

4.1.1 Criteria Weight

The weights given to each criterion by the client are presented below in Table 22. The most important criteria the client considered were air quality and carbon sequestration, followed by employment opportunities and payback period. The client considered aesthetics and project implementation time to be the least important criteria.

Table 22: Each criterion weighted by the client on a scale of 1 to 10.

Criteria	Description	Quantification	Client Weight (1-10)
Social			
Aesthetics	Minimize change in visual effects to surrounding environment	Volume of unnatural structures (ft^3)	**2**
Community Support	Maximize public approval	The percentage of the people who approve the project (%)	**5**
Economic			
Payback Period	Minimize time until a project begins making a profit	The number of years before a project begins to make a profit (years)	**4**
Employment Opportunities	Maximize job opportunities	Number of job opportunities that the project would produce or preserve (#)	**4**
Project Implementation	Maximize ability for implementation of project at the federal, state, and local level	Time required from approval to beginning operation of alternative (months)	**2**
Environmental			
Air Quality	Minimize air quality impacts	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (US tons/year)	**5**
Carbon Sequestration	Maximize sequestration of carbon	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)	**5**

4.1.2 Criteria Scoring Rubric

The criteria scoring rubric is utilized to help provide scores to each of the alternatives for the seven criteria being looked at. The criteria scoring can be viewed in Table 23.

Table 23: The criteria scoring rubric.

		1	2	3	4	5
Criteria	**Quantification**	**Poor**	**Below Average**	**Average**	**Fair**	**Exceptional**
Social						
Aesthetics	Volume of unnatural structures (ft^3)	> 15 million	10 < x ≤ 15 million	5 < x ≤ 10 million	1 < x ≤ 5 million	≤ 1 million
Community Support	The percentage of the people who approve the project (%)	≤ 20%	20 < x ≤ 40%	40 < x ≤ 60%	60 < x ≤ 80%	> 80%
Economic						
Payback Period	The number of years before a project begins to make a profit (years)	> 8	6 < x ≤ 8	4 < x ≤ 6	2 < x ≤ 4	≤ 2
Employment Opportunities	Number of job opportunities that the project would produce or preserve (#)	< 100	100 < x ≤ 200	200 < x ≤ 300	300 < x ≤ 400	> 400
Project Implementation	Time required from approval to beginning operation of alternative (months)	> 84	60 < x ≤ 84	36 < x ≤ 60	12 < x ≤ 36	≤ 12
Environmental						
Air Quality	Amount of NAAQS pollutants (PM_{10}, NO_x, SO_x, CO) (Total US tons/year)	> 4,000	3,000 < x ≤ 4,000	2,000 < x ≤ 3000	1,000 < x ≤ 2000	≤ 1,000
Carbon Sequestration	Amount of 20-year equivalent CO_2 sequestered per year (US tons eq. CO_2 per yr)	≤ -200,000	- 200,000 < x ≤ - 100,000	- 100,000 < x ≤ 0	0 < x ≤ 100,000	> 100,000

4.1.3. Delphi Matrix

The Delphi matrix incorporates both the criteria weights from the clients and the scores given for each criterion. The alternative with the highest overall weighted score will be utilized as the base case for the Pugh method analysis. The Delphi matrix can be viewed in Table 24.

Table 24: The Delphi matrix incorporating both the client weights and given scores for each criterion.

Criteria	Weight of Criteria	Alternative Scores (1-5)			
		Biomass Fuel Densification Facility	**Particleboard Facility**	**Distribution Network**	**Community-Scale Biomass Gasification**
Social Criteria					
Aesthetics	3	4	3	5	4
Community Support	7	4	1	5	2
Economic Criteria					
Payback Period	4	5	1	5	3
Employment Opportunities	4	2	2	2	2
Project Implementation	2	3	4	4	4
Environmental Criteria					
Air Quality	5	1	5	5	5
Carbon Sequestration	5	1	3	1	5
Overall Weighted Score		**84**	**76**	**116**	**104**

4.2 Pugh Method

This section of the document describes the alternative decision analysis using the Pugh method. This decision methodology is a comparative analysis that examines the main pros and cons of an alternative with respect to a reference case. The best alternative from the Delphi method, the Distribution Network alternative, was used as the reference case for this analysis. The alternatives chosen to be compared to the reference case were a combination of the other alternative combined with the Distribution Network. This was done due to the adaptability of the Distribution Network alternative which had the potential to combine with another alternatives. The combined alternatives evaluated in this analysis are the Community-Scale Biomass Gasification Facilities with Distribution Network, the Particleboard Facility with Distribution Network, and the Biomass Densification Facility with Distribution Network.

The process for this decision method was to give pluses or minuses to each combined alternative compared to the reference case; this was done with respect to the social, economic, and environmental criteria. Table 25 describes the Pugh method analysis and results.

Table 25: The Pugh method comparing against the Distribution Network as the base case.

Constraint	Distribution Network and Community-Scale Gasification	Distribution Network and Particle Board Facility	Distribution Network and Fuel Densification Facility
Social			
Aesthetics	-	-	-
Community Support	-	-	-
Economic			
Payback Period	-	-	+
Employment Opportunities	+	+	+
Project Implementation	-	-	-
Environmental			
Air Quality	+	-	-
Carbon Sequestration	+	+	-
Net Scores			
Net Negatives	**4**	**5**	**5**
Net Positives	**3**	**2**	**2**

4.3 Preferred Alternative

Using the Delphi and Pugh methods, it was determined that the optimal alternative for utilization of woody biomass waste residues in Humboldt County is a combination of the Distribution Network and Community-Scale Biomass Gasification facilities alternatives. This was determined by first using the Delphi matrix to determine the best scoring alternative, the Distribution Network. The best alternative was combined with each of the other alternatives independently and scored with the Pugh method with the Distribution Network as the reference case. The biggest issue for all the alternatives was scaling productivity up to meet the large supply of woody biomass material. By combining alternatives, this issue is minimized making it more feasible that the total supply of material will be consumed. What set the gasification and distribution network alternatives apart was their high scores with regards to carbon sequestration and air quality emissions, which were weighted heavily by the client. The combined alternative will be analyzed and scaled to where a certain percentage of the woody biomass be utilized by the Distribution Network, and the other portion be utilized by the Community-Scale Biomass Gasification Facilities.

5. Preferred Alternative Analysis

This section of the document discusses the preferred alternative. The section describes the logistics of the combined alternative, discusses how the alternative performs with respect to each project criterion, provides a location optimization model, proposed sites, a sensitivity analysis on two important model parameters, and the advantages and disadvantages of implementing the preferred alternative.

5.1 Description of Preferred Alternative

The preferred alternative was chosen to be a combination of the Community-Scale Biomass Gasification Facilities alternative and the Distribution Network alternative. In total, there are 2.4 million cubic yards, or 619,000 US tons, of material needed to be consumed annually by the preferred alternative. When combining alternatives with the distribution network, the goal of the gasification facilities was changed to offset 80% of the electricity generated annually by the DG Fairhaven and HRC Scotia combustion biomass powerplants. Only six gasification facilities were found to be needed to offset 80% of the annual electricity generation from the existing plants, as shown in Figure 62 of Appendix G. It was assumed that the total electricity demand in Humboldt County is 800 GWh annually, and that the biomass energy facilities currently supply 22% of this demand (Humboldt County 2017, RCEA 2019). All excess biomass not covered by the gasification facilities would be utilized in the distribution network.

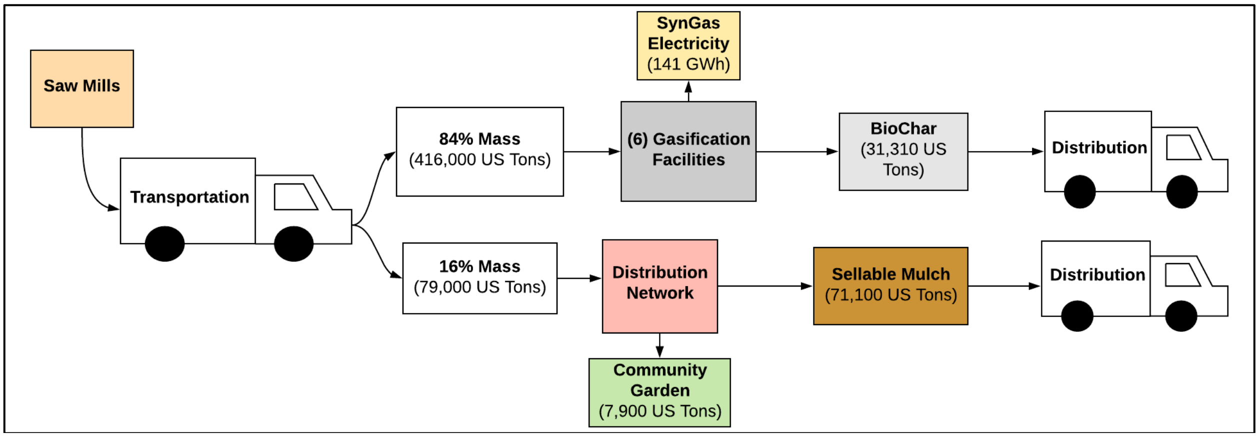

Figure 17: This flowchart describes the general flow of inputs and outputs from the preferred alternative.

It was estimated that 84% of the 2.4 million cubic yards of woody biomass would be needed for the gasification facilities each year to replace 80% of the current biomass energy production in Humboldt County. This means the excess 16% of woody biomass would enter the distribution network. The excess material in the distribution network would be utilized in a community garden within Humboldt County, and distributed for non-combustive uses throughout California. The farther the material is transported to a consumer, the higher the price, meaning that distributing the material closer to the distribution network itself would be preferred; the same idea would apply for biochar produced from the gasification facilities. Figure 17 and Table 26 provide a summary of how the material will be split between the two gasification facilities and distribution network.

Table 26: Split of total biomass between the distribution network and gasification facilities in the preferred alternative.

	Percent of woody biomass	**Total consumption (US tons/yr)**
Distribution Network	16%	78,000
Community-Scale Biomass Gasification	84%	417,000

The distribution network needed to be scaled down for the preferred alternative, this would be done by limiting the network to one distribution center and community garden in Humboldt County. Other alterations include reduced capital cost, implementing a cost of $7 per cubic yard for local and non-local purchases, and proportionally minimizing the number of employees. The new total acreage for the facility and community garden would be up to 150 acres. The following sections will further describe the analysis of the combined alternative.

5.2 Quantitative Criteria Analysis of Preferred Alternative

This quantitative criteria analysis describes the quantified values for each project criterion. This analysis examines the different criteria to describe the economic, social, and environmental impacts of the project's implementation. Please refer to Appendix G to view calculations associated with the quantitative results.

5.2.1 Social Criteria Analysis

A total for the Aesthetics and Community Support criteria was calculated for the Community-Scale Biomass Gasification and Distribution Network alternatives, as shown in Table 27. The preferred alternative would have a combined aesthetics footprint of 1,856,900 ft^3 and an average approval rating of 59%.

Table 27: Social analyses for preferred alternative.

Criteria	Distribution Network	Gasification	Total/Average
Aesthetics (footprint ft^3)	14,900	1,842,000	1,856,900
Community Support (%)	85	33	59

5.2.2 Economic Criteria Analysis

The Economic Criteria Analysis section examines the Employment Opportunities, Project Implementation, and Payback Period criteria for the preferred alternative. The direct jobs for the preferred alternative was calculated to account for the usage percentages of the preferred alternative.

With the Distribution Network being scaled down, the new number of direct employees was downsized to be 15, consisting of 1 manager, 3 sales employees, and 11 landscapers. The amount of indirect jobs describes the employment from the preferred alternative's transportation activities. The direct jobs for the gasification facilities was found using an estimate of 5 jobs per MW rating of a gasification plant (CEC 2019). Indirect jobs were calculated by utilizing the number of estimated truckloads of biomass needed to sustain six gasification plants and assuming that one truck driver could deliver two truckloads of biomass per day. Table 28 shows how many direct and indirect jobs are created by the preferred alternative. It was assumed that 90% of the material going into the Distribution Network is sold, while the remaining 10% is added to the community garden.

Table 28: Employment opportunities from the preferred alternative.

Employment Type	Distribution Network	Gasification	Total
Direct	15	200	215
Indirect	20	16	36

Project implementation was assumed to be 48 months. The 48-month time period includes time to complete State and Federal level permits, if need be, and time for construction of the Distribution Network and six gasification facilities. A simple combined payback period analysis is provided in Table 29 using Eqn. 5. Note that the capital cost for each alternative accounts for construction and equipment cost, as well as associated fees to hook up to the existing electricity grid for the gasification facilities (CEC 2019). A present worth net benefit analysis was performed on the preferred alternative to account for a 10-year loan that compounds annually and utilizes an interest rate of 6.4% (Porcu et al. 2019). An average inflation rate of 1.69% was calculated utilizing inflation rates for the years 2015 to 2020, and would be utilized to calculate the present worth benefits (BLS 2020). A cash flow diagram showing annual revenue and costs can be viewed in Figure 18, and calculations associated with the present worth net benefit analysis are presented in Figure 60 of Appendix G. Results and intermediate values of the present worth net benefit analysis are shown in Table 30.

Table 29: The breakdown of a simple payback period for the preferred alternative.

	Distribution Network	**Gasification**	**Total**
Capital Cost ($)	4,070,000	101,250,000	105,320,000
Annual Revenue ($)	2,354,000	37,183,000	39,537,000
Annual O&M Cost ($)	1,418,000	12,312,000	13,730,000
PBP (years)	---	---	4

$$PBP = \frac{C_i}{N_t C_t + N_b C_b + P t C_e + \dot{m}_{bc} C_{bc} - C_{OM}} \quad \text{Eqn. 5}$$

<u>Where:</u>

PBP = Payback period (yr)
C_i = Capital cost of alternative ($)
N_t = Average number of tours provided each year (yr^{-1})
C_t = Average tour cost ($)
N_b = Average cubic yards of biomass sold annually (yd^3/yr)
C_b = Cost per cubic yard of biomass ($\$/yd^3$)
P = Average operational power output of the gasification facility (MW)
t = Hours of gasification facility operation per year (hr/yr)
C_e = Cost of electricity ($/MWh)
$\dot{m}_{bc}$ = Average mass of biochar produced per year (kg/yr)
C_{bc} = Average cost of biochar per kg ($/kg)
C_{OM} = Average yearly operation and maintenance costs ($/yr)

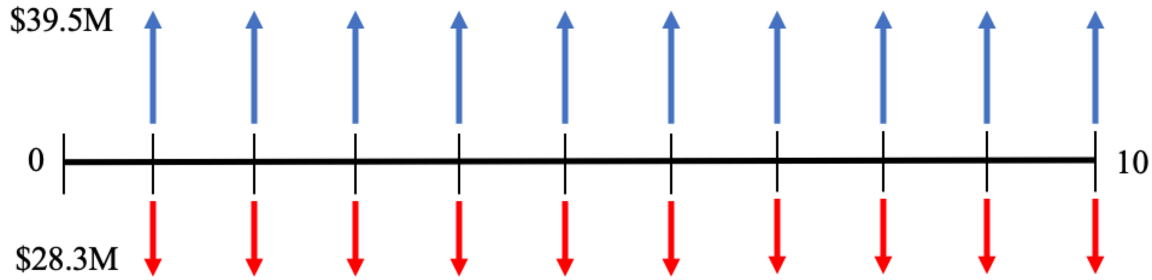

Figure 18: A cash flow diagram of the present worth benefit analysis showing annual revenue and annual costs. Annual costs are the sum of annual O&M costs and annual loan payments.

Table 30: Parameters and results from the present worth net benefit analysis of the preferred alternative.

