Alternative Uses for Mill Wastes in Humboldt County

Prepared for Redwood Coast Energy Authority

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Environmental Resources Engineering 492

Capstone Design Project, Spring 2020

May 12, 2020

Acknowledgments

The research and analyses conducted for this report are a result from Humboldt State University's B.S. Environmental Recourses Engineering ENGR-491 Capstone class. We would like to thank our advisors, Dr. Sintana Vergara and Dr. Tesfayohanes Yacob for their efforts and guidance through the entirety of the semester, and Richard Engel and Anamikah Singh from RCEA for their direct communications and technical information provided for this project. Another special thanks is deserved for Bob Marino of DG Fairhaven's power plant, for the facility tour and question-answer session provided. It should be mentioned that a document provided by Michael Furniss, "Biomass Power in Humboldt County" was the basis of initial alternatives research provided and considered.

List of Acronyms

BAU	Business as Usual
BDMT	Bone-Dry Metric Tonne
CAP	Climate Action Plan
CCE	Community Choice Energy Program
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOE	Department of Energy
EPA	Environmental Protection Agency
GHG	Green House Gas
H_2	Hydrogen Gas
LCOE	Levelized Cost of Electricity
MWh	Mega-Watt Hour
O&M	Operations & Maintenance
PG&E	Pacific Gas & Electric Company
$PM_{2.5}$	Particulate Matter (less than 2.5 micrometers in diameter)
PM_{10}	Particulate Matter (less than 10.0 micrometers in diameter)
RCEA	Redwood Coast Energy Authority

Executive Summary

Humboldt County's lumber industry has provided an energy resource for the community with the combustion of mill wastes as a biofuel. DG Fairhaven, located on the Samoa peninsula, and the Humboldt Sawmill Company, located in Rio Dell, have provided nearly 30% of the power supply to Humboldt County residents in recent years, through PG&E transmission lines. The current treatment of the mill waste is a vital component to the area's energy demands but has generated community concern regarding health risks associated with criteria air pollutants and their related environmental impacts.

The purpose of this project is to explore alternative uses for 281,000 BDMT/year of mill waste that meet air quality, environmental, financial, and production constraints. The four alternatives that were evaluated consisted of a pyrolysis system, modular gasification system, pulping and tissue manufacturing, and organic mulch facility. These alternatives were then compared to each other using the following economic, environmental, and social criteria: payback period, operational flexibility, life-cycle greenhouse gases, particulate matter, NO_X, SO_X, CO, carbon sequestration, decentralized utilization, ecological impact, employment opportunities, and public concern. The criteria were given weights between 1 (least important) and 10 (most important) by the RCEA, who placed the greatest influence on the payback period and emissions/pollutants associated with the project.

Modular gasification was chosen as the preferred alternative, in both the Delphi Matrix and Pugh Method. Gasification converts woody biomass feedstock into a synthetic gas mixture of CO and H_2, commonly referred to as syngas, which is used to produce electricity. A byproduct of the gasification process is biochar, which is a highly porous, carbon-based material that can be used as a soil amendment or in high grade filters. Electricity is sold at a market rate of $78/MWh, which is a 20% increase from the current rate of $65/MWh. To offset the costs of producing electricity through gasification, biochar is sold at a market rate of $1.5/kg to local buyers. Using the project's capital cost, O&M costs, an 8% interest rate, and revenue from the sale of electricity and biochar, a discounted payback period of 24.1 years was calculated.

GHG emissions for the preferred alternative were calculated to be 317,000 MT CO_2-eq/year which is estimated to be a 27% reduction when compared to the BAU case. Combined particulate matter, VOC, CO, SOx, and NOx had combined emissions of 253 MT/year, a reduction of 89% compared to the BAU case (Figure 1) (CARB 2020c).

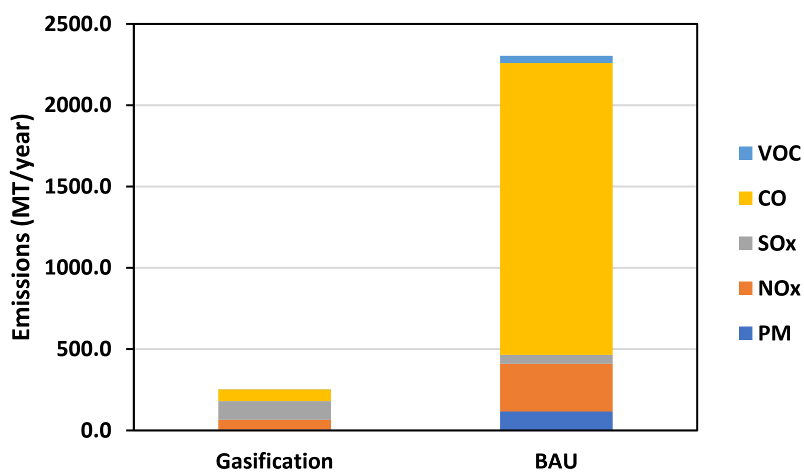

Figure 1. Comparison of emissions for gasification and BAU case.

While the reduced emissions and estimated 287 jobs created opportunities make this an appealing alternative compared to the BAU case, there are many challenges with community-scale gasification. Due to certain biomass characteristics, such as inconsistencies in the type and size of biomass feedstock, large-scale gasification is not technically feasible. To work around this, a total of 16 – 3 MW modular gasification systems, each having an estimated lifespan of 30 years, would be required to replace the existing demand of 48 MW. This presents a substantial total capital investment cost of approximately $270,216,000. For this alternative to be feasible, there would need to be a biochar market in Humboldt County capable of purchasing approximately 42,150 MT of biochar annually. The biochar could also be exported, which would result in a net change in the overall price of the product. Additionally, the location selected for this alternative assumes that the DG Fairhaven parcel would be used as the site for the gasification systems. This site was selected because of its proximity to the PG&E sub-station. Grid interconnectivity would be required to harness the produced electricity. Ideally, multiple locations with grid interconnectivity would be used to reduce the costs and emissions associated with transportation.

In addition to these challenges, the feasibility of the preferred alternative is highly dependent upon the electricity selling price, the LCOE, and the interest rate. The LCOE is essentially the cost of producing electricity for this alternative, which is offset through the sale of biochar. A sensitivity analysis was performed on the payback period through independent modifications of the electricity selling price, LCOE and the interest rate (Figure 2). The electricity selling price was the most sensitive input parameter. Selling 100% of the biochar at $1.5/kg sets the LCOE at -$61/MWh, which off sets the costs associated with operating the facility and increases annual profit. Reducing the biochar market price would require increasing the rate at which electricity is being sold for the alternative to be feasible.

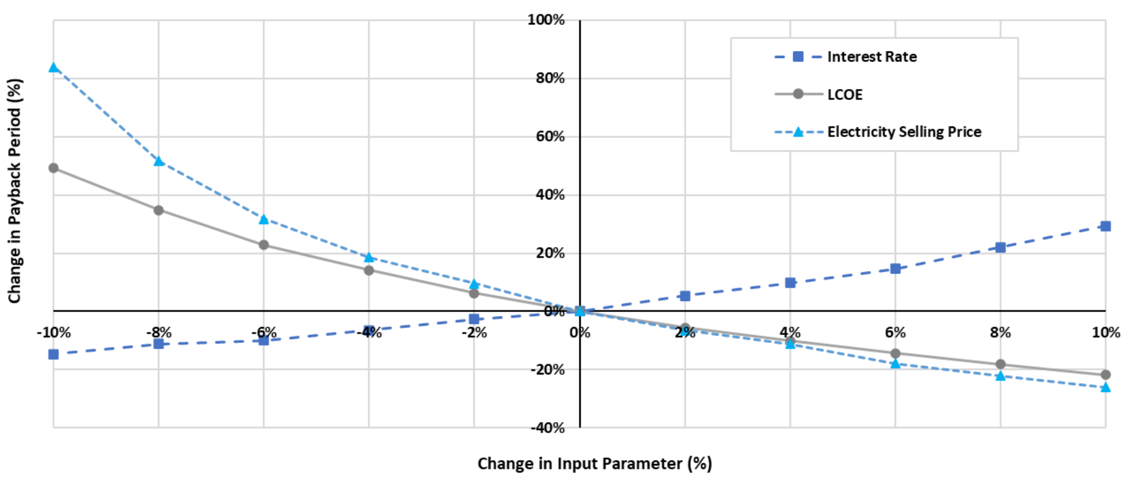

Figure 2. Results of sensitivity analysis performed on interest rate, LCOE, and electricity selling price.

Recommendations for future work include: (1) optimizing the location of multiple modular gasification systems to reduce the costs and emissions associated with transportation of woody biomass, (2) establishing a biochar market within Humboldt County or a method of exporting biochar, (3) educating the public about the advantages of gasification, and (4) identifying possible loans, financing, or incentives that could reduce the capital costs associated with this project. While there are many aspects of this alternative that are attractive, the success of this project is highly dependent upon several factors. Addressing these recommendations would help to solidify modular gasification as an alternative to the incineration of woody biomass within Humboldt County.