Present Worth Net Benefit Analysis	
Interest rate	6.4%
Inflation rate	1.69%
Present Worth Cost	$123,320,000
Present Worth Benefit	$360,970,000
Present Worth Net Benefit	$237,650,000

5.2.3 Environmental Criteria Analysis

The Environmental Criteria Analysis section breaks down the emissions resulting from the preferred alternative. A summary of GHG emissions and NAAQS pollutant emissions are summarized in Table 31. Process emissions for the distribution network are emissions associated with running the community garden and office space. Other emissions include the decomposition of the woody biomass as mulch and the transportation of the material. Gasification process emissions are from the gasification process itself. Gasification process emissions are reported, but are assumed to be negligible due to being considered carbon neutral in California (CEC 2020a). If the process GHG emissions of gasification are considered net zero, the total GHG emissions of the preferred alternative would be -16,500 US tons of CO_2e per year. Other emissions for gasification include sequestration from biochar, transportation to agricultural consumers, and construction of the facilities. A summary of GHG and NAAQS pollutant emissions from the preferred alternative and compared to the existing facilities is shown in Figure 19. These values do not consider emission offsets from the original biomass power facilities, and net emissions include carbon sequestration.
Figure **20** shows the percent contribution to NAAQS pollutant emissions by alternative and by process.

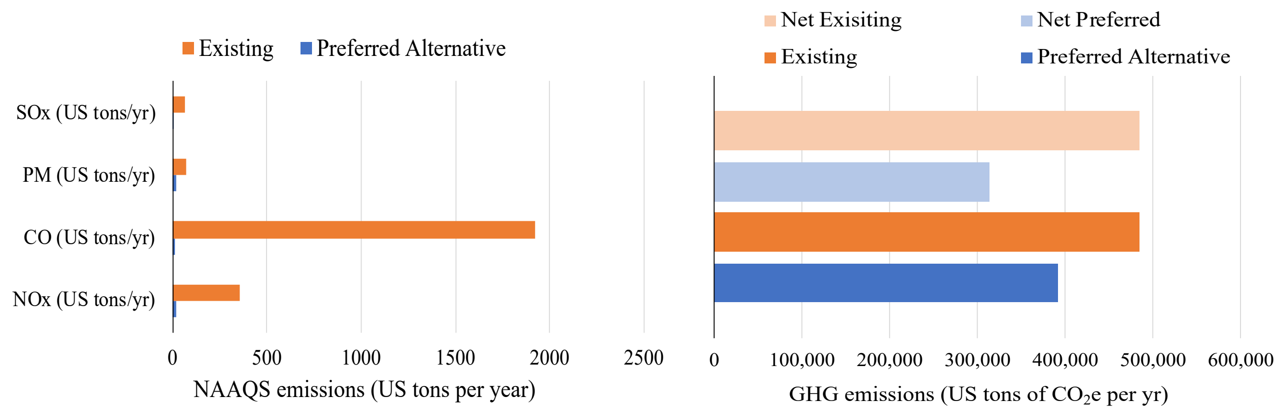

Figure 19: NAAQS and GHG emissions for the preferred alternative and existing biomass powerplants.

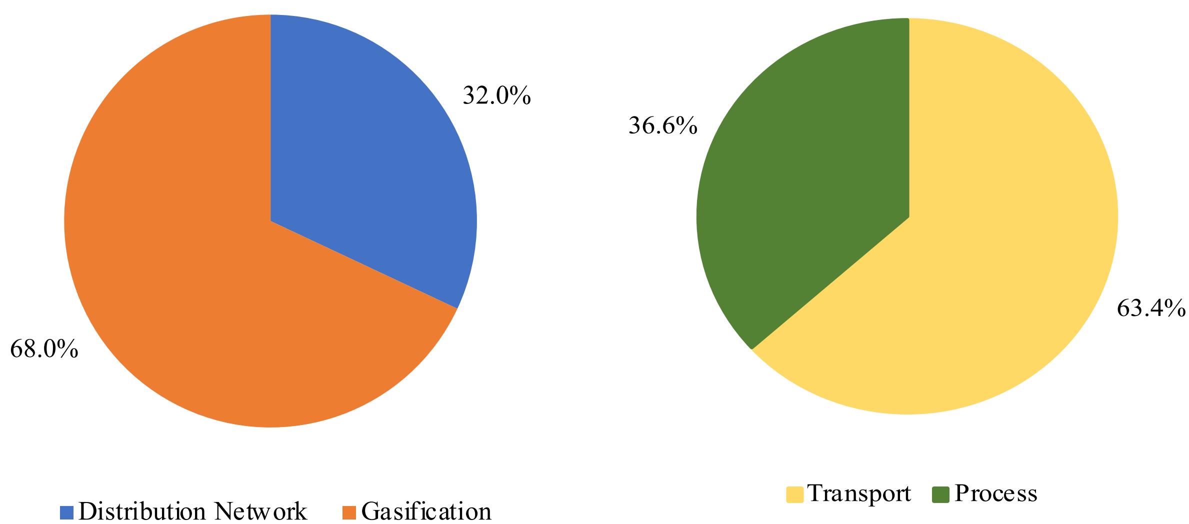

Figure 20: A breakdown of NAAQS pollutants for the preferred alternative's gasification and distribution network processes, and for the amount of pollutants coming from operations and transportation.

Table 31: Summary of emissions from preferred alternative.

	Distribution Network	Gasification	Total
Process GHG emissions (US tons CO_2e/yr)	60,300	329,500	389,800
Other GHG emissions (US tons CO_2e/yr)	1,200	-78,000	-76,800
Total GHG emission (US tons CO_2e/yr)	61,500	252,700	313,000
NO_x emission (US tons per year)	15.0	18.2	33.2
CO emissions (US tons per year)	6.4	11.4	17.8
PM emissions (US tons per year)	0.9	17.2	18.1
SO_x emissions (US tons per year)	0.04	0.2	0.24

5.3 Optimization Model for Facility Locations

An optimization analysis was performed to evaluate the best locations in Humboldt County for placing the preferred alternative's gasification facilities and distribution network facility. The placement of the facilities is an important decision when considering transportation of incoming feedstock and local distribution of biochar throughout the County. The goal of this optimization model is to reduce the amount of transportation that would be required to carry out the preferred alternative.

The optimization technique used was a genetic algorithm which uses information about a system to determine the optimal string of decisions that will lead to a maximum or minimum objective function value. For the context of this project, the objective is minimizing the travel distance from any major Humboldt County city to a gasification facility and the distribution network facility. The string of decisions denotes different travel paths that might be taken from any city to any facility. The results from the optimization model are the cities chosen to place the gasification facilities and distribution network, and the maximum travel distance that is expected to go from any city to the closest facility site. The eight Humboldt County cities evaluated in this optimization model included Garberville, Rio Dell, Fortuna, Ferndale, Eureka, Arcata, McKinleyville, and Trinidad.

This optimization model assumed travel solely along US Route 101, and that there would be a total placement of two gasification units per city for three out of the eight cities, and one distribution network in one of the cities. The current grid transmission infrastructure throughout the County is assumed to be adequate to serve the generated energy to customers. This assumption was based on examining how existing powerplants interconnect to the grid, and comparing it to the generation capacity of the preferred alternative (CEC 2020b). A depiction of the current grid infrastructure in Humboldt County with respect to the optimized gasification facility locations is depicted in Figure

59 of Appendix F. The distances between each city was determined using Google Maps' directions utility; this is the same utility used to previously determine the distance from Piercy to Crescent City (Google Maps 2020a).

The solution to the optimization model and the cities that were chosen to have gasification facilities were McKinleyville, Garberville, and Fortuna. The model was executed a second time to find the optimal place to put the distribution network facility, and discovered that Rio Dell would be the optimum location. The placement of the gasification units in these cities translates to a maximum travel distance of 13.5 miles from any one given city to a gasification facility. The placement of the distribution network translates to a maximum travel distance of 48.4 miles from any one given city to the distribution network facility. The optimization matrix used for this analysis is depicted in Figure 57 and Figure 58 of Appendix F. A map of the optimized gasification sites and distribution network facility is depicted below in Figure 21.

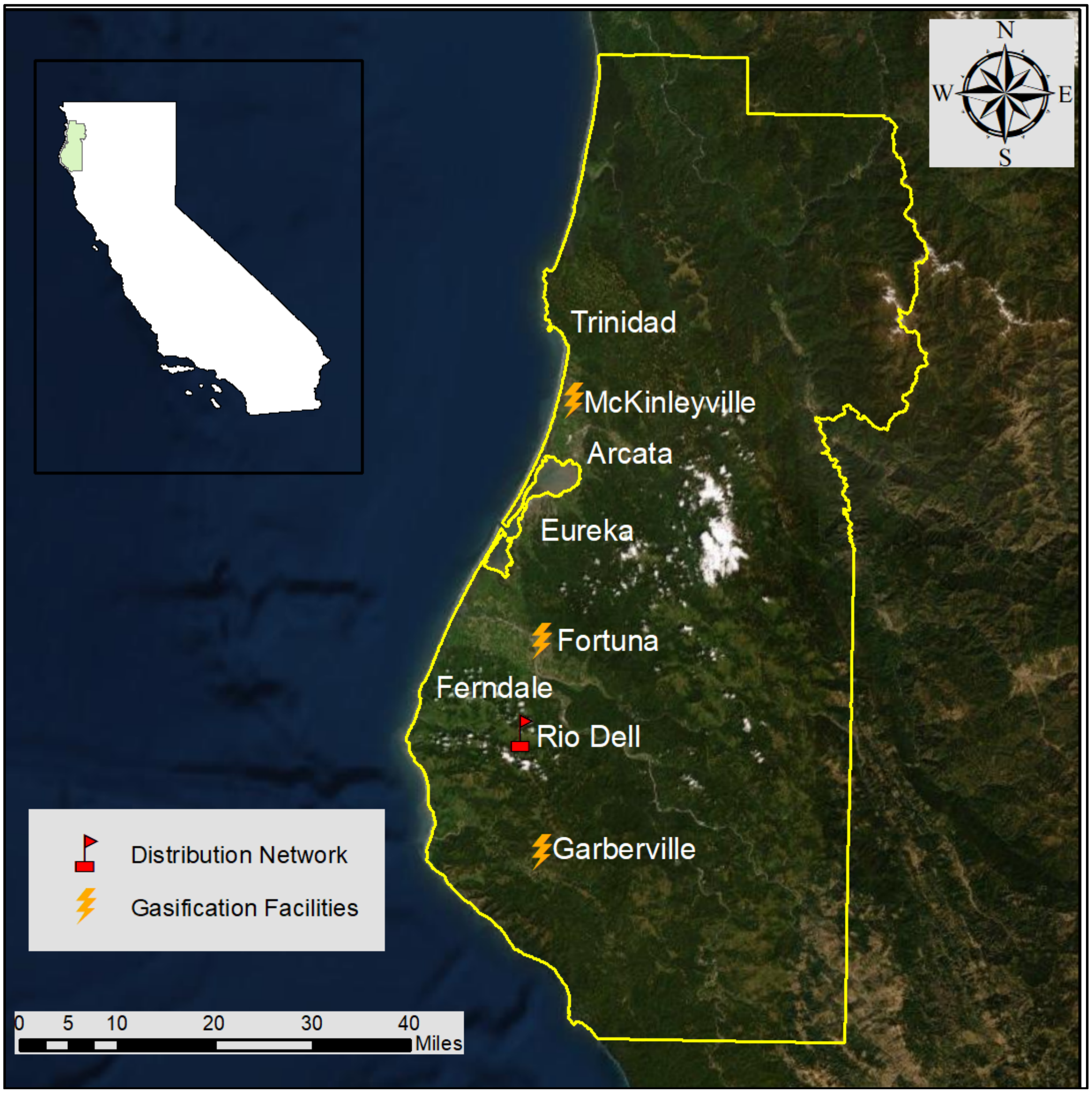

Figure 21: Results of facility location optimization model (Adapted from: Humboldt GIS 2020*)*.

5.4 Proposed Facility Locations

The proposed locations for the gasification facilities and distribution network center were selected by applying a combination of Structured Query Language statements in the ArcMap geospatial analysis software tool. The main shapefile used for the analysis was the parcel shapefile provided by the Humboldt County GIS Data Download home page. The shapefile contains a compilation of parcels and their corresponding attributes such as a description of the assigned land use category, land area, parcel number, and vacancy.

To identify parcels that could serve as potential sites for the Gasification facilities in McKinleyville, Fortuna, and Garberville a 5-mile buffer was applied to each city. The parcels within each buffer were then isolated. The parcels were then analyzed for potential sites by applying SQL statements in the attributes table. Parcel descriptions categorized as “Vacant”, “Industrial”, “Industrial-Heavy”, or “Industrial-Vacant”, and met a land area of greater than or equal to 10 acres was applied to isolate the potential gasification facilities in each proposed city. A compilation of the proposed parcels in McKinleyville, Fortuna, and Garberville can be viewed in Appendix H.

The same buffer and clip method were applied for proposed site locations for the Distribution Network in Rio Dell. The parcel description used to isolate potential sites included “Rural-Vacant” and “Vacant Agricultural” with a land area greater than or equal to 50 acres. A map of proposed site locations for the Distribution Network can also be found in Appendix H.

5.5 Sensitivity Analysis

This section of the document describes the sensitivity analyses performed. The goal of this analysis was to examine how variations in the project parameters would affect the final economic and environmental analysis. Specifically, the effects on simple payback period, total capital cost, annual cashflow, and total NAAQS pollutant emissions were analyzed. The parameter variations considered included the electricity produced by gasification and the electricity selling price. These are important variations to consider because local energy demand and energy pricing may change in future years.

The electricity production by the preferred alternative was varied for multiple reasons. Over the next couple decades there will most likely be a shift towards renewable and local energy sources in the County which may warrant an expansion of the gasification facilities in Humboldt County. Also, population or industry changes could affect total electricity demand in the County in general. General county and state plans with energy goals could also influence electricity prices in years to come. The expected swap to all local renewable energy sources in the next decade could also have a significant impact on electricity pricing.

The total energy demand in Humboldt County was altered by plus and minus 15 percent, and plus and minus 30 percent. The electricity selling price was altered by plus and minus 5%, 10%, and 15%. The base case for energy demand was 176 GWh, and the base case for electricity selling price was $0.156 per KWh. The results of the sensitivity analyses are presented in Figure 22.

When increasing the energy demand, capital cost went continuously up, whereas NAAQS pollutants emitted dropped. The reason NAAQS pollutants dropped is because less biomass needed to go to the distribution network center, which was originally contributing to quite a bit of the emissions in the base case. The NAAQS emissions begin to go back up at plus 15% because the distribution network is essentially not being utilized anymore, and an increased number of gasification plants is causing more annual emissions.

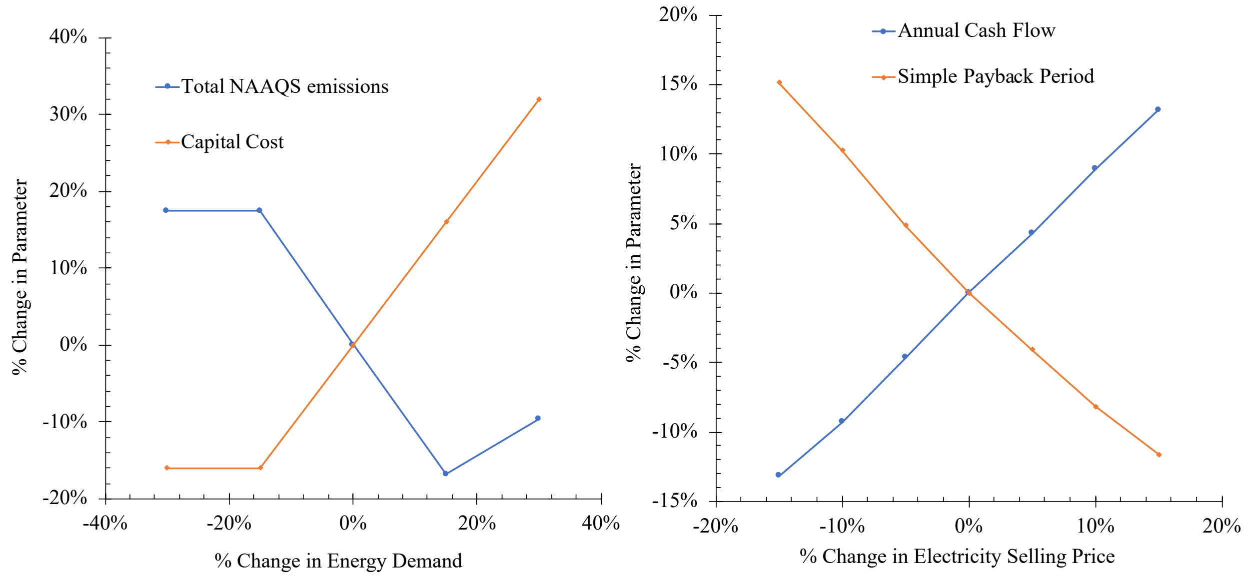

Figure 22: Sensitivity analysis results for change in total energy demand and electricity selling price.