Table of Contents

Acknowledgments i
List of Acronyms i
Executive Summary ii
1 Introduction 1
1.1 Objective 1
2 Background 1
2.1 Climate Change 1
2.1.1 Climate Change in California 2
2.1.2 Climate Change in Humboldt 2
2.2 Redwood Coast Energy Authority 3
2.2.1 Energy Use 4
2.3 Stakeholders 6
2.4 Site Information 7
2.4.1 Location 7
2.4.2 Climate 8
2.4.3 Floodplain 8
2.5 Ecology 8
2.5.1 Native and Endangered Species 9
2.5.2 Soils 9
2.5.3 Hydrology 9
2.5.4 Climate Change 10
2.6 Regulations & Permitting 10
2.6.1 Air Quality 10
2.6.2 Feedstock 12
2.6.3 Stormwater 12
2.7 Biomass Plant Characterization 12
2.7.1 Site Information 12
2.7.2 Woody Biomass Processing Capabilities 14
2.7.3 Emissions 15
2.7.4 Air Quality 15
2.7.5 Air Quality Controls 15
2.7.6 Air Quality Concerns 15
2.8 Biomass Characterization 16
2.8.1 Energy Content 16

2.8.2 Incineration Byproducts 16
2.8.3 Biomass Context 16
2.9 Alternative Technologies: (Energy) 17
2.9.1 Combustion 17
2.9.2 Pyrolysis 17
2.9.3 Gasification 18
2.10 Alternative Technologies: (non-Energy) 19
2.10.1 Biochar 19
2.10.2 Alternative Uses for Bark 20
2.10.3 Alternative Uses for Sawdust and Shavings 20
3 Alternatives 21
3.1 Constraints 21
3.2 Criteria 22
3.3 Alternative 1: Pyrolysis for Biochar Production 22
3.3.1 Cost Analysis 24
3.3.2 Pyrolysis Performance for Economic Criteria 24
3.3.3 Pyrolysis Performance for Environmental Criteria 24
3.3.4 Pyrolysis Performance for Social Criteria 25
3.4 Alternative 2: Gasification for Power Generation 25
3.4.1 Gasification Performance for Economic Criteria 26
3.4.2 Gasification Performance for Environmental Criteria 26
3.4.3 Gasification Performance for Social Criteria 27
3.5 Alternative 3: Tissue Paper Products (TPPs) 27
3.5.1 Tissue Paper Performance for Economic Criteria 29
3.5.2 Tissue Paper Performance for Environmental Criteria 30
3.5.3 Tissue Paper Performance for Social Criteria 31
3.6 Alternative 4: Organic Mulch 31
3.6.1 Organic Mulch Performance for Economic Criteria 32
3.6.2 Organic Mulch Performance for Environmental Criteria 33
3.6.3 Organic Mulch Performance for Social Criteria 33
4 Decision Analysis 34
5 Preferred Alternative 35
5.1 Project Description 36
5.2 Analysis of Economic Criteria 37
5.3 Analysis of Environmental Criteria 40

5.4 Analysis of Social Criteria 40
5.5 Summary of Preferred Alternative 41
6 Recommendations 41
7 References 42
8 Appendix A: Continued Background Information 49
8.1 Additional Figures 49
8.2 Financing, Loans, and Incentives 49
9 Appendix B – Analysis of Alternatives 50

List of Figures

Figure 1. Comparison of emissions for gasification and BAU case. ii
Figure 2. Results of sensitivity analysis performed on interest rate, LCOE, and electricity selling price. iii
Figure 3. Emission trends for transportation and electricity production from 1990 to 2016, with projected goals for 2030 (Barboza & Lange 2018, Rogers et al. 2007). 2
Figure 4. Emissions inventory in Humboldt County for 2015. Wastewater treatment and leaked refrigerants have been removed from this figure because their combined percentage of the total was less than one percent (Humboldt County n.d.). 3
Figure 5. Humboldt County annual electricity consumption from 2009 – 2018 (CEC 2020). 4
Figure 6. RCEA 2018 power mix for CCE customers and potential mix for 2030 (RCEA 2019). 5
Figure 7. Humboldt County project locator map (Seale 2020). 7
Figure 8. Humboldt Sawmill Company parcel with 100-year and 500-year flood zones (Source: FEMA 2015, National Mapper) (Seale 2020). 8
Figure 9. Potential increase and decrease of areas burned for high carbon emission scenario projected to 2085 (CDPH 2017). 10
Figure 10. Location of DG Fairhaven parcel number 40112111 (Seale 2020). 13
Figure 11. Location of Humboldt Sawmill Company parcel number 20535123 (Seale 2020). 14
Figure 12. Typical supply chain for Humboldt Sawmill Company and DG Fairhaven (Furniss, M. 2020). 14
Figure 13. Biochar produced from gasification held in a hand for scale (Furniss 2020). 19
Figure 14. Flowchart of pyrolysis process showing the inputs and outputs (Campbell et al. 2018). 24
Figure 15. Flow chart of gasification-based power generation (Adapted from Sansaniwal et al. 2017). 26
Figure 16. Flowchart of the papermaking process as adapted from "Handbook for Pulping and Papermaking." (Beirmann 1996) 29
Figure 17. Flowchart of mulch production alternative (Lee et al. 2010). 32
Figure 18. Comparison of normalized weighted scores of criteria for each alternative. 35
Figure 19. Proposed location of preferred alternative (Google Earth Pro 2020). 36
Figure 20. Configuration of gasification system (CEC 2019-b) 36
Figure 21. Commercial 3 MW Organic Rankine Cycle (ORC) Generator (CEC 2019-b) 37
Figure 22. Results of sensitivity analysis performed on interest rate, LCOE, and electricity cost. 39
Figure 23. Impacts of biochar price on the LCEO (CEC 2019b) 39
Figure 24. Comparison of emissions for gasification and BAU case 40
Figure 25. Thermal Oil (TO) heater (CEC 2019-b) 49

List of Tables

Table 1. Net and cumulative revenues from 2017, projected to the year 2026 that show a net revenue of $105M that could be applied to development projects (RCEA 2017). 4
Table 2. Rate comparison of PG&E and RCEA energy options for residential tiered rate plan (E-1) (RCEA 2020b). 5
Table 3. Rate comparison of PG&E and RCEA energy options for large commercial and industrial plan (E-19SV) (RCEA 2020b). 6
Table 4. Federal criteria air pollutant standards (EPA 2019a). 11
Table 5. State classifications of criteria air pollutants (APCD 2020). 11
Table 6. Median concentration of common air pollutants emitted from the Humboldt Sawmill Company, DG Fairhaven, and Humboldt Bay PG&E powerplants from 2008 – 2017 (CARB 2020-c). 15
Table 7. Emissions in pounds per ton of fuel (Furniss 2020). 16
Table 8. Average heating values for Douglas-fir components (USDA 1979). 16
Table 9. Emissions of forest biomass harvesting, transportation, and combustion in pounds per BDMT of forest residuals (Sierra Club 2019) 17
Table 10. Approximate yields of solid, liquid, and gas products in percent weight from the biomass thermochemical conversion of pyrolysis and gasification (Akhtar et al. 2018) 18
Table 11. Comparison of the prominent thermochemical conversion processes and their typical operating temperature, pressure, and other variables (Basu 2013). 18
Table 12. Table of criteria used for scoring alternatives 22
Table 13. Inputs and outputs of the pyrolysis process. 23
Table 14. A list of common additives used in papermaking, their chemical compositions, and concentrations added in kg of additive per ton of paper produced (Abildgaard et al. 2003, Biermann 1996). 27
Table 15. The four main processes in pulping wood with the inputs and outputs. Tissue making uses chemical processes, which yield around 50% pulp for the inputted material (Biermann 1996). 28
Table 16. Life cycle emissions for composting (Lee et al. 2010). 33
Table 17. Possible scores and associated qualitative criteria used in Delphi Matrix decision analysis 34
Table 18. Results of Delphi Matrix decision analysis. 35
Table 19. Summary of capital costs (CEC 2019b) 37
Table 20. Summary of annual O&M costs (CEC 2019b) 38

1 Introduction

Humboldt County has a rich history in the lumber industry, with 400 mills operating by the late 1800's (THA 2020). Mill residuals were historically combusted in conical burners, which emitted particulate matter, greenhouse gases, dioxins, and other air pollutant that negatively impacted the surrounding community and environment. In the 1980's, several biomass power plants emerged as a means of combusting mill residuals to produce energy (Morris 2000). This form of sustainable energy production gained popularity because it reduced our dependence on non-renewable energy sources, such as fossil fuels (Morris 2000).

Today, woody biomass in Humboldt County is being used as fuel in two biomass electric power generation facilities: DG Fairhaven Power Company and Humboldt Sawmill Cogeneration Plant. The biomass is dried and combusted in a furnace that creates steam in a boiler. The steam is used to rotate turbines and create power that is introduced into the grid via PG&E. Like conical burning, this process produces criteria air pollutants that are harmful to the environment and human health. However, air quality standards set by federal, state, and county offices have restricted pollutants and byproducts exiting these facilities. Even with the pollution control equipment implemented at both facilities, air pollution is still a problem.

There has been much community concern regarding air quality and GHG emissions which has triggered the investigation of alternatives for the mill residue that could further the economic and environmental goals of Humboldt County. Energy and non-energy alternatives were considered for this analysis. The alternatives analyzed include pyrolysis, gasification, organic mulch, and pulping.

1.1 Objective

The objective of this project is to find alternative uses for sawmill waste categorized as biomass and compare the possibilities to the BAU case, where the biomass is being incinerated. Environmental impacts, economic feasibility, community acceptance, and longevity of design will be considered in the analysis of each option and will be presented to RCEA to review as possibilities for future design of the system.

The scope of this project considers the feedback given by the community regarding concerns related to increased GHG emissions because of biomass combustion. The feasibility of the chosen alternative will be decided upon by the constraints and criteria in later sections. Budget was not a concern brought forth by the client therefor it is not listed as a criteria/constraint. Humboldt County will be considered as the area of interest throughout the analysis of alternative uses for sawmill waste.

2 Background

2.1 Climate Change

Climate change and air pollution are among the top threats to the health of the planet, with air pollution contributing to 6.5 million deaths per year (Figueres et al. 2018); a number which is expected to double by the year 2050 (Lelieveld et al. 2015). Acute respiratory infection, heart disease, and other non-communicable diseases would lessen with the decline of harmful air pollutants, such as carbon monoxide, nitrogen dioxide, and sulfur dioxide (Haines et al. 2009). On October 20, 2018 the first meeting of the Global Conference on Air Pollution and Health was held, where global, national, and local leaders were able to discuss the health and climate change implications of air pollutants. The result of this meeting was requesting the attendees and leaders of their communities to develop strategies to reduce deaths caused by air pollution by the year 2030 with improvements in electricity generation, transportation, and food and agriculture, (Figueres et al. 2018).

2.1.1 Climate Change in California

The California Global Warming Solutions Act (AB 32) of 2006 is a plan to reduce California's overall carbon footprint by reducing GHGs from 14 to 10 tons-per-capita-day by the year 2020 (CARB 2020a). One of AB 32's key strategies of success weighed on California's ability to reduce GHG emissions from transportation by 30%. The plan was successful and reached its goal of reducing GHGs to levels comparable to 1990 levels with a large reduction in electricity generation, as the state continues to move toward more renewable energies (Barboza & Lange 2018). Even with this big win, GHG reduction is not evenly distributed across California's key strategies. The state had hope to reduce GHGs within the following industries: electricity generation, the cement industry, forestry, agriculture, and waste and recycling (CARB 2020a). While there was an initial drop in transportation GHGs from 2007 to 2013, emissions from this source are rising again and continue to be the largest source of emissions in California at 169 million metric tons (MMT) of GHGs in 2016, compared to 69 MMT resulting from electricity production. Figure 3 demonstrates the increase of emissions from 1990 to 2004 and the decrease from 2004 to 2030. The total GHG emissions had dropped to 429 MMT CO_2-eq (Barboza & Lange 2018).

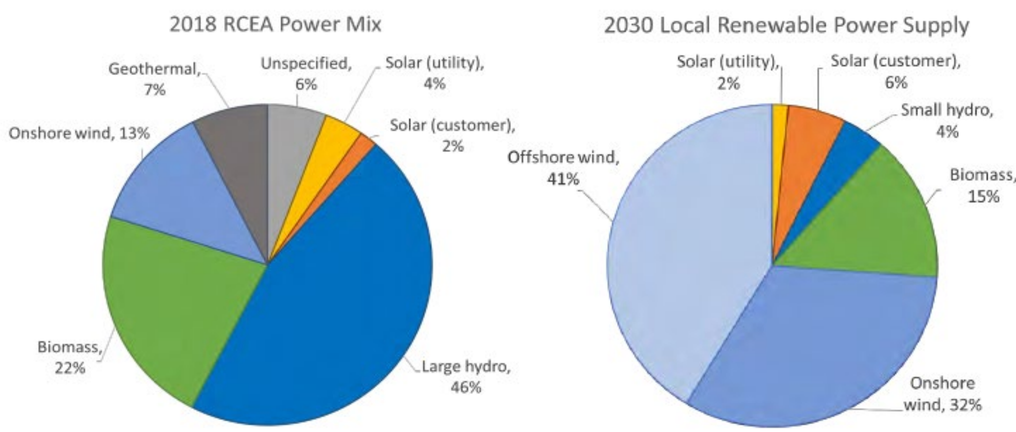

Figure 3. Emission trends for transportation and electricity production from 1990 to 2016, with projected goals for 2030 (Barboza & Lange 2018, Rogers et al. 2007).

The current California Climate Strategy's goals include reducing total GHG emissions to 40% below the previous 1990 target of 427 MMT of CO_2-eq (Rogers et al. 2007). Transportation and electricity production accounted for 35% and 11% of this total, respectively. In 2004, these percentages increase to 38% and 12% for transportation and electricity generation, while the total MMT CO_2-eq increase to 480 (Roger et al. 2007). Transportation emissions, while having decreased overall, are shown to have the smallest change, and are predicted to continue to increase (Barboza & Lang 2018). The largest contribution to the transportation emissions in California are made up of passenger cars and "light-duty" trucks, which make up 70% (Rogers et al. 2007). The State of California has no intended measures to reduce the amount of passenger vehicles on the road but can reduce transportation emissions through improved efficiency of delivery and heavy-duty trucks, and passenger buses (CARB 2020a).

2.1.2 Climate Change in Humboldt

The State of California has set a requirement for all local governments to create a Climate Action Plan (CAP) which sets an outline of tasks that the local government will carry out to reduce GHG emissions. The Regional CAP Partnership consists of Humboldt County, the RCEA, and the following cities in Humboldt County: Arcata, Eureka, Blue Lake, Ferndale, Fortuna, Rio Dell, and Trinidad (Humboldt County 2020). In 2015, RCEA conducted a GHG emissions inventory, that has been used as the baseline data for the Regional

CAP that is currently being drafted. The results of the inventory are shown in Figure 4. Wastewater treatment and leaked refrigerants were removed from the dataset that created the figure because their combined emissions were less than one percent of the total emissions in Humboldt County.

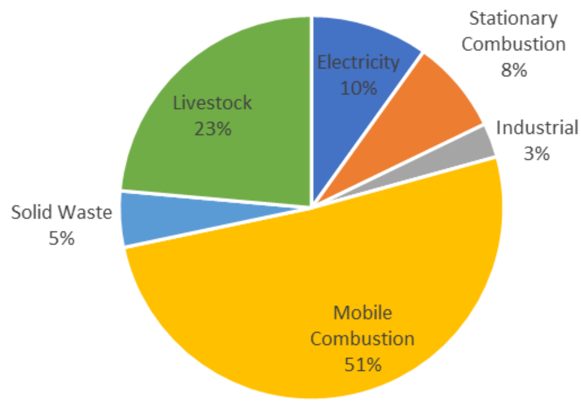

Figure 4. Emissions inventory in Humboldt County for 2015. Wastewater treatment and leaked refrigerants have been removed from this figure because their combined percentage of the total was less than one percent (Humboldt County n.d.).

In Humboldt County the category contributing most to total emissions was determined to be vehicle fuel combustion at 50%, with livestock manure management and electricity generation and consumption following at 23% and 10% (Humboldt County 2020). By 2030, Humboldt County would like to reduce the vehicle miles driven and replace 6,000 fuel combustion vehicles on the road with electric vehicles (EV) (RCEA 2019). These measures are expected to reduce transportation emissions by 65% by the year 2030. To reduce miles driven, alternatives to driving would be encouraged as new and extended biking and walking paths would be infilled and expanded (RCEA 2019). Other ideas presented at the Arcata CAP Workshop in May 2019 included incentives for carpoolers, an EV bus fleet, and free public transportation (McGuigan 2019). Electricity generation is procured and managed by RCEA and distributed with a mix of local renewables and electricity provided by PG&E. Currently, the County is committed to provide 100% renewable energy to its customers by 2025 (McGuigan 2019).

2.2 Redwood Coast Energy Authority

RCEA is a Joint Powers Agency formed by the same organizations in the Regional CAP Partnership and includes, the Humboldt Bay Municipal Water District (RCEA 2019). The RCEA purpose is to integrate sustainable and renewable energy initiatives and resources, and make clean energy available for its customers, while reducing Humboldt County's environmental impact through GHGs. The "Community Choice" program offered by RCEA includes an option to use local renewables as an alternative to power provided by PG&E, with a goal of reaching net zero GHG emissions from energy sources by 2030 throughout Humboldt County (RCEA 2019).

RCEA's responsibility to the public includes the procurement of electricity, load forecasting, and the scheduling of supply-demand transactions with the California Independent System Operator (CAISO). They are also responsible for setting electricity rates that meet minimum revenue requirements to create opportunity for economic development, while still being lower than PG&E projected rates (RCEA 2017). Projected cashflow analysis, illustrated in Table 1, shows net revenue of $75M that could be used in the development of future energy infrastructure and projects. During the first 5 years of operations, RCEA plans to reserve upwards of $30M as discretionary funds that would not be included in the cumulative revenue to be used in renewable energy projects (RCEA 2017).

Table 1. Net and cumulative revenues from 2017, projected to the year 2026 that show a net revenue of $105M that could be applied to development projects (RCEA 2017).

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Revenue	$29.2M	$46.3M	$48.6M	$50.8M	$53.6M	$56.2M	$59.3M	$62.8M	$65.7M	$69.4M
Operations & Maintenance	$25.1M	$41.0M	$41.1M	$43.0M	$44.8M	$45.2M	$46.6M	$48.3M	$49.6M	$51.4M
Net Revenue	$4.1M	$5.3M	$7.5M	$7.7M	$8.9M	$11.0M	$12.7M	$14.5M	$16.1M	$18.0M
Cumulative Revenue	$4.1M	$9.4M	$16.9M	$24.7M	$33.5M	$44.5M	$57.2M	$71.7M	$87.8M	$105.8M

2.2.1 Energy Use

Humboldt County relies on RCEA and PG&E for a combination of different energy sources. RCEA provides approximately 650 GWh of annual load to Humboldt County (RCEA 2020c). From 2009 – 2018, the average total electricity consumption for Humboldt County was approximately 864 GWh (Figure 5) (CEC 2020). This total electricity consumption is a sum of residential and non-residential users with respective average annual uses of 428 GWh and 436 GWh (CEC 2020). Over this ten-year period, the total electricity consumption was reduced by approximately 11.8 %, from 908 GWh to 801 GWh. During this period, residential electricity consumption was reduced by 19.5 %, while non-residential consumption was reduced by 3.8 %.

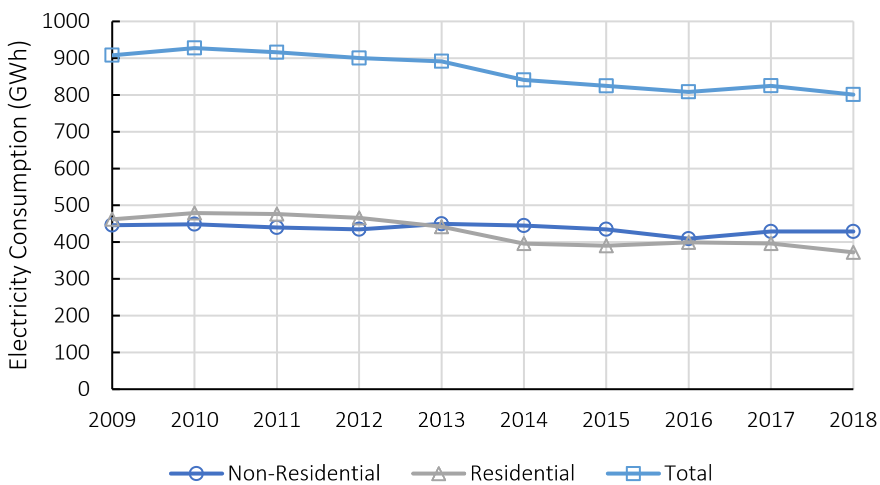

Figure 5. Humboldt County annual electricity consumption from 2009 – 2018 (CEC 2020).