Decreasing energy demand causes capital cost and NAAQS pollutants to go down and then remain constant. The reason the values remain constant at minus 15% energy demand is because the same number of gasification plants are needed to for minus 15% as minus 10%, and the same amount of biomass is going to the distribution network center annually.

When increasing electricity selling price from the base case, the annual cashflow increases and simple payback period decreases. The reason this is happening is because more money is being made from the consumer to help pay down the initial capital cost for the project. Decreasing electricity selling has an inverse affect, with annual cash flow decreasing and simple payback period increasing.

5.6 Advantages and Disadvantages of Preferred Alternative

This section describes the key advantages and disadvantages of implementing the preferred alternative. These advantages and disadvantages are depicted in Table 32 below. Some important advantages are low NAAQS pollutant emissions and the ability of this alternative to help RCEA and Humboldt County reach local renewable energy goals. Due to this, there is likely grant money available to help this project come to fruition. The dispersion of the gasification facilities will also help with grid resilience in Humboldt County. Future projects could possibly adapt one of the gasification plants into a microgrid. The distribution network brings in many benefits for the local community. The approximate 150-acre community garden would be a unique attraction that most communities in California do not have. Some disadvantages to the preferred alternative are large capital costs greater than 105 million dollars and a decentralized system. Grant money and loans will likely help with the large capital costs. With four total sites, the preferred alternative may have issues with management and organization. It is easier to manage one facility rather than multiple spread out by a significant distance. Another consideration is that there is relatively low local demand for non-combustive uses of the wood waste and for biochar. Both markets could benefit greatly from consumer education on how these materials can be utilized for agriculture, gardening, erosion control, etc. The community garden has the potential to showcase and participate in such consumer education with the available space and resources. The last disadvantage of this alternative is public perception of the gasification facilities. Condensation from smokestacks and the presence of multiple factory-like facilities in the community may upset some community members.

Table 32: The advantages and disadvantages for the preferred alternative.

Advantages	Disadvantages
Better balance of social, economic, and environmental criteria	Low demand for non-combustive uses of material and biochar
Low NAAQS pollutant emissions	Large capital costs
Helps meet RCEA 2030 goal for local renewable energy sources	Decentralized
Community benefits	Public perception

5.7 Limitations

This section discusses the limitations in our study, and considerations for the implementation of the preferred alternative. The preferred alternative is heavily dependent on having a reliable stream of waste woody biomass for proper operation. Although, excess biomass can be stored and distributed in the distribution network, and the community garden can still act as a community benefit if no biomass is coming in. If this stream of material is interrupted or reduced, it would mean that the distribution network would receive less biomass material and could potentially mean that the gasification facility would need to scale back its energy generation. Due to the high capital costs, reaching upward of $100 million, this investment should be backed with reliable contracts between local sawmills and facility operators. Other limitations of this study include how variations in the incoming biomass material would impact the preferred alternative. The preferred alternative analysis did not consider how changes in composition, moisture, and quantity would affect the performance of the solution with respect to the social, economic, and environmental criteria.

6. Recommendation

The recommended alternative use of waste woody biomass in Humboldt County is to utilize a distribution network with six modular gasification units. The distribution network will act to provide community education, a source of biomass for non-combustive uses, and supply biomass equalization within the County rather than sending biomass to a landfill. The gasification facilities will help to offset 80% of electricity generated by the two existing combustion biomass powerplants, HRC Scotia and DG Fairhaven, which may be taken offline in the near future. The gasification facilities also produce less comparative emissions and help RCEA to meet their 2030 goal of fully renewable.

Future analyses should include finding specific locations for the distribution network and gasification facilities, as well as looking more into seeing if grant funding could be available to help fund this project. It is highly recommended that the client investigate the potential for the gasification facilities to be funded through State grant money since gasification makes up a majority of the capital cost, and is considered a renewable energy resource in California (CEC 2020a). It is also recommended that the client investigate a potential partnership for incoming biomass sources and evaluate the seasonal variations in biomass quantity and composition.

Appendices

Appendix A – Biomass Densification Facility Quantitative Criteria Analysis

This appendix provides example calculations performed for the Biomass Densification Facility alternative (Figure 23 - Figure **29**). The figures below are results for the social, economic, and environmental criteria quantifications.

Aesthetics		Reference
Total Area of Facility (ft^2)	560,000	2
Total Area devoted to Structures (ft2)	125,000	1
Holding Area (ft^2)	435,000	
Height of Structures (ft)	30	
Volume of Structures (ft^3)	3750000	
Working Assumptions		

The total area of the facility is based on the current area occupied by the sawdust at DG Fairhaven and an additional 125, 000 square feet. This value comes from a wood product manufacturer facility which implemented briquetting machines (Reference 1).

References

1. "Walnut Creek Cast Study | Briquetting Case Studies | Briquette Machines | RUF Briquetting Systems." (2020). RUF Briquetting Systems, <https://www.ruf-briquetter.com/news/case-studies> (Mar. 14, 2020).

2. "Google Maps." (2020). Google Maps, Google, <https://www.google.com/maps/@40.8701928,-124.0900619,14z> (Mar. 14, 2020).

Figure 23: Sample calculations for alternative aesthetics.

Community Support (Case 1)		Reference
Number of Participants	66	1
Number of People who Approve	45	1
Number of People who Disapprove	21	1
Percentage of People who Approve	68	1
Perentage of People who Disapprove	32	1

Community Support (Case 2)		Reference
Percentage of People who Approve	71	2
Percentage who Disapprove	29	2

Average Support %	**69.6**

References
1. Omwenga, S. C. (2018). "An Evaluation of Renewable Energy Adoption in Kenya. A Case Study of Biomass Briquette Production and its use in Study of of Biomass Briquette Production and its use in Industrial Boiler Operations." University of Nairobi, Kenya. (Accessed Mar. 23 2020)

2. Plate, R. R., Monroe, M. C., and Oxarart, A. (2010). "Public Perceptions of Using Woody Biomass as a Renewable Energy Source." Journal of Extension, Volume 48(Issue #3), 15. (Accessed Mar. 23 2020)

Figure 24: Calculations for community support of a woody biomass densification facility.

Payback Period (Years)	**1.13**	Reference
Initial Cost of Facility (Year 1)	29387200	
Buildings	28125000	1
Briquette Machine (30)	412,500	2
Dryer (2)	550,000	3
Screw Conveyors (30)	$299,700	4
Average Cost of Briquettes per Mass ($/ton)	$160.00	2
Average Number of Briquettes Sold Per Year (US TONS)	247619.20	
Average Annual Salary of Employees ($/year)	80,000	5
Average Number of Employees	115	2
Average Annual Operation and Maintenance Cost ($/year)	4524387.833	5
Maintenance and Repair ($/year)	2938720	
Electricity ($/year)	1524115.24	11
Water ($/year)	61552.59259	6
Equipment Prices		
RUF Briquetting Machine (1)	$13,750	2
Flexible Screw Conveyor (1)	$9,990	4
Norris Thermal Systems Dryer (1)	$225,000	3
Briquette Pricing		
Mass per pallet (lbs)	2000.00	7
Packs per pallet	88.00	7
Mass per pack (lbs)	22.73	
Price for 1 pack of 12 logs	6.99	8
Price per Ton of Briquettes ($/Ton)	615.12	
Mass per Pack (lbs)	20.00	9
Price per Pack of Briquettes	6.29	9
Lbs to Tons	2000.00	
Price per Ton of Briquettes ($/Ton)	629.00	
Price per Back of Briquettes	9.98	10
Mass per pack (lbs)	30.00	10
Price per Ton of Briquettes ($/Ton)	665.33	
Average Retail Price ($/US TON)	636.5	
Alternate Payback Period (Years)	0.20	
Electricity Costs		
Briquetter Power Rating (hp)	125	12
Hours of Operation per Day	8	
Horsepower to MW	0.0007457	
Megawatt Hours per day for 27 Operational Machines	20.13	
Megawatt Hours per year	7348.87	
Megawatt Hours to kilowatt Hours	1000	
Cost per kilowatt hour ($)	0.1648	11
Electricity Costs per Year ($)	1211094.35	
Dryer Requirements		
Energy Rating (Wh/MJ)	0.47	
MJ Energy	4041273600	
Energy (kWh)	1899398.59	
Electricity Cost per Year ($/Year)	313020.89	

-Construction cost per square foot in San Francisco (1)
-Personal Communication with Sales person at Ruf Briquetting Systems (2)
-30 briquetting machines, 2 employees each (2)
-2 Dryers, 2 employees each (3)
-30 Screw Conveyors for each Machine
-Average wholesale cost of finished briquettes (2)
-10% of capital costs for maitenance

References

1. Garcia, C. (Accessed 2020). "U.S. Construction Costs Per Square Foot | Cumming Insights - Construction Market Analysis." Cumming Insights. (March 13, 2020)
2. dan@ruf-briquetter.com, Dan, Sales at Ruf Briquetting Systems, Personal Communication Mar. 13, 2020, (Interviewer Kevin Isacsson March 13 2020).
3. Norris, Aaron. (Personal Communication March 13, 2020), "Norris Thermal Technologies.". Norris Thermal Technologies, <https://www.norristhermal.com> (Mar 13, 2020).
4. "Flexible Screw Conveyors - Move Virtually Any Bulk Material - Flexicon Corporation." (Accessed 2020). <https://www.flexicon.com/Bulk-Handling-Equipment-and-Systems/Flexible-Screw-Conveyors/index.html> (Mar. 13, 2020).
5. Sahoo, K., Bilek, E., Bergman, R., and Mani, S. (2019). "Techno-economic analysis of producing solid biofuels and biochar from forest residues using portable systems." Applied Energy, 235, 578–590. (Mar. 13, 2020)
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7. "American Wood Fibers 6-Pk Fuel Bricks." (Accessed 2020). <https://www.truevalue.com/american-wood-fibers-6-pk-fuel-bricks> (Apr. 5, 2020).
8. "BIO BLOCK Fire Log 12 pk - Ace Hardware." (Accessed 2020). <https://www.acehardware.com/departments/heating-and-cooling/fireplaces/fireplace-logs/4593307?x429=true&gclid=EAIaIQobChMIpoan5PXR6AIVARgMCh2RRQOtEAQYASABEgJspfD_BwE&gclsrc=aw.ds> (Apr. 5, 2020).
9. "Compressed Wood Fire Logs 12 Pack - BIO BLOCK Firewood." (Accessed 2020). *BIO BLOCKS*, <https://bio-blocks.com/bio-block-products-compressed-blocks-fire-starters-kindling-fire-pits/compressed-wood-fire-logs-12-pack-of-bio-block/> (Apr. 5, 2020).
10. "EZ BURN 30 lb. Fire Log - Lowe's". (Accessed 2020). https://www.lowes.com/pd/30-lb-Fire-Log/1000107725. (Apr. 5 2020)
11. EIA (2019). "State Electricity Profile." <https://www.eia.gov/electricity/state/california/> (Accessed April 5th, 2020). U.S. Energy Information Administration.
12. RUF Briquetting Systems. (Accessed 2020). <https://www.ruf-briquetter.com/news/case-studies> (Mar. 14, 2020).

Figure 25: Sample calculations for payback period for woody biomass densification facility.

Employment Opportunities		Reference
Dryer (2)	4	2
Briquette Machine Operators	27	1
Raw and Finished Product Handlers	27	1
Management	1	
Truck Drivers	56	
Total Created Jobs	94	
Total Preserved Jobs	21	
Total Indirect Jobs (Truck Drivers)	56	
Total Estimated Job Opportunties	115	

Assumptions
-Truck Drivers were based on
-Only one manager needed for entire facility.
-One dryer requires at most two people to operate (2).
-each briquetter requires at most two employees at all time (1).

References
1. dan@ruf-briquetter.com, Dan, Sales at Ruf Briquetting Systems, (Personal Communication Mar. 13, 2020)
2. Norris, Aaron. (Personal Communication March 13, 2020), "Norris Thermal Technologies.". Norris Thermal Technologies, <https://www.norristhermal.com> (Mar

Figure 26: Employment generation calculations for woody biomass densification facility.

Project Implementation Time		
Maximum Project Implementation Time (Years)	7.01	
Time to reach full production (Years)	0.003	2
Training (Years)	0.01	2
Prior to Permitting (Years)	2	1
Prior to Construction (Years)	4	1
Prior to Discharge (Years)	0.67	1
Prior to Operation (Years)	0.33	1
Average Time to Permitting	3.5	

Assumptions
-Maximum project implementation time is based on the maximum time it takes each part of the permitting process to be completed.
- Operations can being the day after all equipment has been set up and employees are trained.

References
1. West Biofuels (2020). "Major Permits." West Biofuels, LLC, <http://www.westbiofuels.com/> (Accessed March 12th, 2020).
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Figure 27: Calculations for woody biomass densification facility project implementation time.

Environmental Criteria				
Amount of NAAQS Pollutants Emmited per Year				
Transportation to Facility with Heavy Truck				
Travel from Sawmill to Facility (total miles/day)	825	Scotia to DG Fairhaven (33 miles)		Reference
Travel from Sawmil to Facility (total km/day)	1327.71			5
Pollutant	Emission Rate	Mass of Pollutants (g)	Mass of Pollutants (kg/year)	-
CO2 (g/km)	473	628004.702	229221.716	2
Nox (g/km)	5.73	7607.753	2776.830	2
HC (g/km)	0.97	1287.874	470.074	2
CO (g/km)	2.45	3252.878	1187.301	2
Particles (g/km)	0.34	451.420	164.768	2
Sox (g/km)	0.08	106.216	38.769	2
Total (kg/year)			233859.5	
Transportation of Final Product with Heavy Truck				
Total Extent of Truck Travel (Total miles/day)	8223	Facility to Regional Markets (see assumptions)		Reference
Total Extent of Total Truck Travel (km/day)	13233.60			5
Pollutant	Emission Rate	Mass of Pollutants (g)	Mass of Pollutants (kg/year)	-
CO2	473	6259494.13	2284715.36	2
Nox	5.73	75828.54	27677.42	2
HC	0.97	12836.59	4685.36	2
CO	2.45	32422.33	11834.15	2
Particles	0.34	4499.42	1642.29	2
Sox	0.08	1058.69	386.42	2
Total (kg/year)			2330941.0	
Final Use				
Metric Tons of Briquettes (80% Utilization)	224640			
Kg of Briquettes	224640000	Combustion Efficiency		Reference
Energy Density MJ/kg	17.99	0.8		1
Energy (MJ)	4041273600	3233018880	Total (kg)	-
CO (mg/MJ)	150	4.84953E+11	484952.83	2,3
Nox (mg/MJ)	100	3.23302E+11	323301.89	2,3
SO2 (mg/MJ)	11	35563207680	35563.21	2,3
CH4 (mg/MJ)	3	9699056640	9699.06	2,3
N20 (mg/MJ)	0.6	1939811328	1939.81	2,3
PM (mg/MJ)	31	1.00224E+11	100223.59	2,3
Total Emissions (kg)		955680.38	955680.38	
Total Emissions (kg/Year)		937107845.70		
Conversion Factor (KG to Metric Tons)		0.001		
Total Emission (Metric Tons/Year)		937107.85		
Conversion Factor (Kg to US TONS)	0.00110231			
Electricity Generation for Production				
Briquetter Power Rating (hp)	125.00			12
Hours of Operation	8.00			
Horsepower to MW	0.00075			
Megawatt Hours per day for 27 Operational Machines	20.13			
Megawatt Hours per year (MWh/year)	7348.87			
Sulfur dioxide (lbs/MWh)	0.00			4
Nitrogen oxide (lbs/MWh)	0.80			4
Carbon dioxide (lbs/MWh)	491.00			4
SO2 (lbs/year)	0.00	US Tons/Year	0.00	
NO (lbs/year)	5879.10	US Tons/Year	2.94	
CO (lbs/year)	3608296.89	US Tons/Year	1804.15	
Dryer Requirements				
Energy Rating (Wh/MJ)	0.47			1
MJ Energy (Wet Biomass)	8082709110			
Energy (MWh/year)	3798.87			
Sulfur dioxide (lbs/MWh)	0E+00			4
Nitrogen oxide (lbs/MWh)	0.8			4
Carbon dioxide (lbs/MWh)	491			4
SO2 (lbs/year)	0.00	US Tons/Year	0	
NO (lbs/year)	3039.10	US Tons/Year	1.52	
CO (lbs/year)	1865246.78	US Tons/Year	932.62	

VOC Emissions from Dryer		Reference
VOC Emissions (mg/MJ)	11.43	1
Total VOC Emissions (mg)	46191757248	
Total VOC Emissions (kg)	46191.76	
Total VOC Emissions (MT)	23.10	
Total VOC Emissions (US TONS/year)	9273.00	

Total		Total	
CO (kg/year)	2998889.9	**CO (US TONS/year)**	**6042.5**
Nox (kg/year)	353756.1	**Nox (US TONS/year)**	**394.4**
SO2 (kg/year)	40718.6	**SOx (US TONS/year)**	**44.9**
CH4 (kg/year)	22720.5	**CH4 (US TONS/year)**	**25.0**
N20 (kg/year)	3746.9	**N20 (US TONS/year)**	**4.1**
PM (kg/year)	100648.8	**PM (US TONS/year)**	**110.9**
		Total (US TONS/year)	**6592.7**

Assumptions
- 80% Utilization of Woody Biomass
-All briquettes are sold and combusted for commercial and industrial heating in one year
-One truckload of raw and finished material is transported to and from the facility eevery day
-80% Combustion Efficiency of briquettes
-8-Hour 365 Day Operation
-Briquettes have energy density of 17.99 MJ/kg
- 25 metric tons per truckload
-25 truckloads per day to facility
-28 truckloads pf woody biomass a day to facility
-8 truckloads per day to San Francisco CA and Portland OR for 25% utilization at each location
-6 truckloads per day to Sacramento CA and Reno NV for 20% utilization at each location
-3 truckloads per day throughout Humboldt County for 10% utilization at each location
-27 screws and briquetters operational at all time, 3 for redundency location

Reference
1. Alanya-Rosenbaum, S., Bergman, R. D., Ganguly, I., and Pierobon, F. (2018). "A Comparative Life-Cycle Assessment of Briquetting Logging Residues and Lumber Manufacturing Coproducts in Western United States." Applied Engineering in Agriculture, 34(1), 11–24. (Mar. 13, 2020)
2. SEI. (2010). Greenhouse gas an air pollutant emissions of alternatives of woody biomass residues, Stockhom Environmental Institute.
3. Eriksson, E., Blinge, M., Lövgren, G. (1996). "Life Cycle Assessment of the Road Tran sport Sector." The Science of the Total Environment, 189, 69-76.
4. EIA (2019). "State Electricity Profile." <https://www.eia.gov/electricity/state/california/> (Accessed April 5th, 2020). U.S. Energy Information Administration.
5. "Google Maps." (2020). Google Maps, Google, <https://www.google.com/maps/@40.8701928,-124.0900619,14z> (Mar. 14, 2020).

Figure 28: NAAQS Pollutant calculations for woody biomass densification facility.

Transportation GHG Emissions			
Transportation of Final Product with Heavy Truck			
Average Extent of Truck Travel (Total miles/day)	8223	Facility to Regional Markets (see assumptions) (4.)	
Average Extent of Total Truck Travel (km/day)	13233.60		
Pollutant	Emission Rate (g/km)	Mass of Pollutants (g)	Mass of Pollutants (kg/year)
CO2	473	6259494.13	2284715.36
Transport of Woody Biomass to Facility			
Travel from Sawmill to Facility (total miles/day)	825	Scotia to DG Fairhaven (33 miles) (4.)	
Travel from Sawmil to Facility (total km/day)	1327.71		
Pollutant	Emission Rate (g/km)	Mass of Pollutants (g)	Mass of Pollutants (kg/year)
CO2	473	628004.7015	229221.72
Processing			
Reference	Kg of Briquettes	Given:	
	224640000	Briquette Production	Kg CO2 eq
3	Energy Density MJ/kg	0.8% kg CO2 eq/ MJ Heat	25864151.04
3	17.99	Sawdust Drying	Kg CO2 eq
3	Combustion Efficiency	69.5% kg CO2 eq/MJ Heat	4493986265
3	0.8	Total kg CO2 eq/year	4519850416
Final Use			
Reference		Given:	
	Metric Tons of Briquettes	224640	
3	Kg of Briquettes	224640000	Combustion Efficiency
3	Energy Density MJ/kg	17.99	0.8
	Energy (MJ)	4041273600	3233018880
3	1.0% kg CO2 eq./MJ Heat		
	Total kg CO2 eq/yr	32330188.8	

Assumptions:
- Combustion of sawdust is averted pre-briquetting
- One truckload of raw and finished material is transported to and from the facility eevery day
- 80% combustion efficiency of briquettes
-0.8 kg CO2 eq/MJ Heat produced for briquetting machine operation
-69.5% kg CO2 eq/MJ Heat produced for drying process
-1% kg CO2 eq/MJ Heat produced during combustion.

Initial Transportation	
Transportation Emissions (MT CO_2/yr)	**2514**
Sequestered Carbon (MT CO_2/yr)	**0**
Briquetting and Final Use	
Transportation Emissions (MT CO_2/yr)	**2514**
Operational Emissions (MT CO2/yr)	**4519850**
End Use (Combustion) (MT CO2/yr)	**32330.2**
Total Generated Emissions (MT CO_2/yr)	**4554695**
Sequestered Carbon Emissions (MT CO_2/yr)	**0**
Net GHG Emissions (US tons CO_2/yr)	**5010164.0**
Net GHG Emissions over 20 years (US tons CO_2)	**100203279.9**
US TONS TO METRIC TONS	1.1
METRIC TONS TO KG	0.001

References
1. SEI. (2010). Greenhouse gas an air pollutant emissions of alternatives of woody biomass residues, Stockhom Environmental Institute.
2. Eriksson, E., Blinge, M., Lövgren, G. (1996). "Life Cycle Assessment of the Road Transport Sector." The Science of the Total Environment, 189, 69-76.
3. Alanya-Rosenbaum, S., Bergman, R. D., Ganguly, I., and Pierobon, F. (2018). "A Comparative Life-Cycle Assessment of Briquetting Logging Residues and Lumber Manufacturing Coproducts in Western United .States." Applied Engineering in Agriculture, 34(1), 11–24. (Mar. 13, 2020) .
4. 5. "Google Maps." (2020). Google Maps, Google, <https://www.google.com/maps/@40.8701928,-124.0900619,14z> (Mar. 14, 2020).

Figure 29*:* Calculations for carbon sequestered or emitted during 20-year period of densification operations.

Appendix B – Particleboard Facility Quantitative Criteria Analysis

Spreadsheet calculations conducted for each criterion when analyzing the Particleboard Facility alternative can be viewed in Figure 30 - Figure 44. All these quantified values were determined by assuming 80% utilization of the 561,000 metric tons of incoming biomass, which retains a moisture content of 50% and density of 247 kg/m^3.

Summary Table	
Capital	**($)**
Facility Capital	$225,191,746
Operation Expense	**Cost($/yr)**
Power/Fuel	$8,269,932
Labor/Mgmt	$20,648,441
Glue/Wax	$15,358,781
Other	$10,035,107
Wood (assumed free)	$0
Profit	**Value ($/yr)**
Wholesale Price (Profit)	$74,032,959
Payback Period (Years)	**11.4**

Figure 30: The payback period cost breakdown for the Particleboard Facility alternative.

Arauco Grayling Particleboard Facility		
Grayling Physical Size (ft2)	Facility sqft per capacity (ft2/ft3)	
820,000	0.031238095	
Grayling Capacity (ft3)		
26250000		
Alternative Plant Size		
Alternative Capacity (ft3/yr)		
11728736.77		
Alternative sqft	Assumed Height (ft)	**Alternative Volume (ft3)**
366383.3962	22	8,060,435

Sources:

Arauco (2020). Grayling. < https://www.arauco.cl/na/este_es_arauco/grayling-project/> (Accessed Mar. 13th, 2020).

Assumptions:

- Approx. 11.7 million cubic ft of particle board is produced annually
- Average Facility Height is about two stories or 22 ft

Figure 31: The computations, sources, and assumptions for the footprint criterion of the Particleboard Facility alternative.

Support of Manufactured housing		
	86.7 %	unsafe
	13.3 %	Safe
Preference to use Wood for Particle board by experts		
Waste Type	% support	
Sawdust	11	
Wood Chips	10	
Bark	5	
Total PB support	8.666666667	

Total Support Estimated
10.98333333
Public Support Estimate
11%

Sources:

(Public Safty Opinion on Particle board housing)
Grosskopf, K. R., and Cutlip, D. (2006). "SAFETY, SUSTAINABILITY AND PUBLIC PERCEPTION OF MANUFACTURED HOUSING IN HOT, HUMID CLIMATES." 15.

(Expert Support)
Kunttu, J., Hurmekoski, E., Heräjärvi, H., Hujala, T., and Leskinen, P. (2020). "Preferable utilisation patterns of wood product industries' by-products in Finland." Forest Policy and Economics, 110, 101946.

Assumptions:

*Public saftey opions and expert biomass usage opinions is similar to the public opinion in Humboldt County

Figure 32: The computations, sources, and assumptions for the community support criterion of the Particleboard Facility alternative.

Initial Cost Projection ($/ft3)								
index	Year	Power/Fuel	Labor/Mgmt	Glue/Wax	Other	Wood	Variable	Price (Value of Product)
1	1962	0.064	0.288	0.192	0.16	0.224	0.928	1.664
2	1963	0.064	0.288	0.192	0.16	0.224	0.928	1.664
3	1964	0.064	0.288	0.192	0.16	0.224	0.928	1.664
4	1965	0.064	0.288	0.192	0.16	0.224	0.928	1.824
5	1966	0.064	0.288	0.192	0.16	0.256	0.928	1.632
6	1967	0.064	0.288	0.192	0.16	0.224	0.928	1.472
7	1968	0.064	0.32	0.192	0.16	0.256	0.96	1.664
8	1969	0.064	0.32	0.192	0.16	0.224	0.96	1.984
9	1970	0.064	0.352	0.224	0.16	0.224	0.992	1.536
10	1971	0.064	0.352	0.224	0.16	0.224	1.024	1.44
11	1972	0.064	0.384	0.256	0.16	0.224	1.12	1.536
12	1973	0.064	0.416	0.352	0.192	0.256	1.312	1.824
13	1974	0.096	0.448	0.512	0.224	0.288	1.568	1.856
14	1975	0.128	0.448	0.608	0.256	0.288	1.728	1.728
15	1976	0.128	0.512	0.512	0.256	0.32	1.728	1.856
16	1977	0.16	0.544	0.448	0.256	0.352	1.728	2.176
17	1978	0.192	0.608	0.48	0.288	0.384	1.952	3.52
18	1979	0.192	0.64	0.544	0.32	0.512	2.24	2.72
19	1980	0.256	0.704	0.608	0.384	0.544	2.496	2.88
20	1981	0.32	0.768	0.608	0.416	0.672	2.752	3.008
21	1982	0.352	0.832	0.608	0.448	0.704	2.944	3.136
22	1983	0.352	0.864	0.64	0.448	0.64	2.976	3.232
23	1984	0.352	0.864	0.672	0.448	0.704	3.04	3.488
24	1985	0.352	0.864	0.64	0.448	0.608	2.944	3.264
25	1986	0.32	0.896	0.608	0.416	0.608	2.848	3.424
26	1987	0.288	0.896	0.576	0.416	0.64	2.848	3.616
27	1988	0.288	0.896	0.672	0.448	0.64	2.944	3.584
28	1989	0.352	0.928	0.672	0.448	0.672	3.008	3.68
29	1990	0.352	0.928	0.64	0.448	0.672	3.008	3.456
30	1991	0.288	0.928	0.64	0.448	0.736	3.04	3.424
31	1992	0.32	0.928	0.672	0.448	0.768	3.136	3.648
32	1993	0.32	0.96	0.736	0.48	0.8	3.264	4.32

index key for Regression Eqns	
index	corresponding year
32	1993
33	1994
34	1995
35	1996
36	1997
37	1998
38	1999
39	2000
40	2001
41	2002
42	2003
43	2004
44	2005
45	2006
46	2007
47	2008
48	2009
49	2010
50	2011
51	2012
52	2013
53	2014
54	2015
55	2016
56	2017
57	2018
58	2019
59	2020

Figure 33: The data used for the payback period criterion of the Particleboard Facility alternative. The index numbers are to denote the x-values of the regression equations (Spelter 1994).

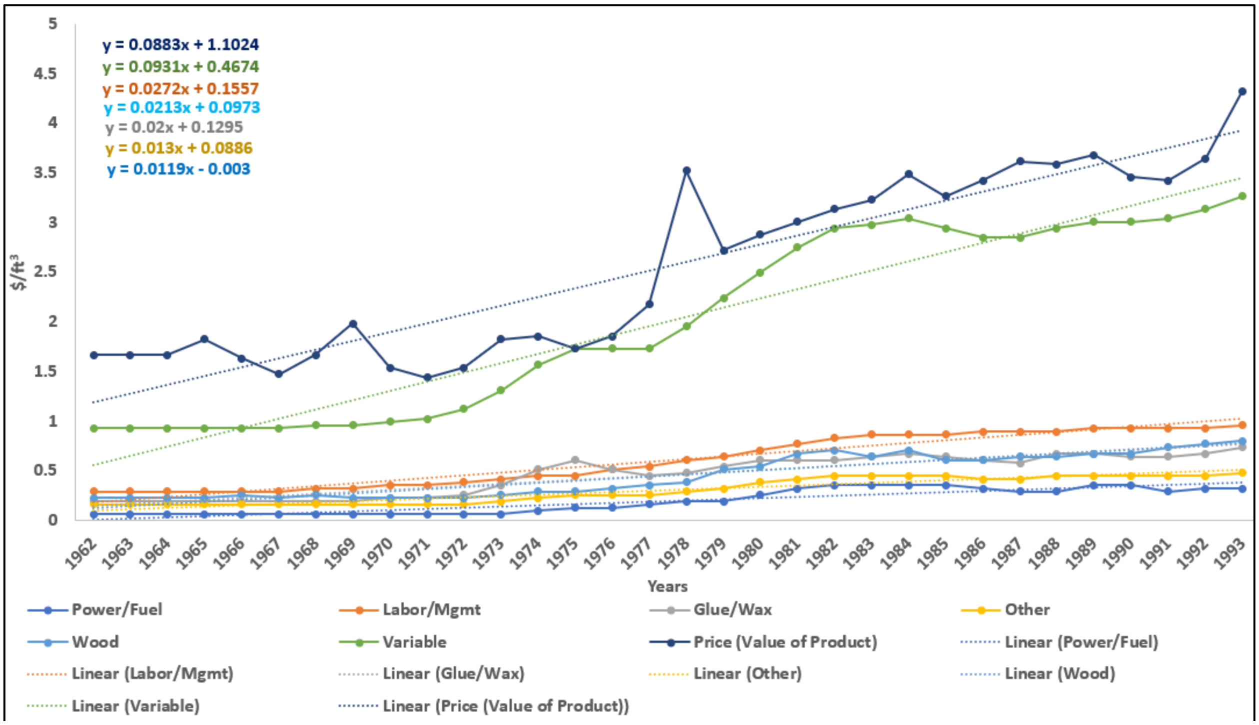

Figure 34: The graphical depiction of changes in expenses and price of particleboard from 1962-1993.