2.2.1.1 *Community Choice Energy Program*

In 2017, RCEA implemented Humboldt County's CCE Program with the intention of expanding local sources of renewable energy to support economic development, lower consumer rates, and reduce greenhouse gas (GHG) emissions (RCEA 2020a). RCEA services approximately 60,000 customers (92%) in Humboldt County through the CCE program, while the remaining 8% opt out for PG&E service (Engel, personal communication, 2020). The CCE program creates collective annual savings of approximately $2 million for Humboldt County customers (Engel, personal communication, 2020). The CCE program consists of a combination of different renewable energy sources, known as the RCEA Power Mix, and includes large hydro, biomass, onshore wind, geothermal, solar (utility), solar (customer), and unspecified (RCEA 2019)

(Figure 6). The 2030 potential power mix for Humboldt County will include more local renewable source of energy with the development of onshore and offshore wind projects (Figure 6).

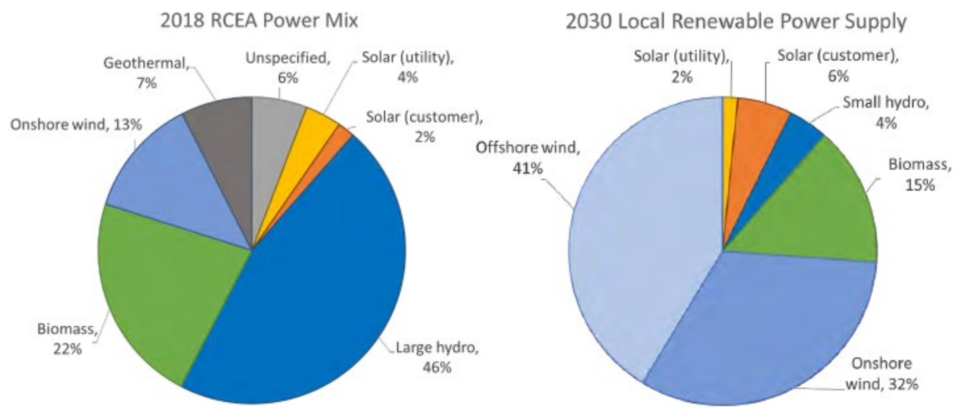

Figure 6. RCEA 2018 power mix for CCE customers and potential mix for 2030 (RCEA 2019).

2.2.1.2 *Energy Costs in Humboldt County*

Combined, RCEA and PG&E offer a variety of different electricity services to residential and non-residential customers. These services vary by how the electricity is generated and whether it is considered a renewable source of energy. PG&E has a standard electricity package using non-renewable energy sources (natural gas) in addition to the Solarchoice energy package, that consists of 100% renewable energy from solar power (RCEA 2020b). RCEA offers the REpower and REpower+ energy packages, which consist of 42% and 100% renewable energy sources, respectively (RCEA 2020b). Below, Table 2 shows a comparison of PG&E and RCEA energy options for a standard residential tiered rate plan. The REpower energy package offered by RCEA has total electricity cost of $0.28034/kWh, while the standard PG&E energy package has a total electricity cost of $0.28172, creating savings of approximately 0.49% for REpower customers (RCEA 2020b). The REpower energy package is the default energy package for the CCE program and is considered 42% renewable (RCEA 2020b).

Table 2. Rate comparison of PG&E and RCEA energy options for residential tiered rate plan (E-1) (RCEA 2020b).

Residential: E-1	PG&E	PGE Solarchoice (100% Renewable)	REpower (42% Renewable)	**REpower+** (100% Renewable)
Generation Rate ($/kWh)	$0.11778	$0.09436	$0.08877	$0.09877
PG&E Delivery Rate ($/kWh)	$0.16394	$0.16394	$0.16394	$0.16394
PG&E PCIA/FF ($/kWh)	N/A	$0.02979	$0.02763	$0.02763
Total Electricity Cost ($/kWh)	$0.28172	$0.28809	$0.28034	$0.29034

Below, Table 3 shows a comparison of PG&E and RCEA energy options for commercial and industrial customers. The REpower energy package offered by RCEA has total electricity cost of $0.18889/kWh, while the standard PG&E energy package has a total electricity cost of $0.19013, creating savings of approximately 0.66% for REpower customers (RCEA 2020b). Between the REpower and standard PG&E energy packages, the cost of electricity is approximately 33% lower for commercial and industrial customers than it is residential customers, while their annual electricity consumption is roughly equivalent.

Table 3. Rate comparison of PG&E and RCEA energy options for large commercial and industrial plan (E-19SV) (RCEA 2020b).

Commercial/Industrial: E-19 SV	PG&E	PGE Solarchoice (100% Renewable)	REpower (42% Renewable)	REpower+ (100% Renewable)
Generation Rate ($/kWh)	$0.10583	$0.08079	$0.07747	$0.08747
PG&E Delivery Rate ($/kWh)	$0.08430	$0.08430	$0.08430	$0.08430
PG&E PCIA/FF ($/kWh)	N/A	$0.02830	$0.02712	$0.02712
Total Electricity Cost ($/kWh)	$0.19013	$0.19339	$0.18889	$0.19889

2.3 Stakeholders

Community members, groups, businesses, and government groups all hold a stake in how the sawmill biomass is processed and used. Currently, the biomass is being burned which has caused community concern regarding the air quality around the biomass plants. The following is a list of who benefits and suffers from the BAU case, where mill wastes are being used as fuel at Humboldt Sawmill Company and DG Fairhaven to generate electricity.

Who benefits from BAU?

- Consumers: RCEA's Community Choice Option allows their customers to use electricity provided by local and renewable generators. The rate for this option comes at a lower price point than PG&E and provides a greater percent of renewables than PG&E, as RCEA sets this rate low enough to benefit their customers.
- Employees of Biomass Powerplants: Employees and their families benefit from the steady source of income, medical benefits, and retirement plans made available to them from working at Humboldt Sawmill Company and DG Fairhaven.
- Local Economy: While providing jobs and benefits for community members, the powerplants are contributing to the local economy. The employees have income to spend at local stores to support their needs. The trickle down and cycle of money in the economy in Humboldt, supports its future economic stability.
- Lumber Industry: Without biomass powerplants, lumber mills would have to find alternative ways to dispose of their waste. Powerplants pay the mills for their waste, which would otherwise have to be hauled to landfills which at increased transportation fees and tipping fees for disposal.
- Farmers: Local farmers and ranchers benefit from adding the fly ash to their soil. Fly ash is used as a soil amendment to reduce the soils bulk density, improves the moisture retention of the crop area, and increase the uptake of minerals into the crops (Kalra et al. 1998).

Who suffers from BAU?

- Neighbors: Air quality regulations are put in place to protect human health, but these limits are not set to zero emissions neighbors or the powerplants could be affected by close range emissions coming from the stacks.
- PG&E: The continued growth of communities creating local renewables takes away from PG&E's profits. PG&E still owns the transmission system and has continued to be responsible for all billing.

2.4 Site Information

This section is dependent on the preferred design alternative and will not be fully completed until a design is chosen. The following section will include general information about Humboldt County's location, climate, historic land use, and economic background in the lumber industry.

2.4.1 Location

Humboldt County is in the coastal region of Northern California and Eureka, its largest city, is 270 miles North of San Francisco on Highway 101. The most recent census population for Humboldt County is 136,000 in 2018. The landscape includes mountain ranges, farmland, river valleys, and the Pacific Ocean (Figure 5). A project locator map including the locations of the DG Fairhaven and Humboldt Sawmill Company power plants can be viewed below (Figure 7).

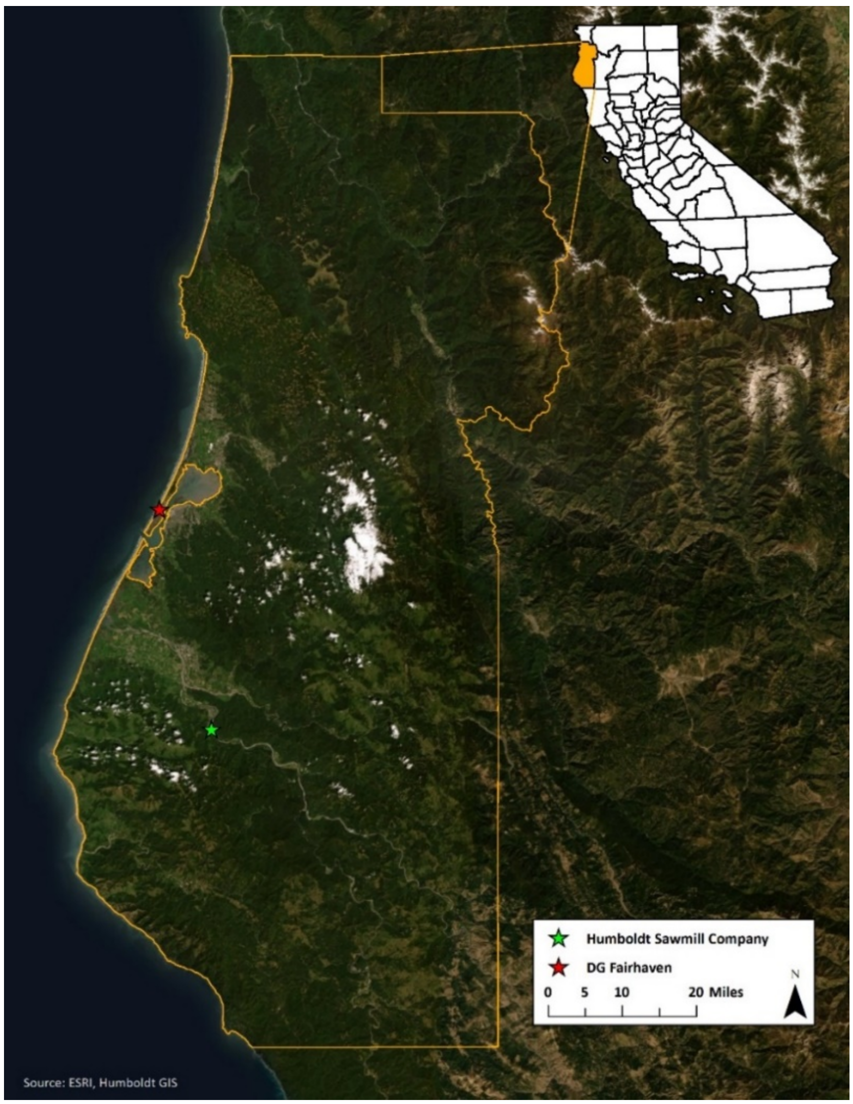

Figure 7. Humboldt County project locator map (Seale 2020).