Parameters/Conversions		
(ft2)	thickness (3/8")	ft3
1000	0.03125	31.25
Facility Cost (@3/8") ($/1000ft2)	600	
Facility cost ($/ft3)	19.2	
index :	59	
ft3 produced:	11,728,737	

Cost in Year 2020		
Expense	Cost ($/ft3)	Cost($/yr)/ Value ($/yr)_
Power/Fuel (a)	0.7051	$8,269,932
Labor/Mgmt (b)	1.7605	$20,648,441
Glue/Wax (c)	1.3095	$15,358,781
Other (d)	0.8556	$10,035,107
Wood (assume free) (e)	0	$0
Variable (sum a-e)	5.9603	$69,906,790
Facility cost	19.2	$225,191,746
Value of Product (from data)		
Price (Value)	6.3121	$74,032,959
Price Home Depot	9.98	$117,052,793
Price (AVG)	8.14605	$95,542,876
Wood (n/a expense)	1.354	$15,880,710

Retailer Value 2020		
Average	**Lowes**	**Home Depot**
$/ft3	$/ft3	$/ft3
9.98	9.98	10.48

Cost Breakdown			
Cost	Direct Breakdown	Using Variable Cost	
Capital Req	$225,191,746	$225,191,746	
Annual Profit (Producer Price)	$74,032,959	$74,032,959	
Annual Profit (Home Depot Price	$117,052,793	$117,052,793	
Expenses	$54,312,261	$54,026,080	
Net Profit (Producer Projected)	$19,720,698	$20,006,879	
Net Profit (Retailer)	$62,740,532	$63,026,713	
Avg Profit	$41,230,615	$41,516,796	
Payback Period			
	Direct Brk (Yrs)	**Variable Cost (Yrs)**	**Sales Type**
Producer Profit	11.4	11.3	Producer
Using Retail Sale Price	1.2	1.2	Retailer
Average Profit	2.8	2.8	Bulk Distributor

Figure 35: The computations and final values for the payback period criterion of the Particleboard Facility alternative.

Assumptions:

*Approx. 11.7 million cubic ft of particle board is produced annually

*Projected costs and profit from the data are correct

*Facility sells particleboard at producer prices

*Particle Facility technology has matured and their respective installation costs have remained relatively steady since the mid 1990's

Sources Used:

(Cost/Profit Data Source)
Spelter, H. (1994)." Capacity, production, and manufacturing of woodbased panels in North America." *U.S. Department of Agriculture, Forest Service, Forest Products Laboratory*, Madison, WI, FPL-GTR-82.

(Retail Cost source)
Lowes (2020). Underlayment Particle Board Panel.
<https://www.lowes.com/pd/Underlayment-Particle-Board-Actual-0-375-in-x-4-ft-x-8-ft/1000154061> (Accessed Mar. 13th, 2020).

(Retail Cost source)
Home Depot (2020). Particle Board Panel.
<https://www.homedepot.com/p/Particleboard-Panel-Common-3-8-in-x-4-ft-x-8-ft-Actual-0-369-in-x-48-in-x-96-in-604461/100058485> (Accessed Mar. 13th, 2020).

Figure 36: The sources and assumptions for the payback period criterion of the particleboard facility.

Based on Georgia Pacific	
Jobs at plant A	
200	Jobs
Capacity (3/4") Plant A	
270000000	ft2
16875000	ft3
Jobs at plant B	
310	Jobs
Capacity(3/4") Plant B	
260000000	ft2
16250000	ft3

Arauco Grayling Facility	
Jobs	Amt.
Permenant	200
Support (1-2 per permentant)	300
Construction Jobs	0
Grayling Capacity (3/4")	
420000000	ft2
26250000	ft3

Averaging	
Avg Jobs/Capacity (Job/ft3)	Capacity
1.66588E-05	1E+07
Anticipated Jobs Created	
Job Type	Amt
Facility Jobs	195.39
Construction (atleast 3 year)	0
Total Permentant Jobs	195.39

Sources:

(Plant Capacity US)
US SEC. (2005). Georgia-Pacific Building Products Plants and Mills. <https://www.sec.gov/Archives/edgar/data/41077/000119312505039002/dex991.htm> (Accessed Mar. 13th, 2020).

(Jobs plant A (Gaylord))
Lapastora,C. *(2016).* Georgia Pacific Plant closing: 10 Years Later.*Up North Live.* <https://upnorthlive.com/news/local/georgia-pacific-plant-closing-10-years-later> (Accessed Mar. 13th, 2020).

(Jobs Plant B (Russellville))
BizJournal *(2002).* Georgia-Pacific shuts down several plywood production facilities. <https://www.bizjournals.com/atlanta/stories/2002/11/11/daily38.html> (Accessed Mar. 13th, 2020).

(Grayling Plant Capacity/Jobs)
Arauco (2020). Grayling.
< https://www.arauco.cl/na/este_es_arauco/grayling-project/> (Accessed Mar. 13th, 2020).

Assumptions:

- Approx. 11.7 million cubic ft of particle board is produced annually
- Employment opportunities for a Humboldt County facility are similar to other facilities in the country

Figure 37: The computations, sources, and assumptions for the employment opportunities criterion of the Particleboard Facility alternative.

Grayling Facility Implementation Time
Years of Planning
2.00
Years to build Arauco Grayling
2.00
Grayling Capacity (ft3)
26,250,000.00
Year/Capacity (yr/ft3)
0.00

Alternative Time Estimation
Alternative Capacity (ft3)
11,728,736.77
Years for Alt. construction (yr)
1.79

*Atleast

Sources:

(Construction 2017-2019)
Arauco (2020). Grayling.
< https://www.arauco.cl/na/este_es_arauco/grayling-project/> (Accessed Mar. 13th, 2020).

(Planning 2015-2017)
Johnson, J., Clor, C. (2019). ARAUCO Officially Opens Grayling Particleboard Plant . *9&10 News.* <https://www.9and10news.com/2019/04/17/arauco-officially-opens-grayling-particleboard-plant/>(Accessed Mar. 13th, 2020).

Assumptions:

- Approx. 11.7 million cubic ft of particle board is produced annually
- That the facility implementation of a facility in Humboldt County would be similar to the grayling facility

Figure 38: The computations, sources, and assumptions for the project implementation criteria of the Particleboard Facility alternative

		Conversion/Assump.			
		Finished Annual Prod (m3)	US ton/Metric Ton		
		332120.9971	1.10231		
Onsite Emissions					
	kg/m3	Kg Emitted	Metric Tons	NAAQ Regulated?	US Ton/year
NO (Rivela 2006)	0.12	39854.51965	39.85451965	y	43.93203555
NO2 (Rivela)	0.05	16606.04985	16.60604985	y	18.30501481
CO2 (Rivela)	58.24	19342726.87	19342.72687	n	na
CO (Rivela)	1.31	435078.5062	435.0785062	y	479.5913881
SOx (Wilson 2010)	6.00E-03	1.99E+03	1.99E+00	y	2.20E+00
Methane (Wilson)	0.0017	564.605695	0.564605695	n	na
PM 10 (Wilson)	0.21	69745.40939	69.74540939	y	76.88106222
PM (Wilson)	0.04	13284.83988	13.28483988	n	na
Acetaldehyde (Wilson)	0.00063	209.2362282	0.209236228	n	na
Acrolein (Wilson)	0.000038	12.62059789	0.012620598	n	na
Formaldehyde (Wilson)	0.055	18266.65484	18.26665484	n	na
Methanol (Wilson)	0.025	8303.024927	8.303024927	n	na
Phenols (Wilson)	0.0047	1560.968686	1.560968686	n	na
HAPS (Wilson)	0.079	26237.55877	26.23755877	n	na

Figure 39: The onsite NAAQS emissions from Particleboard Facility alternative.

Pre-Calcs.					
Distance Incoming Distance (Miles)	33	Conversions/Assump.			
Distance Distribution (Miles)	500	km/mile	Trips/Day (incoming/outgoing)		
Fuel consump. (Truck w/ trailer) (mL/km)	451	1.61	50		
Fuel consump. (Truck w/ trailer) (mL/km)	280.1242236		10		
Total Fuel Consump. (ml)	45660.24845				
***Distribution Emissions**					
Emission	g/km	g/mile	g emission/day	kg emission/year	US Ton/Year
CO2	1191	1917.51	12751441.5	4654276.148	5130.45514
NOx	18.98	30.5578	203209.37	74171.42005	81.75989804
HC	1.48	2.3828	15845.62	5783.6513	6.375376665
CO	4.3	6.923	46037.95	16803.85175	18.52305382
PM10	0.55	0.8855	5888.575	2149.329875	2.369227815
SOx	0.21	0.3381	2248.365	820.653225	0.904614256

Figure 40: The distribution NAAQS emissions from Particleboard Facility alternative.

NAAQS Crit. Pollutants Summary	
Pollutant	**US Ton/year**
Nox	144
CO	498
Sox	3.10
PM 10	79
Sum	724

Assumptions:

* Approx. 322,000 m3 of particleboard produced annually

*Distribution demands for the facility 60 truck travelling 163 miles a day. This included 50 trucks to bring incoming feedstock, and 10 trucks to distribute the finished particleboard

*The truck type responsible for distribution is a truck with a trailer

Sources:

Rivela, B., Hospido, A., Moreira, T., and Feijoo, G. (2006). "Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector." The International Journal of Life Cycle Assessment, 11(2), 106–113.

Wilson, J. B. (2010). "LIFE-CYCLE INVENTORY OF PARTICLEBOARD IN TERMS OF RESOURCES, EMISSIONS, ENERGY AND CARBON." WOOD AND FIBER SCIENCE, 42, 17.

(Distribution (Emission))
Eriksson Elin, Blinge Magnus, and Lovgren Goran. (1996). "Life cycle assessment of the road transport sector." The Science of the Total Environment. (1996) 69-76.

USEPA (2016). NAAQS Table. <https://www.epa.gov/criteria-air-pollutants/naaqs-table> (Accessed Mar. 13th, 2020).

Figure 41: The final values, sources, and assumptions for the air quality criteria of the Particleboard Facility alternative.

Operational Emissions					
	kg/m3	Kg Emitted	US Ton/year	GWP 20-year CO2 Equiv	US Ton CO2/year
CO2 (Rivela)	58.24	19342726.87	21321.68126	1	21321.68126
N20	0	0	0	264	0
Methane	0.0017	564.605695	0.622370504	84	52.27912231
Other GHG	0	0	0	N/a	0
				Total CO2 from Operation	21373.96038
Distribution Emissions					
Assume PB facility site is at DG fairhaven			Truckloads required		
Distance To	33		Trips/Day	10	
Avg Distance for Distribution	500	km/mile	Assumed Trips/Day	US ton/Metric Ton	
Fuel consump. (Truck w/ trailer)	451	1.61	50	1.10231	
Fuel consump. (Truck w/ trailer)	280.1242236		10		
Total Fuel Consump. (ml)	9244.099379				
Emission	g/km	g/mile	g emission/day	kg emission/year	US Ton/Year
CO2	1191	1917.51	12751441.5	4654276.148	5130.45514
NOx	18.98	30.5578	203209.37	74171.42005	81.75989804
HC	1.48	2.3828	15845.62	5783.6513	6.375376665
CO	4.3	6.923	46037.95	16803.85175	18.52305382
PM10	0.55	0.8855	5888.575	2149.329875	2.369227815
SOx	0.21	0.3381	2248.365	820.653225	0.904614256

Figure 42: The onsite and distribution GHG emissions from Particleboard Facility alternative.

Decompostion of waste material (Asssume the material will be distributed, used, and landfilled within a 20-year span)			
CO2 from Material Decomposition (kg CO2/bdt of material)	Mois. Cont	Source	
1580	0.5	(Sei 2010)	
Dry Material			
175728.1422	Part. Brd Material (m3)	332120.9971	Assusm
	Density (kg/m3)	640	(Average Moisture Content of Landfill)
US Ton CO2 from decomp.	Moisture Content (%)	0.25	25
306056.8837	Dry Mass (kg)	159418078.6	
	Dry Mass (US Ton/year)	175728.1422	

CO2 Emission Summary (Over 20 year)	
Component	CO2 (ktons)
Facility Operation	21
Distribution	5
Prod. Decomposition	15
Total 20-Year	42

Figure 43: The end of life decomposition GHG for the carbon sequestration criterion of the Particleboard Facility alternative.

Sources:

(Op. Emission Data)
Rivela, B., Hospido, A., Moreira, T., and Feijoo, G. (2006). "Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector." The International Journal of Life Cycle Assessment, 11(2), 106–113.

(Op. Emission Data)
Wilson, J. B. (2010). "LIFE-CYCLE INVENTORY OF PARTICLEBOARD IN TERMS OF RESOURCES, EMISSIONS, ENERGY AND CARBON." WOOD AND FIBER SCIENCE, 42, 17.

(Distribution (Emission))
Eriksson Elin, Blinge Magnus, and Lovgren Goran. (1996). "Life cycle assessment of the road transport sector." The Science of the Total Environment. (1996) 69-76.

(Decomposition (GHG))
SEI. (2010) "Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues." Stockholm Environmental Institute.

(Landfill Moisture)
Eck, C. P. (2020). "Effects of Moisture Content in Solid Waste Landfills." Pgs 45-46. (Thesis)

(CO2 EQUIV)
Pachauri, R. K., Mayer, L., and Intergovernmental Panel on Climate Change (Eds.). (2015). *Climate change 2014: synthesis report*. Intergovernmental Panel on Climate Change, Geneva, Switzerland. Pg 87.

Assumptions:

- Approx. 322,000 m3 of particleboard produced annually
- Distribution demands for the facility 60 truck travelling 163 miles a day. This included 50 trucks to bring incoming feedstock, and 10 trucks to distribute the finished particleboard
- The truck type responsible for distribution is a truck with a trailer
- Spent Particleboard goes to Landfill
- Landill Moisture content = 25%
- particleboard density is 640 kg/m3

Figure 44: The sources and assumptions for the carbon sequestration criteria of the Particleboard Facility alternative.

Appendix C – Distribution Network Quantitative Criteria Analysis

The figures given in this appendix show the Distribution Network calculations used to quantify the criteria considered in this report. This includes Figure 45 - Figure 48.

Aesthetics		
	L (ft)	45
	W (ft)	30
	H (ft) avg.	11
	V (ft cubed)	14850
	# of offices	2
	Total V (ft cubed)	29700

Assumptions:

- Length, width, and height dimensions were calculated looking at existing office plans for a 6 person office

Figure 45: Aesthetics calculation to determine volume of unnatural structure.

Community support All statements are weighted equally and are quoted directly from source (NRPA 2018)

Fraction	Statement
0.91	Parks and Recreation are "Important local government services"
0.78	"Americans indicate they want to increase park and recreatinon funding"
0.85	"Americans support efforts such as the 10-minute walk campaign"

Percent approval = 85

Reference: NRPA (2018). "2018 Americans' Engagement with Parks Report" National Recreation and Park Association.

Figure 46: Calculations used to approximate community support.

PBP				
Capital Cost				Assumptions
Building office	$	1,000,000.00	-	Based off avg. local building costs (2 buildings)
Initial landscaping (irrigation, swales, fencing, signs)	$	500,000.00	-	Initial estimate of cost for essential and basic landscaping
Land (acres)	$	300.00		
Property (Subsidized)	$	3,000,000.00	-	$10,000 per acre avg. cost
Promotion and Consumer Outreach	$	70,000.00	-	1-year salary for early consumer relations and outreach
Permiting and Design	$	500,000.00	-	2-year salary and expected fees/emergency
Equipment (Loading/unloading mechanisms, tractor, etc	$	2,000,000.00	-	Approximation based on on-line cost of equipment from vendors.
Capital Cost	$	7,070,300.00		
Income per year				Assumptions
Cost per cubic yard of biomass		$7.00	-	Low cost estimate due to high supply and low demand
Volume of biomass (yd^3)		9.52E+05	-	Assuming 40% of the material is sold (conservative by 5%)
Total yearly income from sales		$6,661,712.84		
Tours per year		100	-	Assuming 1 tour per week at each facility
Avg. Cost per tour	$	30.00	-	Estimate of tour value
Total yearly income		$6,664,712.84		
Yearly Costs				Assumptions
Average electricity consumption (MWh per year)		88.18	-	See emissions calcs
Avg. Electricity cost ($/kWh)		0.1658		EIA 2019
Number of employees		30	-	1 In management, 4 in sales, 25 in grounds management and tour guides
Avg. Salary	$	70,000.00	-	Approximated living wage full-time employee
Initial/Emergency water consumption (gal/yr)		1.55E+07	-	Assuming 2 in/yr over 600 acres for sustainable practices in a wet region. Water harvesting is important aspect of facility and consumption will decrease with time.
Cost per gallon	$	0.01	-	Conservative estimate
O&M materials per year (excluding salaries)	$	200,000.00	-	Avg. cost to fix and update equipment per year
Net Yearly Cost	$	2,601,202.44		
Net annual cash flow		$4,063,510.40		
PBP (Months) Using Eqn. 3		20.87938546		

Figure 47: Calculations used to determine payback period.

Given:

		Reference/Assumption
1000	kg per MT	- Conversion
1.10231	US tons per MT	- Conversion
1.308	cubic yards per meter cubed	- Conversion
473	CO_2 (g/km) for transport	- (Eriksson et al. 1996)
5.73	NO_x (g/km) for transport	- (Eriksson et al. 1996)
0.97	HC (g/km) for transport	- (Eriksson et al. 1996)
2.45	CO (g/km) for transport	- (Eriksson et al. 1996)
0.34	PM 10 (g/km) for transport	- (Eriksson et al. 1996)
0.08	SO_x (g/km) for transport	- (Eriksson et al. 1996)
1.55	MT CO_2 emissions/bdt hog fuel-decomposition	- (SEI 2010)
10	% stay in community garden	- By design and approximated demand
45	% local transport	- By design and approximated demand
45	% CA transport	- By design and approximated demand
35.1	Local Avg. distance traveled (miles)	- Approximation of avg. distance traveled in Humboldt County
517	CA Avg. distance traveled (miles)	- Approximation of avg. distance traveled in CA
33	Distance from mill to network (miles)	
179	Fuel consumption (ml/km) of transport	- (SEI 2010)
247	density of wet biomass (kg/m^3)	- (Ciolkosz 2010)
0.5	Avg. moisture content (fraction)	- Approximated
2379183	cubic yards of wet biomass consumed/yr (w/ 80%)	
561600	Total MT of wet biomass/yr	
71.4	Avg. volume per truckload (yd^3)	- Approximate average using 120 yd^3 trucks
0.758	lb of NOx per MWh	- EIA 2019
0.015	lb of SOx per MWh	- EIA 2019
491	lb of CO_2 per MWh	- EIA 2019
150	# of streetlights at community gardens	- Estimate for parking and main trail through parks
80	Watts per streetlight	- Estimate
11	Hours of operation for lights per day	
10	MWh per office per year	- Estimated using EIA 2018 estimate of yearly household useage
2	# of offices	
20	MWh per year for equiptment and trck dumpers	- Approximated
365	days per year	
1.00E+06	W per MW	- conversion
2000	lb per US ton	- conversion
0.8	Fraction of total biomass utilized	

Intermediate Calculations

# total truckloads	33321.89
# local truckloads	14994.85
# CA truckloads	14994.85
total miles traveled per year:	9378280
toal km traveled per year:	15092179
Volume of biomass/yr in m^3	1818947
kg of wet biomass/yr	4.49E+08
Wet MT of biomass/yr	449280
Dry MT of biomass/yr (bdt/yr)	224640
Dry US tons of biomass/yr	247622.9
Total Electricity consumption (MWh/yr)	88.18

Summary Table

Pollutant	Transportation Emissions (MT/yr)	Decomposition Emissions (MT/yr)	Electricity Emissions (US tons/yr)	Total Emissions (MT/yr)	Total Emissions (US tons/yr)
eq. CO_2	7139	348192	21.64819	355331	391706
NO_x	86.5	0.0	0.033	86.5	95.4
CO	37.0	0.0	0.0	37.0	40.8
PM 10	5.13	0.0	0.0	5.13	5.7
SO_x	1.21	0.0	0.0035	1.21	1.3
		Sum of NAAQS (US tons/yr) =			143

Figure 48: Calculations for determining emissions.

Appendix D – Community-Scale Biomass Gasification Quantitative Criteria Analysis

Calculations conducted for each criterion when analyzing the Community-Scale Biomass Gasification alternative can be viewed in the figures below (Figure 49 Figure 55). The calculations for how many facilities would be needed in to offset 80% of the biomass in Humboldt County are also shown.

Reference:	Given:	
1	Annual Volume of Wet Biomass (MT tons/year)	561600
-	Biomass Utilization Percentage (%)	80
3	Feedstock Consumption (MT bdt/yr)	31560
3	Moisture Content (%)	50

Number of Facilities (#)	8

Conversions:	
m^3 to yd^3	0.7645
MT to US tons	1.1023

References:

1 RCEA (2020). "Presentation - What to Do with Biomass Feedstock in Humboldt County?", February 1st, 2020.
2 Ciolkosz, D. (2010). "Characteristics of Biomass as a Heating Fuel." Penn State Extension, <https://extension.psu.edu/characteristics-of-biomass-as-a-heating-fuel> (Accessed Feb. 6th, 2020).
3 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Assumptions:

- Assume 50% moisture content of biomass
- Using only 80% of the biomass production

*bdt = bone dry ton

Figure 49: Calculations determining how many facilities needed in Humboldt County.

Length of System (ft)	164
Width of System (ft)	39
Height of System (ft)	48
Number of plants (#)	8
Volume of Modular Plant (ft^3)	2456064

References:

1 Powermax (2020). "Wood Waste Gasification Power Plant." <http://www.wxteneng.com/en/Wood-Waste-Gasification-Power-Plant-8.html> (Accessed March 12th, 2020).

Figure 50: Calculations determining the volume of eight facilities.

Biomass Energy Preception			
Reference	Support (%)	Against (%)	Neutral (%)
1	27	32	41
2	56	26	26
3	16	5	79
Average (%)	33	21	49

BioEnergy Knowledge			
Reference	Knowledgeable (%)	Somewhat (%)	No (%)
2	5	40	55
3	13	63	24
Average (%)	9	52	40

References:

1 Plate, R. R., Monroe, M.C., Oxarart, A. (2010). "Public Perceptions of Using Woody Biomass as a Renewable Energy Source." Journal of Extension, 48(3), 1-15.
2 RCEA (2020). "Presentation - What to Do with Biomass Feedstock in Humboldt County?", February 1st, 2020.
3 Roracher, H., Bogner, T., Späth, P., Faber, F. (2015). "Improving the Public Perception of Bioenergy in the EU." 1-95.

Figure 51: Calculations to determine an estimate for community support for the biomass gasification facilities.

Given:	
C_i[2] ($)	16,875,000
P (MW)	3
t (hr/yr)	8184
C_e ($/MWh)	156
m_b (kg/yr)	4,734,000
C_b ($/kg)	0.5
C_{OM}[2] ($/yr)	2052000

PBP (yr):	4

*Looking at one plant here; PBP should remain same for 8 plants.

$$PBP = \frac{C_i}{PtC_e + \dot{m}_b C_b - C_{OM}}$$

Where:

PBP = Payback period in years (yr)
C_i = Total capital investment ($)
P = Average operational power output of the facility (MW)
t = Hours of facility operation per year (hr/yr)
C_e = Cost of electricity ($/MWh)
$\dot{m}_b$ = Average mass of biochar produced per year (kg/yr)
C_b = Average cost of biochar per kg ($/kg)
C_{OM} = Average yearly operation and maintenance ($/yr)

Assumptions:	Reference:
- 30% for construction/installation	2
- 20% contigency	2
- Assuming 2 days maintenance/month	2
- A biochar market is present	2
- Parasitic load of 1 MW for a 5 MW facility	2
- RCEA can sell electricity for $156/MWh	1
- Plant is never producing load at exactly it's rating (1 MW less)	-
- Assuming that for 8 plants the capital cost increases linearly	-

References:
1 Electricity Local (2020). "Residential Electricity Rate for Eureka California." <https://www.electricitylocal.com/states/california/eureka/> (Accessed March 13th, 2020).
2 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Figure 52: Calculations utilized to determine the payback period for the eight facilities.

References:
1 West Biofuels (2020). "Major Permits." West Biofuels, LLC, <http://www.westbiofuels.com/> (Accessed March 12th, 2020).
2 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Conclusion:

The permit process is mainly based on how long it would take to get through the CEQA and/or NEPA process. If one could get a Negative Declaration or Mitigated Negative Declaration (FONSI or Mitigated FONSI in NEPA terms) approved, it would take around 6-12 months to complete the permit approval process. If an EIR (EIS in NEPA terms) is needed, expect 12-48 months to complete the permit approval process.[1,2]

Figure 53: Analysis determining the time it would take to implement eight biomass facilities in Humboldt County.

Reference	Given:	
1	Annual Biomass Consumption (MT bdt/yr)	31560
2	Regional NO_x Transportation Emissions (g/km)	5.73
2	Regional SO_x Transportation Emissions (g/km)	0.08
2	Regional CO Transportation Emissions (g/km)	2.45
2	Regional PM_{10} Transportation Emissions (g/km)	0.34
3	Travel Distance per Truckload (miles/truckload)	163
-	Truckloads per Day (truck/day)	4
-	Number of plants (#)	8
5	Density of Biomass (kg/m^3)	247
6	Percentage of energy Generated by Biomass (%)	22
7	Annual Consumption of Energy in Humboldt County (GWh)	800
8	Control Removal (%)	90

Conversions:	
km to mile	1.6093
MT to US tons	1.1023
m^3 to yd^3	0.7645
kg to MT	1000
Weeks to Years	52
Days to Weeks	7
Truckload to yd^3	120
kWh to Wh	1000
GWh to Wh	1E+09
kg to grams	1000
MT to kg	1000

Mass Loading (g/kWh)*				
PM_{10}	NOx[4]	SOx[4]	CO[4]	Reference
0.14	0.032	-	0.045	2

Annual Operation Emissions (US tons/yr)			
PM_{10}	NOx	SOx	CO
2.72	0.62	0.00	0.87

Annual Transportation Emissions (US tons/yr)			
PM_{10}	NOx	SOx	CO
0.14	2.4	0.03	1.03

Total Air Quality Emissions (US tons/yr)				
PM_{10}	NOx	SOx	CO	Total
22.88	24.32	0.27	15.26	62.72

Assumptions:
- Emissions generated from SOx were not found for this operation
- Truckload = 120 yd^3
- Travel distance is measured along 101 from Piercy to Crescent City
- 90% control reduction in all criteria pollutants

References:
1 West Biofuels (2020). "LifeCycle Assessment" West Biofuels, LLC, <http://www.westbiofuels.com/> (Accessed March 12th, 2020).
2 Eriksson, E., Blinge, M., Lövgren, G. (1996). "Life Cycle Assessment of the Road Transport Sector." The Science of the Total Environment, 189, 69-76.
3 Google Maps (2020). "Distance from Piercy, California to Crescent City, California along Route 101."<https://www.google.com/search?q=piercy+california+to+crescent+city+california &oq=piercy+california+to+crescent+city+california&aqs=chrome..69i57.7459j0j7&sourceid=chrome&ie=UTF-8> (Accessed March 24th, 2020)
4 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.
5 Ciolkosz, D. (2010). "Characteristics of Biomass as a Heating Fuel." Penn State Extension, <https://extension.psu.edu/characteristics-of-biomass-as-a-heating-fuel> (Accessed Feb. 6th, 2020).
6 RCEA (2019). "The Redwood Coast Energy Authority's Comprehensive Action Plan for Energy." Redwood Coast Energy Authority.
7 Humboldt County. (2017) Humboldt County General Plan Update: Final Environmental Impact Report SCH# 2007012089, Humboldt County Board of Supervisors and Planning Commission.
8 USEPA. (2000). "Control of Particulate Matter Emissions - Student Manual." *Environmental Protection Agency*.

Figure 54: Calculations utilized to determine annual NAAQS emissions from the implementation of eight new biomass gasification facilities.

Construction & Transportation GHG Emissions

*Looking at one plant

Reference	Given:	
1	Construction Emissions (MT CO_2e/yr)	8.25
4	Regional Transportation Emissions (g CO_2e/km)	473
-	Truckloads per Day (truck/day)	4
5	Travel Distance per Truckload (miles/truckload)	163
6	Density of Biomass (kg/m^3)	247

Construction Emissions (US tons CO_2e/yr)	**8.25**
Transportation Emissions (US tons CO_2e/yr)	**191.01**

Assumptions:

- 50% would be open burned, 50% would be rid of via mastification if not utilized in gasification plant
- Travel distance is measured along 101 from Piercy to Crescent City
- Truckload = 120 yd^3
- Not considering displaced fossil fuel use to generate electricity
- CO_2e = CO_2 equivalent for 20-year period.

GHG Emissions from Operation

*Looking at one plant

Reference	Given:	
1	Feedstock Consumption (MT bdt/yr)	31560
3	Operations Emissions Factor (MT CO_2/bdt)	1.74

Operation Emissions (US tons CO_2e/yr)	**54914**

Biochar Sequestration

*Looking at one plant

Reference	Given:	
2	Biochar Production (% of Feedstock)	15
-	Total Annual Biochar Production (MT bdt/yr)	4734
2	Actual Carbon (% of Biochar)	69

Sequestered Carbon (US tons CO_2e/yr)	**13202**

Summary GHG of Emission

*Looking at all 8 plants

Category	
Construction Emissions (US tons CO_2e/yr)	8.25
Transportation Emissions (US tons CO_2e/yr)	191
Operation Emissions (US tons CO_2e/yr)	54914
Total Generated Emissions (US tons CO_2e/yr)	**55114**
Sequestered Carbon Emissions (US tons CO_2e/yr)	13202
Saved Carbon Emissions (US tons CO_2e/yr)	**13202**
Number of plants (#)	8

Net GHG Emissions (US tons CO_2e/yr)	-335291	*This value accounts process emissions
Net Carbon Neutral GHG Emissions (US tons CO_2e/yr)	104024	*This value states process emissions as carbon neutral

Conversions:	
km to mile	1.6093
MT to US tons	1.1023
m^3 to yd^3	0.7645
kg to MT	1000
Weeks to Years	52
Days to Weeks	7
Truckload to yd^3	120

*bdt = bone dry ton
*44 amu CO_2/12 amu C

References:

1 Placer County (2012). Cabin Creek Biomass Facility Draft EIR, State Clearinghouse #2011122032, Community Development Resources Agency.
2 West Biofuels (2020). "LifeCycle Assessment" West Biofuels, LLC, <http://www.westbiofuels.com/> (Accessed March 12th, 2020).
3 SEI. (2010). Greenhouse gas an air pollutant emissions of alternatives of woody biomass residues, Stockhom Environmental Institute.
4 Eriksson, E., Blinge, M., Lövgren, G. (1996). "Life Cycle Assessment of the Road Transport Sector." The Science of the Total Environment, 189, 69-76.
5 Google Maps (2020). "Distance from Piercy, California to Crescent City, California along Route 101." <https://www.google.com/search?q=piercy+california+to+crescent+city+california &oq=piercy+california+to+crescent+city+california&aqs=chrome..69i57.7459j0j7&sourceid=chrome&ie=UTF-8> (Accessed March 24th, 2020)
6 Ciolkosz, D. (2010). "Characteristics of Biomass as a Heating Fuel." Penn State Extension, <https://extension.psu.edu/characteristics-of-biomass-as-a-heating-fuel> (Accessed Feb. 6th, 2020).

Figure 55: Calculations utilized to determine the amount of carbon sequestered from the addition of 20 new biomass gasification facilities.

Appendix E – Annual Biomass consumed in Humboldt County from Existing Biomass Powerplants.

Calculations below in Figure 56 show a rough calculation done to quantify how much biomass is consumed annually by the existing HRC Scotia and DG Fairhaven biomass powerplants. Only 80% of the calculated value was utilized when analyzing different alternatives.