2.4.2 Climate

Most of Humboldt County's climate is described as temperate rainforest. These temperate regions are located within 15 to 30 miles of the coast (Humboldt County 2020a). Temperate weather is described as having mild changes in temperature with moderate rainfall, and random periods of drought (Kazemi & Mohorko 2017). In Humboldt County, rainfall occurs in almost every month, with annual totals between 40 and 100 inches, depending on the location (Humboldt County 2020a).

2.4.3 Floodplain

The DG Fairhaven Powerplant is located on the Samoa Peninsula between Humboldt Bay and the Pacific Ocean. According to the FEMA floodplain, this site is unaffected by both 100- and 500-year floods. The Humboldt Sawmill Company is in Scotia, California, 25 miles South of Eureka on Highway 101. The powerplant is bordered by the Eel River and the highway, with the highway East and the river West of the plant. Because of its proximity to the Eel River, the powerplant is in both the 100- and 500-year floodplains, shaded in gray on the map in Figure 8.

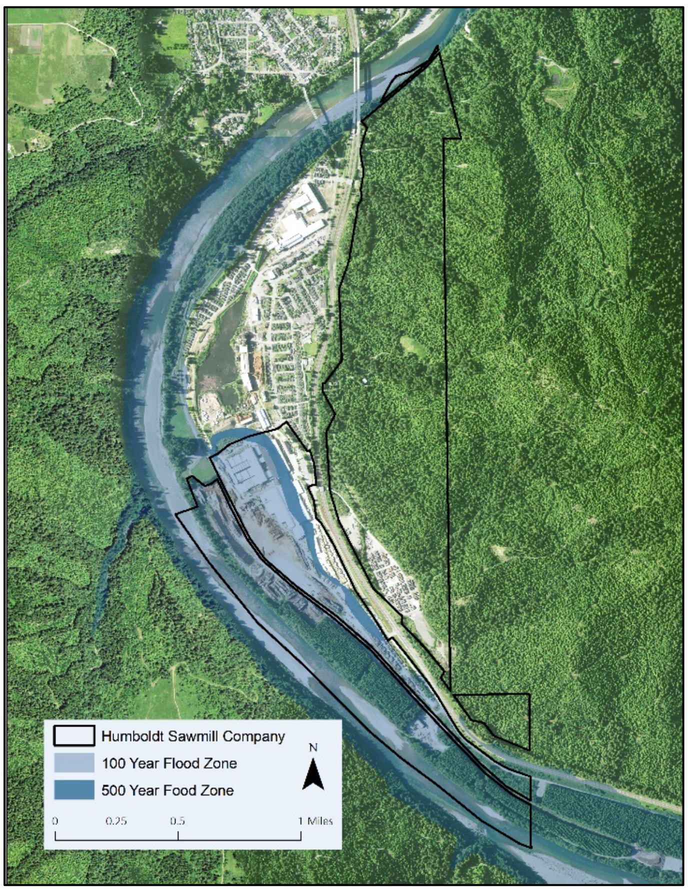

Figure 8. Humboldt Sawmill Company parcel with 100-year and 500-year flood zones (Source: FEMA 2015, National Mapper) (Seale 2020).

2.5 Ecology

Humboldt County is made up of diverse land cover types consisting of 61% coniferous forest, 23% oak woodland, 10% grassland, and 6% other (County of Humboldt 2019a). The following topics characterize Humboldt's ecology including but not limited to native and endangered species, soils, hydrology, and climate change. Each of these topics are influenced by the harvesting or retention of woody biomass.

2.5.1 Native and Endangered Species

As woody material is removed for biofuel utilization in Humboldt County, native species become threatened upon destruction of their habitat. An article by the Ecological Society of America stated, "Early forest ecologists recognized woody debris as one of the most important resources for animal species in forests" (Grodsky 2018). The article also states that most regulatory guidelines for removing woody debris are enforced assuming plants and animals react negatively to decreased volumes of biomass (Grodsky 2018). It is important to keep in mind that there are however exceptions to how each species react to the absence or presence of woody residue given the complexity of the ecological web. The following species are on the Humboldt threatened and endangered species list: Western Snowy Plover, Tidewater Goby, Coho Salmon, Chinook Salmon, Steelhead, Menzies' Wallflower, Beach Layia. The Western Snowy Plover is a small shorebird that nests above the hightide line on the coast of Humboldt and in dunes and beaches at creeks and river mouths. The Tidewater Goby is found in brackish waters near the coastal line. The Goby migrates upstream to tributaries during mating season. Coho Salmon, Chinook Salmon, and Steelhead spend half of their lifecycle in marine waters and the other foraging in freshwater tributaries. The Menzies' Wallflower and the Beach Layia are typically found in the dunes along the coastal region (USFW 2013).

Studies have shown that saproxylic invertebrates, classified as invertebrate's dependent on dead debris for survival (AES 2020), are supported by the presence of woody residue. Woody debris provides shelter, food, a place for laying eggs, and retains the necessary moisture needed for survival by saproxylic invertebrates (Grodsky 2018). Although saproxylic invertebrates are not listed on the Humboldt threatened endangered species list, their ecosystem remains in danger due to biomass harvesting which could potentially become detrimental to their species in the future.

2.5.2 Soils

Characterizing soils in the area of interest is important for determining the frequency at which biomass should be harvested to preserve the soils adequacy of tree fertility and stabilization. The hydrological soil group classified for areas in coastal regions of Humboldt County were of group A, characterizing the soil as having a high infiltration rate. Sandy soils such as these have a high rate of water transmission and lower runoff rates. The hydrological soil group classified for areas inland in Humboldt County were mostly characterized as groups C and D. These soils are very wet and have slow infiltration rates which forces larger rates of runoff (USDA 2019a). Research from the University of California found that soil nutrient levels increased after saw log harvesting and decreased after whole log harvesting (U. of C. 2020). It is likely that woody debris was left behind in the event of saw log harvesting but not in the event of whole log harvesting suggesting a decline in nutrient levels from whole log harvesting due to lack of tree remnant retention. Concern for habitats affected by removal of dead debris due to an increased need for woody biomass was rated high. Much of what is classified as "dead down wood" supports the growth of trees and input of nutrients into the soil ultimately leading to increased biodiversity (U. of C. 2020).

2.5.3 Hydrology

A watershed basin was selected through StreamStats in Samoa to represent the Humboldt coastal region. The data reported a mean annual precipitation of 40.4 inches and 59.5% of area covered by forest. Based on a report generated by StreamStats that characterizes the dense redwood forest in Humboldt County, mean annual precipitation ranges from 63.6 inches with 73% of area covered by forest (USGS 2019). Removal of debris in the event of biomass harvesting results in increased runoff in streams and alters the soil nutrient levels which could negatively impact aquatic and plant life (U. of C. 2020). Consequently, water quality is also affected when woody debris is removed due to alteration in flow paths (U. of C. 2020).

2.5.4 Climate Change

Climate change has already significantly impacted Humboldt ecology through wildfires, temperature change, and sea-level rise. As the planet warms, wildlife acreage in Humboldt is projected to change due to an increase in forest fires. Wildfires that occur periodically are beneficial to the ecosystem encouraging vegetation and the release of nutrients into the soil as well as clearing underbrush that could potentially cause uncontrolled wildfires (CDPH 2017). The downfalls however can be detrimental. The map shown below illustrates the estimated area burned in 2085 assuming the high carbon emission scenario (Figure 9). Based on the map Humboldt County has a projected wildfire risk ranging from 2-5 (CDPH 2017).

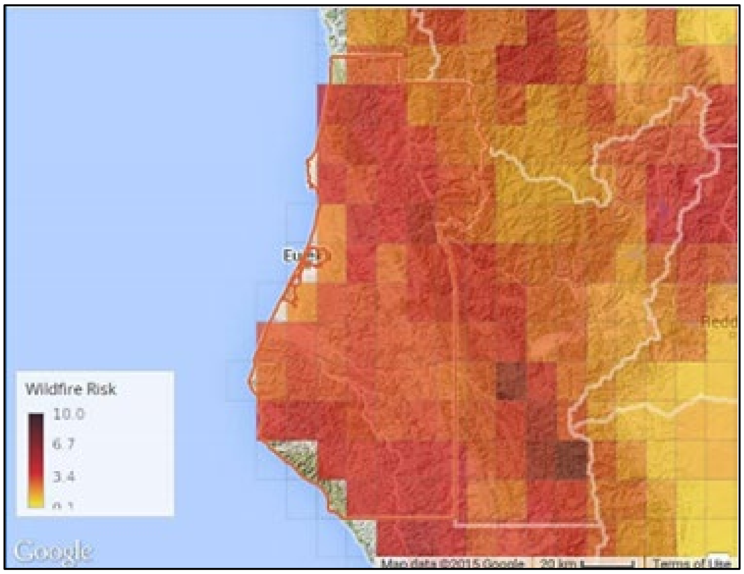

Figure 9. Potential increase and decrease of areas burned for high carbon emission scenario projected to 2085 (CDPH 2017).

Projected sea-level rise is another consequence to climate change that could negatively impact the ecosystems of Humboldt. It is predicted that California coasts will experience a 66-inch sea level rise within the century. Humboldt is already being threatened by the sea-level rise today and will continue to experience this increase based on a map demonstrating baseline flooding areas for a 100-year flood as well as an additional 55 inches of sea-level rise based on the high carbon emission scenario (CDPH 2017).

2.6 Regulations & Permitting

Federal, State, and County laws and agencies enforce regulations and permits that hold jurisdiction over Humboldt County regarding air quality, solid waste, and stormwater discharge.

2.6.1 Air Quality

The Federal Clean Air Act required the Environmental Protection Agency (EPA) to identify and set national standards for the following criteria air pollutants (listed in CFR 40 part 50); Suspended particulate matter (PM_{10} and $PM_{2.5}$), CO, Ozone (O_3), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2) and Lead (Pb) (Table 4) (County of Humboldt 2019b). Ambient air pollutant standards have two classifications identified in the Clean Air Act as follows, "Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings" (EPA 2019a).

Table 4. Federal criteria air pollutant standards (EPA 2019a).

Criteria Pollutant	Primary / Secondary	Averaging Time	Level	Form
CO	Primary	1 hour	35 ppm	Not to be exceeded more than once per year
Pb	Primary & Secondary	Rolling 3-month average	0.15 µg/m^3	Not to be exceeded
NO_2	Primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Primary / Secondary	1 year	53 ppb	Annual Mean
O_3	Primary / Secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
$PM_{2.5}$	Primary / Secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
PM_{10}	Primary / Secondary	24 hours	150 µg/m^3	Not to be exceeded once per year on average of 3 years
SO_2	Primary	1 hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

The North Coast Unified Air Quality Management District (NCUAQMD) is responsible for the issuance of permits, overseeing air quality plans, and monitoring and reporting data for the North Coast Air Basin. The NCUAQMD must review pertinent air quality documents developed by the CEQA. In accordance with the California Clean Air Act of 1988, the State required stricter standards for criteria air pollutants such as PM_{10} and ozone. The State of California also adopted limits for ambient air quality stating whether the pollutant is in "attainment" or not, seen in Table 5 (APCD 2020). The principal pollutant present in Humboldt County is PM_{10}. The NCUAQMD is listed as "attained" for the federal PM_{10} standard however "not attained" for the State 24-hr particulate standard which equals 50 micrograms per cubic meter of PM_{10} (APCD 2020).

Table 5. State classifications of criteria air pollutants (APCD 2020).

Pollutant	Federal	State
Ozone	Unclassified/Attainment	Attainment
SO_2	Unclassified	Attainment
NO_2	Unclassified/Attainment	Attainment
$PM_{2.5}$	Unclassified/Attainment	Attainment
PM_{10}	Unclassified	Non-attainment
Sulfates	No Standard	Attainment
Lead	Unclassified/Attainment	Attainment
H_2S	Standard	Attainment
Vinyl Chloride	Standard	Attainment
CO	Standard	Attainment

Title V of the Clean Air Act ensures permitting to all large facilities (major sources) contributing to pollution as well as some small sources. The "Clean Air Act part 70" permits are mainly issued by state and local agencies whereas the "Clean Air Act part 71" permits are issued by the EPA on a federal level. Major sources are classified as a source which has the potential to emit air pollutants above the threshold which is 100 tons/year (EPA 2019b).

2.6.2 Feedstock

A full solid waste facilities permit must be obtained under Title 14 in the California Code of Regulations for the following facilities. Compost facilities with feedstock other than green material must obtain a Compostable Materials Handling Permit as stated in section 17854. Green material composting cannot generate more than 12,500 cubic yards of feedstock and compost on-site at once per Title 14 section 17857.1. Chipping and grinding operations cannot exceed or handle over 500 tons/day according to Title 14 section 17862.1. Section 17403.7 requires permitting for large volume transfer/processing facilities that process 100 tons or more of solid waste per day (CalRecycle 2019).

2.6.3 Stormwater

The EPA has authorized many facilities to obtain National Pollutant Discharge Elimination System (NPDES) coverage through their state (Stormwater Discharges from industrial activities). The Clean Water Act (CWA) provides the California Water Boards with the jurisdiction to establish regulations and permitting for stormwater discharges through the NPDES permit. Industrial facilities must follow the federal regulations by 40 CFR per the NPDES permit (California Water Boards 2019). There are 11 categories characterizing industrial activities that are regulated by 40 CFR. Category one represents facilities subject to federal stormwater effluent with standards defined in Parts 405-471. Construction sites that disturb more than five acres which are generally permitted separately due to differences in activities are listed in category 10 (EPA 2019c).

Storm water permitting programs are implemented through the California Regional Water Board (CRWB) such as the MS4 permit. The MS4 permit is composed of two phases: Phase I including permits for medium and large municipalities of 100,000 to 250,000 people and more than 250,000 people, respectively, and Phase II regulating small municipalities of less than 100,000 people. Other permit programs implemented by the CRWB include the Statewide Construction Storm Water General Permit and the Statewide Industrial Storm Water General Program. The Industrial Storm Water General Program ensures that facilities adopt the most efficient technology for eliminating pollutants in their storm water discharges. In addition, the program requires industrial facilities create a pollution prevention plan and monitor effluent standards that meet the regulations stated in the statewide permit (CRWB 2019).

2.7 Biomass Plant Characterization

The current system includes two biomass fueled electricity generating facilities: DG Fairhaven, LLC, and the Humboldt Sawmill Company. Together, these facilities generate electricity through the combustion of woody biomass and provide electricity to RCEA.

2.7.1 Site Information

The two-biomass fueled electricity generating facilities that provide power to the RCEA include DG Fairhaven and the Humboldt Sawmill Company. DG Fairhaven has an operational capacity of 15 MW located in Samoa, CA (CBEA 2020a). The extent of the 10.4-acre parcel can be viewed below (Figure 10). This facility started operating in 1986 and it processes over 250,000 tons (wet weight) of biomass per year that is sourced from local sawmills and logging industries (CBEA 2020a). The content of the woody biomass includes sawdust, wood chips, bark, and shavings (RCEA 2016). The current system consists of a boiler that burns woody biomass and produces steam at approximately 180,000 lb/hr to power an 18.75 MW steam turbine generator (RCEA 2016). Natural gas is used to power up the facility and when the moisture content of the biomass exceeds 60% (RCEA 2016). For DG Fairhaven to retain its Qualifying Facility status, co-firing of natural gas must not exceed 20% of the total energy production (RCEA 2016). For the years of 2014 and 2015, DG Fairhaven produced 137,331 MW and 132,589 MW, respectively (RCEA 2016). DG Fairhaven has a 1-year contract with RCEA and in 2018 they provided 10 MW of their 15 MW capacity to RCEA (RCEA 2020c).

Figure 10. Location of DG Fairhaven parcel number 40112111 (Seale 2020).

The Humboldt Sawmill Company is a 32.5 MW facility located in Scotia, CA (CEC 2019a). This facility started operating in 1987 and processes over 150,000 tons (dry weight) of biomass per year that is sourced from local sawmills and logging industries (CBEA 2020b). The current system consists of three boilers that burn woody biomass and produce steam to power three steam turbine generators that generate approximately 125,000 to 175,000 MW annually (CBEA 2020b). This facility provides power to RCEA as well as steam to a neighboring sawmill (CBEA 2020b). The Humboldt Sawmill Company has a 5-year contract with RCEA and in 2018 they provided 13.25 MW of their 32.5 MW capacity to RCEA (RCEA 2020c). The extent of the 599-acre parcel can be viewed below (Figure 11).

Figure 11. Location of Humboldt Sawmill Company parcel number 20535123 (Seale 2020).

2.7.2 Woody Biomass Processing Capabilities

The DG Fairhaven and Humboldt Sawmill Company power plants receive woody biomass from local sawmills that is considered unusable for manufacturing purposes (RCEA 2016). Local sawmills produce 140 truckloads per day, five days a week, for a total of 700 loads per week (Figure 12.) (Furniss 2020). Approximately 15 – 40% of this volume leaves Humboldt County or is used locally (Furniss 2020). The Humboldt Sawmill Company processes 50 truckloads per day, seven days per week, while DG Fairhaven processes 35 truckloads per day, seven days per week (Furniss 2020).

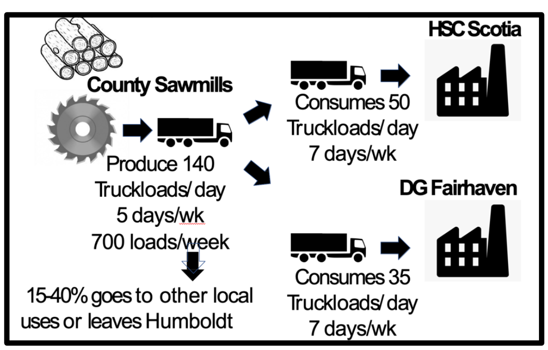

Figure 12. Typical supply chain for Humboldt Sawmill Company and DG Fairhaven (Furniss, M. 2020).

2.7.3 Emissions

This section focuses on the emissions created through the combustion of woody biomass from the DG Fairhaven and Humboldt Sawmill Company power plants.

2.7.4 Air Quality

One of the primary concerns associated with burning biomass to create energy is the production of harmful air pollutants. A ten-year analysis of the emissions produced by the Humboldt Sawmill Company and the DG Fairhaven biomass plants revealed median annual CO_2 emissions of 258,042 and 176,738 MT of carbon dioxide equivalent ($MTCO_2$-eq), respectively (Table 6) (CARB 2020c). It should be noted that while the CO_2 emissions from the PG&E natural gas powerplant is within the range of the two biomass plants, it has significantly lower emissions for other air pollutants. Additionally, the PG&E powerplant has a much larger operational capacity of 163 MW. Other common air pollutants of concern that are emitted include nitrogen oxide (NOx), PM_{10}, $PM_{2.5}$, Benzene, sulfur oxides (SOx), and volatile organic compounds (VOCs), in addition to many others (CARB 2020c). These air pollutants can have adverse effects on human health, the atmosphere, and the environment.

Table 6. Median concentration of common air pollutants emitted from the Humboldt Sawmill Company, DG Fairhaven, and Humboldt Bay PG&E powerplants from 2008 – 2017 (CARB 2020-c).