Reference:	Given:	
1	Annual Mass of Biomass (MT/year)	561600
2	Density of Biomass (kg/m^3)	247

Annual Biomass (yd^3/year)	3.0E+06

Assumptions:

- truckload = 120 yd^3
- Assume 50% moisture content of biomass

Conversion Factors	
kg to MT	1000
m^3 to yd^3	0.7645
Truckload to yd^3	120
Truckload to yd^3	120

References:

1 RCEA (2020). "Presentation - What to Do with Biomass Feedstock in Humboldt County?", February 1st, 2020.
2 Ciolkosz, D. (2010). "Characteristics of Biomass as a Heating Fuel." Penn State Extension, <https://extension.psu.edu/characteristics-of-biomass-as-a-heating-fuel> (Accessed Feb. 6th, 2020).

Figure 56: The calculations utilized to determine the annual biomass consumed by the existing biomass powerplants in Humboldt County.

Appendix F – Optimization Method use for Preferred Alternative Placement

To discover locations for the eight gasification facilities and the distribution network facility, a genetic algorithm was utilized to optimize where to place them in Humboldt County. The results from the optimization model can be viewed in Figure 57 and Figure 58. The grid infrastructure with respect to each proposed gasification site is depicted in Figure 59.

Index	Cities	Garberville	Rio Del	Fortuna	Ferndale	Eureka	Arcata	McKinleyville	Trinidad
1.0	Garberville	0.0	41.5	49.8	57.0	67.0	74.5	80.4	90.0
2.0	Rio Del	41.5	0.0	8.4	15.6	25.7	33.2	39.0	48.4
3.0	Fortuna	49.8	8.4	0.0	7.5	17.5	25.0	30.9	40.3
4.0	Ferndale	57.0	15.6	7.5	0.0	19.6	27.1	32.9	42.0
5.0	Eureka	67.0	25.7	17.5	19.6	0.0	7.7	13.5	23.0
6.0	Arcata	74.5	33.2	25.0	27.1	7.7	0.0	5.8	15.3
7.0	McKinleyville	80.4	39.0	30.9	32.9	13.5	5.8	0.0	10.0
8.0	Trinidad	90.0	48.4	40.3	42.0	23.0	15.3	10.0	0.0

			1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
Site Placement	Changing Variables	Cities	Garberville	Rio Del	Fortuna	Ferndale	Eureka	Arcata	McKinleyville	Trinidad
Garberville	1.0	Garberville	0.0	41.5	49.8	57.0	67.0	74.5	80.4	90.0
Fortuna	3.0	Rio Del	49.8	8.4	0.0	7.5	17.5	25.0	30.9	40.3
McKinleyville	7.0	Fortuna	80.4	39.0	30.9	32.9	13.5	5.8	0.0	10.0
	5.0	Ferndale	67.0	25.7	17.5	19.6	0.0	7.7	13.5	23.0
	4.0	Eureka	57.0	15.6	7.5	0.0	19.6	27.1	32.9	42.0
	8.0	Arcata	90.0	48.4	40.3	42.0	23.0	15.3	10.0	0.0
	2.0	McKinleyville	41.5	0.0	8.4	15.6	25.7	33.2	39.0	48.4
	6.0	Trinidad	74.5	33.2	25.0	27.1	7.7	0.0	5.8	15.3
		Minimum	0.0	8.4	0.0	7.5	13.5	5.8	0.0	10.0

Max	13.5

Notes:
*All values are in miles
*Assumed placement of 3 gasification locations across the county.

Figure 57: This figure describes the genetic algorithm used to optimize the placement of gasification facilities in Humboldt County (Google Maps 2020b).

Index	Cities	Garberville	Rio Del	Fortuna	Ferndale	Eureka	Arcata	McKinleyville	Trinidad
1.0	Garberville	0.0	41.5	49.8	57.0	67.0	74.5	80.4	90.0
2.0	Rio Del	41.5	0.0	8.4	15.6	25.7	33.2	39.0	48.4
3.0	Fortuna	49.8	8.4	0.0	7.5	17.5	25.0	30.9	40.3
4.0	Ferndale	57.0	15.6	7.5	0.0	19.6	27.1	32.9	42.0
5.0	Eureka	67.0	25.7	17.5	19.6	0.0	7.7	13.5	23.0
6.0	Arcata	74.5	33.2	25.0	27.1	7.7	0.0	5.8	15.3
7.0	McKinleyville	80.4	39.0	30.9	32.9	13.5	5.8	0.0	10.0
8.0	Trinidad	90.0	48.4	40.3	42.0	23.0	15.3	10.0	0.0

			1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
Site Placement	Changing Variables	Cities	Garberville	Rio Del	Fortuna	Ferndale	Eureka	Arcata	McKinleyville	Trinidad
Rio Dell	2.0	Garberville	41.5	0.0	8.4	15.6	25.7	33.2	39.0	48.4
	5.0	Rio Del	67.0	25.7	17.5	19.6	0.0	7.7	13.5	23.0
	4.0	Fortuna	57.0	15.6	7.5	0.0	19.6	27.1	32.9	42.0
	6.0	Ferndale	74.5	33.2	25.0	27.1	7.7	0.0	5.8	15.3
	7.0	Eureka	80.4	39.0	30.9	32.9	13.5	5.8	0.0	10.0
	3.0	Arcata	49.8	8.4	0.0	7.5	17.5	25.0	30.9	40.3
	1.0	McKinleyville	0.0	41.5	49.8	57.0	67.0	74.5	80.4	90.0
	8.0	Trinidad	90.0	48.4	40.3	42.0	23.0	15.3	10.0	0.0
		Minimum	41.5	0.0	8.4	15.6	25.7	33.2	39.0	48.4

Max	48.4

Notes:
*All values are in miles
*Assumed placement of one distribution network in the county

Figure 58: This figure describes the genetic algorithm used to optimize the placement of the distribution network facility in Humboldt County (Google Maps 2020b).

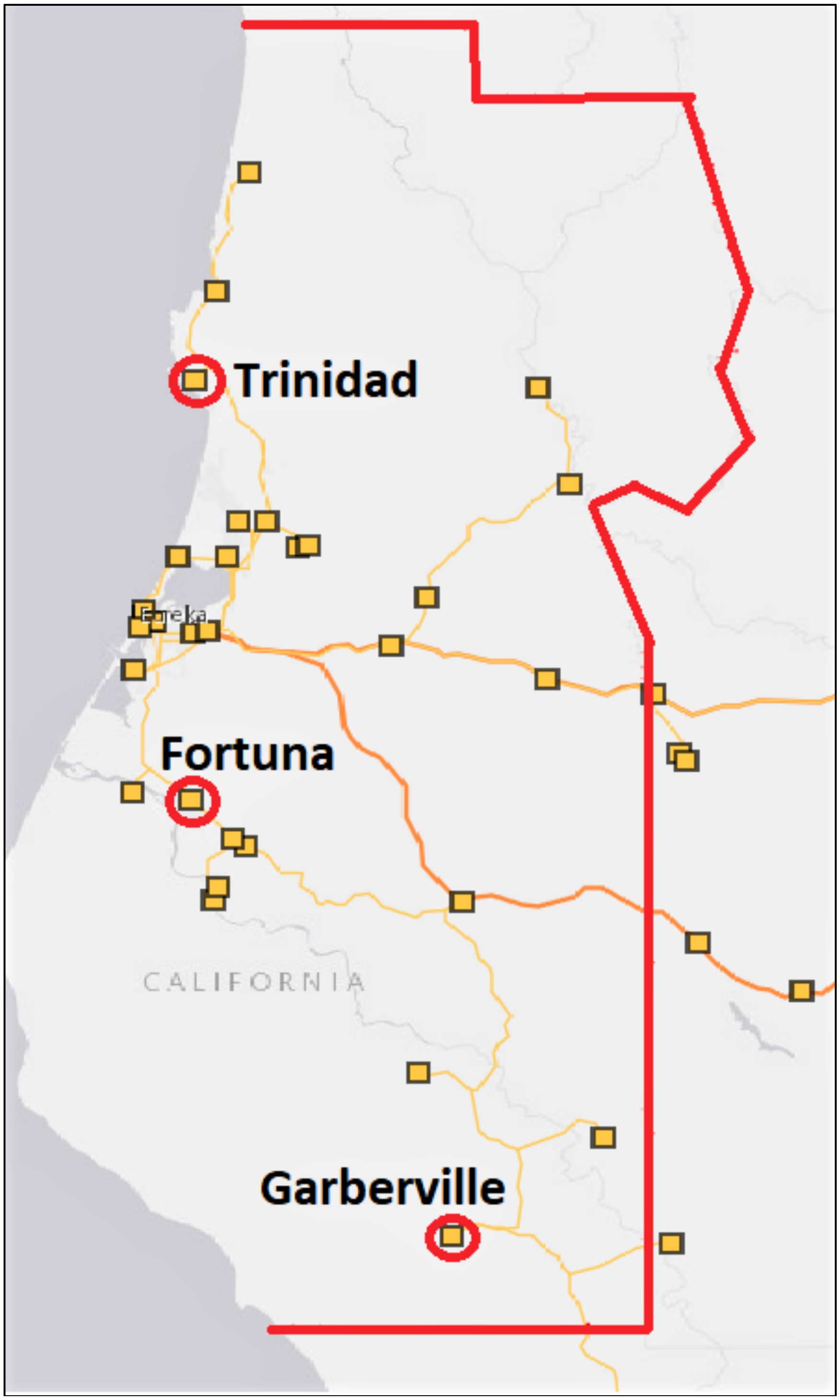

Figure 59: This figure describes the grid transmission infrastructure with respect to optimized site placement (CEC 2020b). The transmission lines and substations are depicted as orange lines and boxes respectively; the red line describes the Humboldt County border.

Appendix G – Analysis of Preferred Alternative

This appendix shows the calculations used for the economic analysis of the preferred alternative as seen in Figure 60 -Figure **62**. The objective of this analysis was to calculate present worth cost, present worth benefit, and present net worth benefit.

		Ref.
n (yrs)	10	
Capital Cost ($)	$105,320,000	
Annual Costs ($)	$13,730,904	
Annual Revenue ($)	$39,536,601	
interest rate	0.064	(Porcu et al. 2019)
annual O&M	$13,730,904.5	
Annual Interest payment ($)	$9,478,800	
Total annual cash flow ($)	$16,326,896	
Total loan payment	$145,820,218.68	
Annual interest payment	$14,582,022	
Capital Costs	$105,320,000.000	
total interest paid	$40,500,218.68	
PWC (P/F, i=1.69%, n=10)	$123,320,498.56	
inflation rate	0.0169	(BLS 2020)
Total Annual Costs	$28,312,926.3	
Total future costs	$145,820,218.68	
PWB (P/A, i=1.69%, n=10)	$360,970,734.25	
PWNB= PWB- PWC	$237,650,235.68	

Figure 60: Calculations for economic analysis of preferred alternative.

Emissions Factors

Transportation		
CO2	473	g/km
NOx	5.73	g/km
CO	2.45	g/km
PM	0.34	g/km
SOx	0.08	g/km
Decomposition		
Eq. CO2	1.55	MT CO2/bdt
Electricity		
NOx	0.758	lb/MWh
SOx	0.015	lb/MWh
Eq. CO2	491	lb/MWh

Conversions	
0.621371	miles/km
27154.286	gal/acre-in
1.00E+06	Wh per MWh
365	days/yr
24	hr/d
11	hr of lights/d
907185	grams/US tons
1.102	US tons/MT
2000	lb/us tons

Given/Assumptions

Electricity	
50	#streetlights
80	Watts/streetlight
1	# offices
10	MWh per office per year
10	MWh for equipment per year
36.1	Total MWh consumed/yr

Transport	
72	cubic yards/truckload avg.
45	% of material that stays in Humboldt County
10	% of material that stays in community garden
45	% of material that is sold out of county
35.1	Humboldt county avg. distance traveled (miles)
517	Out of county average distance travled (miles)
33	Avg. distance from mills to DN (miles)
5189.4372	# tuckloads in to DN/yr
2335.2468	# truckloads out of county/yr
2335.2468	# tuckloads in county/yr
1460541.2	total miles of transport/yr
2350513.9	total km of transport/yr

Water	
4	in/yr of water consumption for garden
150	acres
16292572	US gal of water consumed/yr

Economics	
0.01	$ cost/US gal
$70,000	Average $ salary/yr
90	% of the material that is sold
7	$/cubic yard
0.1658	$ cost/KWh
15	# of employees
$200,000	Yearly O&M ($/yr)

Biomass	
77778.994	wet US tons/yr
38889.497	dry US tons/yr
70560	wet MT/yr
35280	dry MT/yr
373639.48	cubic yards/yr

Emissions

	Transport (US tons/yr)	Decomposition (US tons/yr)	Electricity (US tons/yr)	Total Emissions (US tons/yr)
Eq. CO2	1225.54	60261.768	8.85	61,496.16
NOx	14.85	0	0.01	14.86
CO	6.35	0	0.00	6.35
PM	0.88	0	0.00	0.88
SOx	0.04	0	0.00	0.04
total NAAQS	22.11	0	0.01	22.13

Economics	
$2,353,929	Average Revenue/yr
$1,418,904	Average Costs/yr
$935,024	Net annual cash flow
$4,070,000.00	Capital Cost

Capital Cost			Assumptions
Building office	$750,000.00	-	Based off avg. local building costs (2 buildings)
Initial landscaping (irrigat	$250,000.00	-	Initial estimate of cost for essential and basic landscaping
Land (acres)	150		
Property (Subsidized)	$1,500,000.00	-	$10,000 per acre avg. cost
Promotion and Consume	$70,000.00	-	1-year salary for early consumer relations and outreach
Permiting and Design	$500,000.00	-	2-year salary and expected fees/emergency
Equipment (Loading/unlo	$1,000,000.00	-	Approximation based on on-line cost of equipment from vendors.
Capital Cost	$4,070,000.00		

Figure 61: Analysis of the Distribution Network component for the preferred alternative.

Length of System (ft)	164
Width of System (ft)	39
Height of System (ft)	48
Number of plants (#)	6
Volume of Modular Plant (ft^3)	1842048

References:
1 Powermax (2020). "Wood Waste Gasification Power Plant." <http://www.wxteneng.com/en/Wood-Waste-Gasification-Power-Plant-8.html> (Accessed March 12th, 2020).

Biomass Energy Preception			
Reference	Support (%)	Against (%)	Neutral (%)
1	27	32	41
2	56	26	26
3	16	5	79
Average (%)	33	21	49

BioEnergy Knowledge			
Reference	Knowledgeable (%)	Somewhat (%)	No (%)
2	5	40	55
3	13	63	24
Average (%)	9	52	40

References:
1 Plate, R. R., Monroe, M.C., Oxarart, A. (2010). "Public Perceptions of Using Woody Biomass as a Renewable Energy Source." Journal of Extension, 48(3), 1-15.
2 RCEA (2020). "Presentation - What to Do with Biomass Feedstock in Humboldt County?", February 1st, 2020.
3 Roracher, H., Bogner, T., Späth, P., Faber, F. (2015). "Improving the Public Perception of Bioenergy in the EU." 1-95.

Given:	
Annual Electricity Load in Humboldt County (GWh)	800
Percentage Utilized by Biomass (%)	22
Facility Power Rating (MW)	3
Hours of Operation (hr/yr)	8184
Percentage of Existing Energy	80

Conversions	
Mega- to Giga-	1000

Number of Facilities Needed (#)	6

Assumptions:	Reference:
- Parasitic load of 1 MW for a 5 MW facility	1
- Plant is never producing load at exactly it's rating (1 MW less)	-
- Assuming 2 days maintenance/month	1

References:
1 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Summary:

A total of 8 plants are needed to offset 80% of the biomass utilized annually at DG Fairhaven and HRC Scotia. When combining alternatives with the Distribution Network, the goal was changed to offset 80% of the electricity generation. Only 6 gasification facilities are needed to offset 80% of the electricity demands, while the excess biomass not covered by these facilities goes to the Distribution Network alternative.