Facility	MW	CO_2 ($MTCO_2$-eq)	NOx (tons)	PM_{10} (tons)	$PM_{2.5}$ (tons)	Benzene (lbs)	SOx (tons)	VOC (tons)
Humboldt Sawmill Company	32.5	258,042	171	37	34	10,786	32	30
DG Fairhaven	18.7	176,738	152	30	28	8,951	28	19
PG&E (gas)	163	196,121	25	6	6	654	1	12

2.7.5 Air Quality Controls

Both biomass plants have air quality control measures to help mitigate some of the air pollutants that are created from the combustion of biomass. Air quality control measures implemented at both plants include a mechanical multicyclone collector, electrostatic precipitator, and a forced overfire air system (Furniss 2020). Mechanical cyclone collectors operate by introducing a centrifugal force that creates a cyclone that collects relatively large particles greater than 15 μm in diameter (EPA n.d.). Electrostatic precipitators work by creating an electrostatic field that ionizes particles, making them attracted to electrodes of the opposite charge (Science Direct 2011). This technology can capture exceptionally fine particles with diameters less than 1 μm (Science Direct 2011). The main goal of the forced overfire air system is to reduce NOx being created in the combustion process (CECO 2020). Combined, these technologies help to reduce the total volume of emissions produced from the biomass plants, although air quality issues persist.

2.7.6 Air Quality Concerns

Air quality concerns mainly have to do with particulate matter and emissions. These pollution particulates can affect both the lungs and heart if not managed. Severe effects from lung exposure include respiratory diseases, decreased lung function, and death (EPA 2012). Once these particulates are inhaled, they can pass from the lungs into the bloodstream, small particulates especially, where the most significant impacts occur (Furniss 2020). Severe effects from this exposure include heart attacks and premature death among people with heart disease (EPA 2012). Table 7 displays the emissions associated with different common combustions.

Table 7. Emissions in pounds per ton of fuel (Furniss 2020).

	$PM_{2.5}$ (lb/ton)	NO_x (lb/ton)	CO (lb/ton)	VOC (lb/ton)	CO_2 (lb/ton)
Industrial (Dry Fuel)	0.7 – 6.5	8.8	10.8	0.31	3120
Residential Stove	6 – 23	2 – 14	46 – 160	10- 44	~2800
Prescribed Burn	12 – 34	6	167	19	~2700
Wildfire	~30	4	140	12 – 24	~2600

2.8 Biomass Characterization

2.8.1 Energy Content

There are several factors that influence the energy content of woody biomass, and thus the energy produced from biomass power plants. Certain characteristics of woody biomass that can influence the combustion process include the type of tree, density, water content, and quality. Two trees that are commonly harvested in Humboldt County include Douglas-fir, redwood, and tanoak (HCDCDS 2006). The average energy content of Douglas-fir components is approximately 9,686 Btu/lb (Table 8) (USDA 1979). Redwood is also considered a soft-wood and is likely to have similar heating values.

Table 8. Average heating values for Douglas-fir components (USDA 1979).

Density (lb/ft^3)	Wood (Btu/lb)	Bark (Btu/lb)	Twigs (Btu/lb)
33.1	9,100	10,845	9,113

Moisture is one factor that influences the energy content of wood. As the moisture content of wood increases, the energy efficiency of the wood decreases (Bioenergyadvice 2020). A greater input of energy is needed to dry the wood before it can burn. Wood chip material containing 25 - 30% moisture content is considered good quality (Bioenergyadvice 2020). The considerable amount of precipitation that Humboldt County receives can negatively influence the quality and energy efficiency of the woody biomass. According to Bob Marino, the plant manager at the DG Fairhaven plant, the woody biomass has a current moisture content of approximately 56% (Marino, personal communication, 2020). As expected, the moisture content increases during the winter months when there is increased rainfall and decreases during the summer months when it is drier.

2.8.2 Incineration Byproducts

Certain processes within the biomass power plant produce material that can be sold or donated and reused for different purposes. For example, the electrostatic precipitator at the DG Fairhaven plant produces registered organic fly ash as a byproduct that is donated and delivered to farmers to be used as a stable soil amendment to help control soil pH (Marino, personal communication 2020)[2]. The biochar that is generated from the combustion process is sold to a filtering company (RCEA 2016).

2.8.3 Biomass Context

While some are opposed to biomass incineration as a form of energy production due its associated emissions, others view this technology as a means of moving away from fossil fuels. Biomass can be used as a "bridge" solution as we transition from fossil fuels to other forms of renewable energy sources (Furniss 2020). There are still concerns with this technology, but it creates an opportunity as a bridging technology and method of processing unusable woody material produced from local sawmills.

2.9 Alternative Technologies: (Energy)

Thermochemical conversions are processes that convert biomass to energy at high temperatures between 300°C to 1,300°C (Basu 2013). These technologies include combustion, pyrolysis, and gasification which are all prominent in the commercial stages (De et al. 2018). From biomass, products such as liquid, gaseous, and solid fuels can form depending on the process conducted, which are described below.

Biomass conversion has been used since the ability for humankind to harness fire. However, the discovery of more energy dense fossil fuels such as coal and oil has made biomass less incising. This was counteracted by recent realizations of global warming and the detrimental effects of releasing these carbon heavy fossil fuels into the atmosphere when burned (Basu 2013). Now biomass conversion has large motivating benefits including renewable, environmental, and sociopolitical benefits.

2.9.1 Combustion

Combustion is the oldest practiced thermochemical conversion which happens when campfires or wood stoves are ignited. This process involves the burning of biomass and is the technique biomass power plants utilize to produce energy. Combustion operates in temperatures between 700°C and 1,400°C (Table 9) and at low pressures (Basu 2013). Combustion is an exothermic reaction where oxygen and hydrocarbons react within the biomass to produce energy in the form of heat. In 2017 alone, California's combined biomass plants incinerated an approximated 3.4 million Bone-Dry Tons (BDMT) of woody biomass (Sierra Club 2019). Table 9 below displays the different emissions and particulate matter produced for the harvest, transport, and combustion for typical biomass power plants. CO_2 is shown to produce 99.7% of the total emissions weight in combustion.

Table 9. Emissions of forest biomass harvesting, transportation, and combustion in lbs/ BDMT of residuals (Sierra Club 2019).

	Emissions by Supply Chain Phase (lbs/BDMT)		
	Harvest	**Transport**	**Combustion**
VOC	0.034	0.001	0.212
CO	0.242	0.001	3.045
NO_x	0.273	0.004	4.361
PM_{10}	0.010	0.002	0.502
$PM_{2.5}$	0.001	0.002	0.251
SO_x	0.001	<0.001	0.163
CH_4	0.003	<0.001	0.152
N_2O	<0.001	<0.001	0.436
CO_2	69.13	0.05	3510

2.9.2 Pyrolysis

Pyrolysis is the thermal decomposition of a woody organic substance otherwise known as biomass. Unlike Combustion, this process utilizes an anoxic environment with high temperatures between 300°C to 1300°C (Basu 2013, Campbell et al. 2018). In this reaction heat must be supplied externally, or sometimes from the combustion of the gas it produces (Severy et al. 2018). Pyrolysis produces three by-products consisting of a liquid: bio-oil, a solid: biochar, and a gas: synthetic gas or syngas (Tisserant and Cherubini 2019). Syngas is a versatile fuel which can be used in boilers, engines, and electricity generators to produce energy (Akhtar et al. 2018). The production of these by-products is controlled through three main subcategories consisting of slow, intermediate, and fast pyrolysis.

Slow pyrolysis utilizes a slow heating rate which yields mainly biochar and syngas; approximately 35% by weight for both (Table 10). This process produces the largest amount of biochar by weight out of all pyrolysis subcategories and typically operates at 400-500 °C (Campbell et al. 2018). Fast pyrolysis rapidly heats the biomass at temperatures between 850-1250 °C and produces mainly bio-oil; approximately 70% by weight (Akhtar et al. 2018, Basu 2013, Campbell et al. 2018). Intermediate pyrolysis uses aspects from both slow and fast pyrolysis where the main product is bio-oil. Here, bio-oil, syngas, and biochar make up 50%, 25%, and 25% of the yield by weight respectively (Akhtar et al. 2018). Typically, biochar yields by weight decrease as pyrolysis reactor temperatures increase (Spokas 2010).

Table 10. Approximate yields of solid, liquid, and gas products in percent weight from the biomass thermochemical conversion of pyrolysis and gasification (Akhtar et al. 2018).

	Product Distribution (wt %)		
Technology	**Solid (Char)**	**Liquid (Bio-Oil)**	**Gas**
Slow Pyrolysis	35	30	35
Fast Pyrolysis	10	70	20
Gasification	10	5	85

Several different types of pyrolysis reactors are used today. Among the most popular there are fixed/moving bed, bubbling fluidizer bed, circulating fluidizer bed, ultrarapid reactor, rotating cone, alblative reactor, vacuum reactor (Basu 2013). Mobile pyrolysis units have even been designed where they can be transported to a biomass storage location. These mobile units can fit on a standard sized trailer and produce bio-oil, syngas, and biochar products (Pyrotech Energy 2016). This decreases transportation costs assuming the biomass takes more effort to transport than the usable oil, gas, and solids produced.

2.9.3 Gasification

Gasification is a process similar to pyrolysis but takes it a step further by introducing partial oxidation and increasing the reaction temperature in the reactor (Severy et al. 2018). Instead of an anoxic environment used in pyrolysis, a small level of oxidant is used with temperatures between 500°C and 1,300°C (Table 11). During partial oxidation, the oxidant can consist of oxygen, air, subcritical steam, or a blend of these (Basu 2013). This process's heat demand is supplied from the combustion of the oxidant and biomass feedstock inside the reactor. Gasification produces two main by-products; the primary being syngas which is 85% by weight (Table 10), and the secondary being biochar which is 10% by weight. This ratio of CO and H_2 depends entirely on the properties of the feedstock as well as the operating conditions of the process (De et al. 2018).

Table 11. Comparison of the prominent thermochemical conversion processes and their typical operating temperature, pressure, and other variables (Basu 2013).