Given:	
C_i^{*} ($)	16,875,000
P (MW)	3
t (hr/yr)	8184
C_e ($/MWh)	156
m_b (kg/yr)	4,734,000
C_b ($/kg)	0.5
C_{OM}^{*} ($/yr)	2052000
Number of Plants	6

*Looking at one plant here; PBP should remain same for 6 plants.

PBP (yr)	4
Annual Revenue ($/yr)	##
Annual Cost ($/yr)	##

*This value does not consider a loan

$$PBP = \frac{C_i}{PtC_e + \dot{m}_b C_b - C_{OM}}$$

Where:

PBP = Payback period in years (yr)
C_i = Total capital investment ($)
P = Average operational power output of the facility (MW)
t = Hours of facility operation per year (hr/yr)
C_e = Cost of electricity ($/MWh)
$\dot{m}_b$ = Average mass of biochar produced per year (kg/yr)
C_b = Average cost of biochar per kg ($/kg)
C_{OM} = Average yearly operation and maintenance ($/yr)

Assumptions:	Reference:
- 30% for construction/installation	2
- 20% contigency	2
- Assuming 2 days maintenance/mc	2
- A biochar market is present	2
- Parasitic load of 1 MW for a 5 MW	2
- RCEA can sell electricity for $156/	1
- Plant is never producing load at ex	-
- Assuming that for 6 plants the cap	-

References:
1 Electricity Local (2020). "Residential Electricity Rate for Eureka California." <https://www.electricitylocal.com/states/california/eureka/> (Accessed March 13th, 2020).
2 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Given:	
Size of plant (MW)	5
Jobs per MW (#/MW)	5
Number of plants (#)	6
Number of Workers per Truckload	2
Moisture Content Factor	1.5
Biomass Consumption (MT bdt/year)	31560
Size of Truckload (yd^3)	120
Density of Biomass (kg/m3)	247
Number of Plants (#)	6

Direct Jobs (#):	150
Indirect Jobs	18

References:
1 CEC. (2019). Modular Biomass Power Systems to Facilitate Forest Fuel Reduction Treatment, California Energy Commission, California.

Conversions:	
m^3 to yd^3	0.764555
Days to Year	365
kg to MT ton	1000

Figure 62: Analysis of the Community-Scale Gasification components for the preferred alternative.

Appendix H - Parcel Locations and Numbers

This appendix includes figures of the existing combustion biomass powerplants showing their parcel boundaries and APN numbers (Figure 63 Figure 67). This appendix also includes figures showing specific parcel locations that could be utilized to implement the preferred alternative.

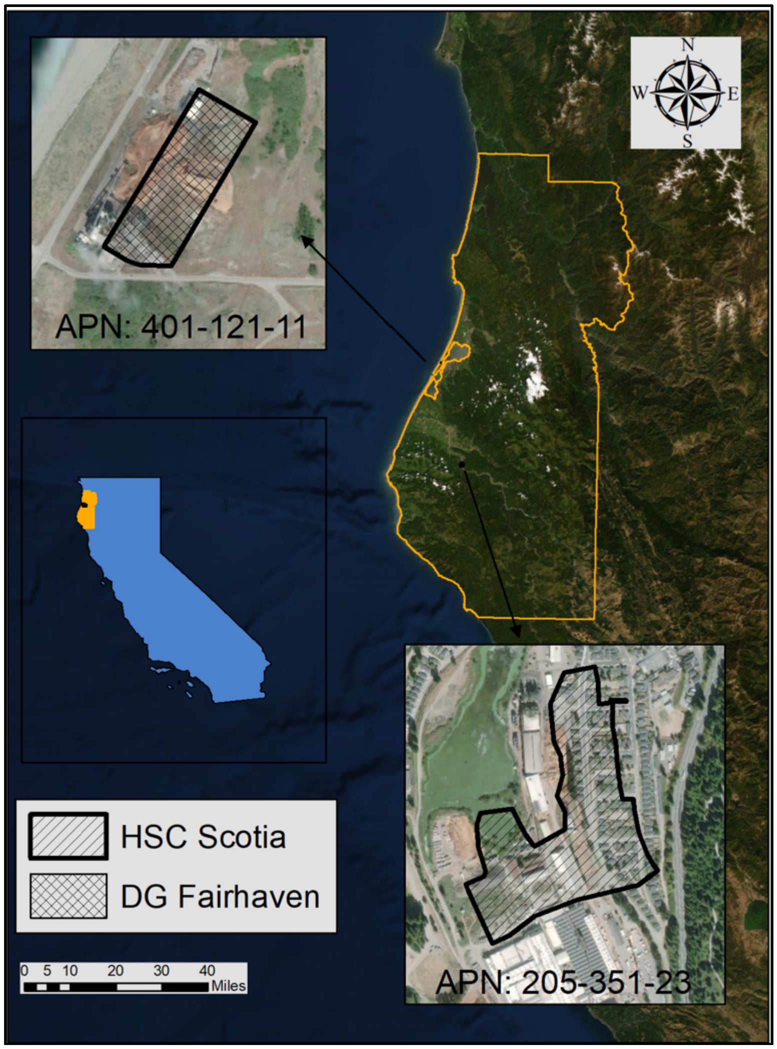

Figure 63: Parcel boundaries and numbers for DG Fairhaven and HSC Scotia (Adapted from Humboldt County GIS 2020).

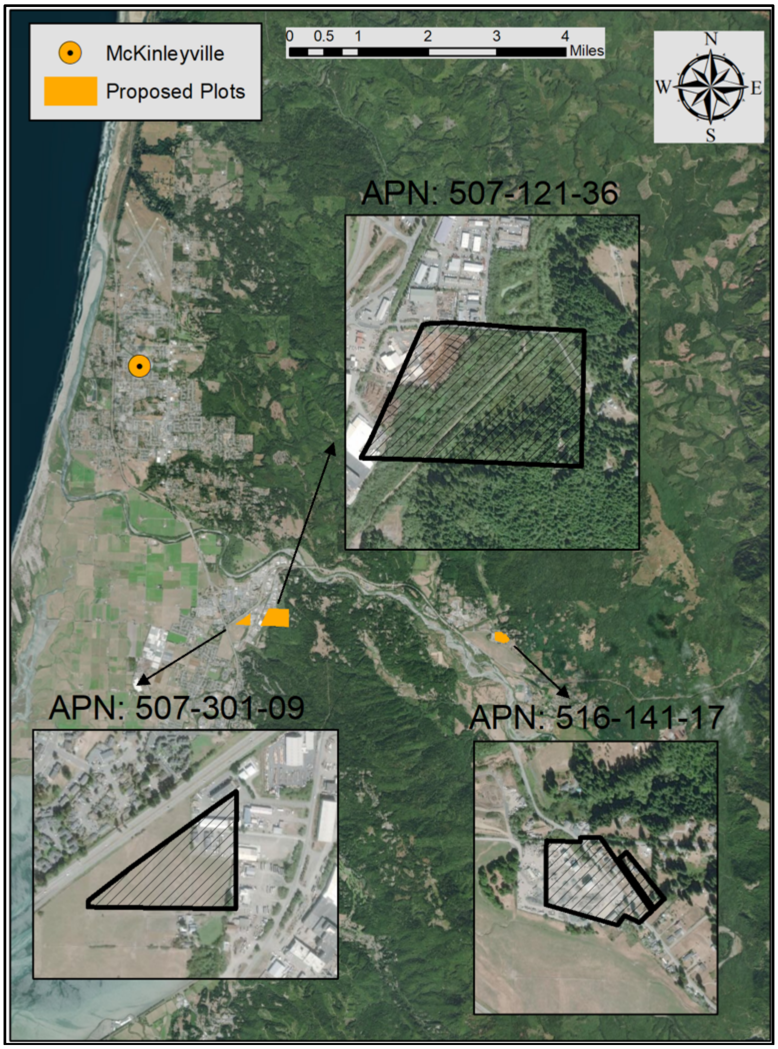

Figure 64: Parcel numbers and locations for McKinleyville gasification facilities (Adapted from Humboldt GIS 2020).

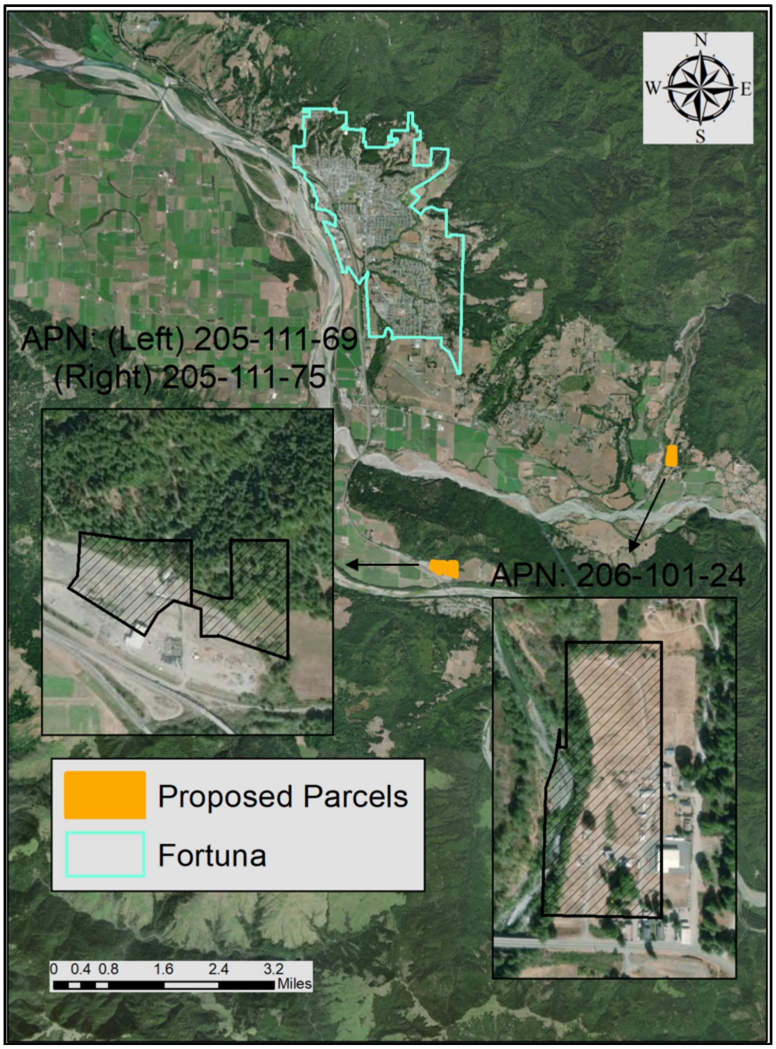

Figure 65: Parcel numbers and boundaries for proposed gasification facilities in Fortuna (Adapted from Humboldt GIS 2020).

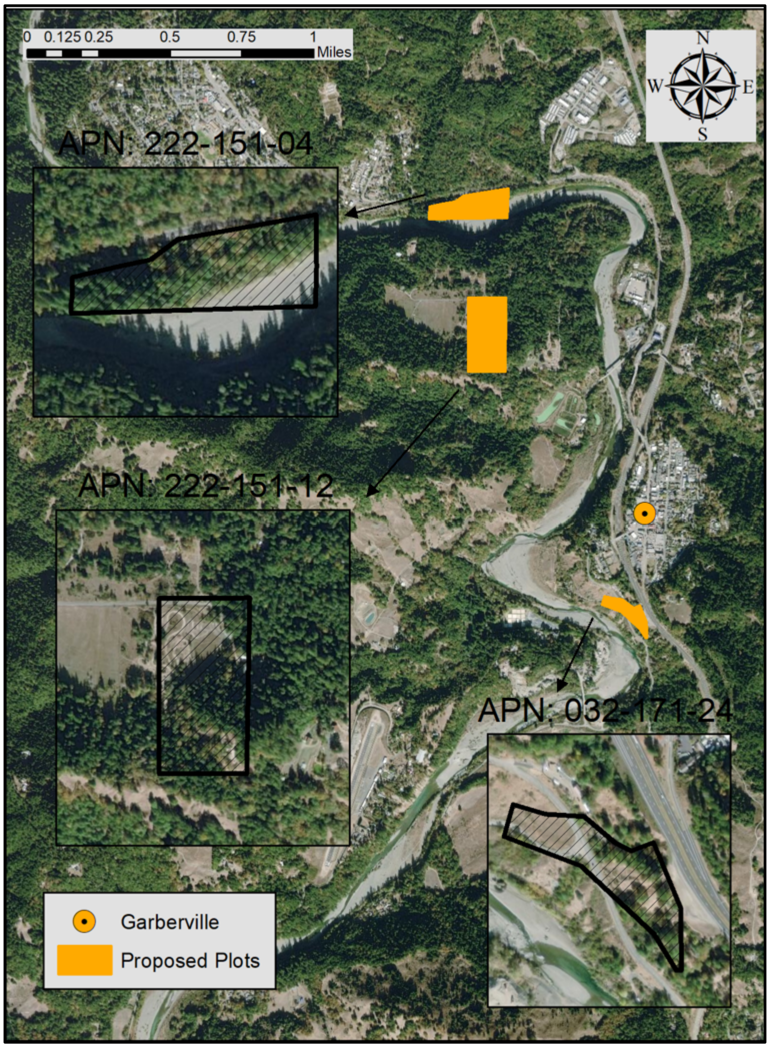

Figure 66: Parcel numbers and boundaries for proposed gasification facilities in Garberville (Adapted from Humboldt GIS 2020).

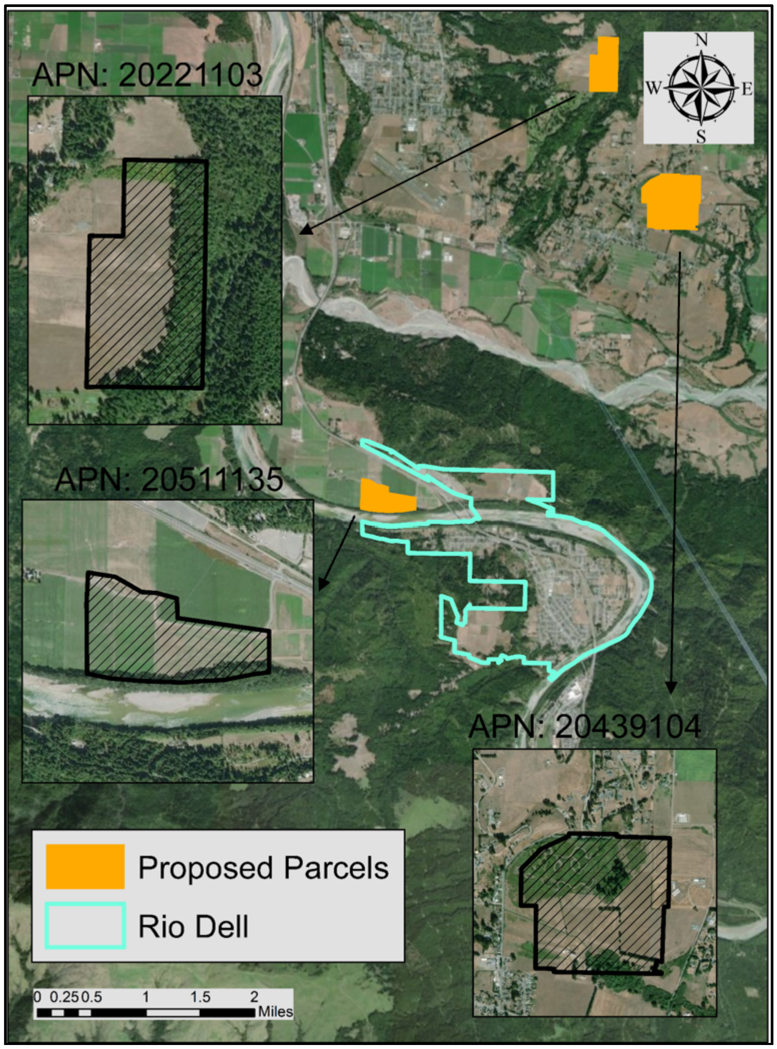

Figure 67: Parcel numbers and boundaries for the Distribution Network in Rio Dell (Adapted from Humboldt GIS 2020).

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