Process	Temperature (°C)	Pressure (MPa)	Catalyst	Drying
Liquefaction	250 – 330	5 – 20	Essential	Not required
Pyrolysis	300 – 600	0.1 – 0.5	Not required	Necessary
Combustion	700 – 1400	≥ 0.1	Not required	Not essential, but may help
Gasification	500 – 1300	≥ 0.1	Not essential	Necessary

Overall, gasification includes three main steps consisting of pretreatment of the feedstock, gasification, and gas clean-up. Pretreatment of the feedstock consists of drying and reducing the biomass in size by crushing and grinding to maximize surface area (De et al. 2018). The hydrogen content of the feedstock directly relates to the vaporization temperature and the syngas produced. The higher the hydrogen content, the higher the probability of more syngas being produced with lower vaporization temperatures (Basu 2013).

2.10 Alternative Technologies: (non-Energy)

2.10.1 Biochar

Biochar contains an estimated market size of 400,000 tons per year as if 2018 (Severy 2018). Biochar (Figure 13) is a black and highly porous material produced with thermochemical conversion technology used in the processes of pyrolysis and gasification from biomass feedstock (Furniss 2020). The woody biomass utilized in these processes consist of a wide range of organic material with varying moisture contents. Biochar consists of primarily carbon, hydrogen, nitrogen, oxygen, and other trace elements (Basu 2013).

Figure 13. Biochar produced from gasification held in a hand for scale (Furniss 2020).

The Oxygen to Carbon (O:C) molar ratio is an indicator of biochar carbon stability where biochar holds values between 0.0 to 0.6 (Spokas 2010). Higher carbon stability is attributed to high carbon sequestration, where carbon sequestration is the process of capturing and storing carbon over a specified period of time. Carbon sequestration is the largest benefit of biochar which carries the ability to mitigate climate change effects by providing long term storage for carbon (Furniss 2020). Studies suggest biochar with O:C ratios greater than 0.6, between 0.2 to 0.6, and below 0.2 result in carbon half-life values of less than 100 years, 100 to 1,000 years, and greater than 1,000 years respectively (Spokas 2010). Therefore, lower O:C molar ratios result in a longer sequestration period. This biochar decomposition is attributed to biological and physical deterioration when exposed to soil containing microbes. Biological deterioration is caused by microbial degradation from extracellular enzymes. Physical deterioration is caused by the breakdown in structure from microbes enlarging cracks in individual grains (Spokas 2010). Biochar does not decompose but degrades at an increased rate when exposed to a microbial rich soil environment (Furniss 2020, Spokas 2010).

The cost to produce biomass power is estimated to vary depending on fossil fuel prices and not change drastically in the next 10 years (Furniss 2020). Biochar can be sold at higher prices when it is produced with (Campbell et al. 2018):

- High carbon content
- Low H:C ratio
- Low O:C ratio
- High ion exchange capacity
- Low ash content
- High surface area
- High conductivity
- Low levels of contaminants

Applications of biochar include soil amendments and remediation of contaminated soils (Severy et al. 2018). The most common use of biochar consists of mixing it into soils to improve the soil quality (Furniss 2020). Upon mixing, the water retention capacity, fertility, and microbial health and efficiency of the soil have been proven to increase (Severy et al. 2018). Recent research displays a connection between electron channels in biochar and an enhancement in soil microbial ecology (Sun et al. 2017). Tropical regions which typically contain highly weathered and acidic soils experienced an average 25% increase in agricultural yield with the addition of biochar. This is due to biochar contributing increased soil moisture capacity (Tisserant and Cherubini 2019). One risk of biochar is its potential ability to adsorb and accumulate pesticides in the soil by adsorption. However this is counteracted by biochar's ability to degrade these chemicals over time (Tisserant and Cherubini 2019). Biochar production is also expensive to scale in size due to cost of materials and operation (Furniss 2020).

2.10.2 Alternative Uses for Bark

On average, typical log is composed of approximately 9 – 15% bark by volume and can be used for a variety of different applications (USDA 1971). At both biomass plants, it is currently being used for combustion to generate energy. According to Richard Engel at RCEA, lumber mill residuals are generally considered low quality, making them unusable for resale (personal communication 2020). However, low-grade bark can be utilized for a variety of applications. Bark can be pressed into briquets or used as other wood-based materials, such as building insulation boards or fiberboards (USDA 1971). Bark can also be utilized as mulch or a soil amendment. Bark has a slower decomposition rate compared to wood and requires less nitrogen, making it an attractive soil amendment (USDA 1971).

2.10.3 Alternative Uses for Sawdust and Shavings

In addition to soil amendments, residual lumber byproducts can be used for construction purposes or by the agricultural industry in the form of animal feed. Sawdust can be incorporated as a roughage ingredient for cattle that primarily consume grain to promote proper salvation and digestion (USDA 1969). Mulch material is often used on highway embankments as a method of erosion control and to help establish vegetation (USDA 1969). Sawdust and shavings can also be used as an addition or filler to lightweight concrete (USDA 1969). While many of these alternative uses are attractive, many of them require the woody biomass to have certain qualities, such as low-moisture content or free of contaminants.

3 Alternatives

Four technologies were selected as alternatives to be investigated further. In this section the following topics will be discussed for each alternative: inputs and outputs, processes or reactions involved, scale of operation, diagram of process, and a qualitative summary of performance relative to each constraint and criteria. The economic, environmental, and social criteria previously discussed will be investigated in reference to each of the four alternatives and will be scored with weights to determine the best alternative for the client.

Two of the alternatives include the processes of pyrolysis and gasification. These alternatives would substitute for the loss of energy created at the biomass powerplants if the mill residues were redirected from being combusted. Gasification is a thermochemical process that converts carbonaceous material into a combination of CO and H_2 called synthesis gas (syngas), in addition to biochar (Dai et al. 2015). Syngas can then be used to create power through combustion reactions.

Another alternative for the mill residues, is to created paper products. There is an abandoned papermill on the Samoa Peninsula, near the DG Fairhaven powerplant. Recycled paper and softwood mill waste could be pulped in the papermill and tissue paper products could be produced. Possible outcomes of this alternative include local jobs, soil amendments from pulping sludge, and a reduction in number of trees harvested to produce paper.

The final alternative discussed is the production of organic mulch. Organic mulch is incorporated into soils to enhance soil quality and promote slope stabilization. Woody biomass that would have otherwise been combusted in the BAU case would be sent to chipping mills for mulch production. Mulch installments throughout Humboldt County would provide landscaping job opportunities and mitigate potential floods as well as serve as an erosion control tactic. Little to no CO emissions and particulate matter is generated within this alternative satisfying public concern.

3.1 Constraints

The following is a list of constraints, which all given Biomass alternatives must satisfy in order to be considered feasible:

- Meet air quality standards for all pollutants and particulate matter stated in Table 12.
- Meet all regulations established and permitting required by the federal, state, and district government.
- Reduce or maintain the GHG emissions related with the BAU case, by implementing sustainable practices or renewable technologies.
- Ability to treat or use all the mill residues that are currently being utilized by the powerplants for public power.
- Establish and maintain financial sustainability through breaking even in revenue.

3.2 Criteria

Below, Table 12 displays criteria for all biomass conversion alternatives providing a description and method of comparison. Each criterion is placed into one of three categories: economic, environmental, and social. Weighting factors ranging from 0-10 were then assigned to each criterion based on relative importance and normalized so each criteria class was equal to 10.

Table 12. Table of criteria used for scoring alternatives

Criterion	Description	Method of Comparison	Weight
Economic			
Payback Period	The amount of time to payback the capital cost of the project	Minimize: payback period (years)	**5**
Operational Flexibility	Ability of system to accommodate various woody biomass loads	Maximize: scalability range of mass treated (rank)	**5**
Environmental			
GHGs	Represented as CO_2-e	Minimize: production of CO_2-equivalence (MT CO_2-e/BDMT processed)	**2**
Particulate Matter	Particulate matter represented as a total of $PM_{2.5}$ and PM_{10}	Minimize: production of particulate matter (kg/BDMT processed)	**2**
NOx	NOx concentration	Minimize: production of NOx (kg/BDMT processed)	$\mathbf{1.\overline{3}}$
SOx	SOx concentration	Minimize: production of SOx (kg/BDMT processed)	$\mathbf{1.\overline{3}}$
CO	Carbon monoxide concentration	Minimize: production of CO (kg/BDMT processed)	$\mathbf{1.\overline{3}}$
Carbon Sequestration	Percent of carbon sequestered after treatment	Maximize: carbon sequestration (%)	**0.5**
Decentralized Utilization	Import or export radius to transport the biomass for treatment	Minimize: transport distance (km)	**1**
Ecological Impact	System footprint of project	Minimize: footprint (km^2)	**0.5**
Social			
Employment Opportunities	Ability to provide community with employment opportunities	Maximize: jobs created (#)	**6**
Public Concern	Concerns of public from emissions, noise, smell, and aesthetics	Minimize: public concern (rank)	**4**

3.3 Alternative 1: Pyrolysis for Biochar Production

Pyrolysis is a complex thermochemical process which transforms biomass into three main products: biochar, bio-oil, and syngas. This conversion technology is gaining popularity worldwide and is now recognized as a large combatant towards global warming through the ability to sequester carbon for hundreds to thousands of years.

Pyrolysis needs two things to occur: biomass and heat. Heat is almost always supplied by an external source consisting of inexpensive gas such as natural gas or propane. The outputs from this process include biochar, bio-oil, syngas, various emissions, and particulate matter (Table 13). Depending on the temperature and pressure, these products can vary in amount compared to each other (Table 10).

Table 13. Inputs and outputs of the pyrolysis process.

Inputs	Outputs
Biomass	Biochar
Heat [1]	Bio-Oil
	Syngas
	Emissions [2]
	Particulate Matter [3]

1 – Heat is typically supplied from combustion of natural gas and sometimes propane or the syngas production.
2 – Emissions include CO, C_3H_8, NO, SO_2, O_2, & CO_2.
3 – Particular Matter includes $PM_{2.5}$ and PM_{10}.

Pyrolysis is a thermochemical conversion technology which uses high temperatures to break down the biomass through thermal decomposition. It involves multiple complex sets of reactions that form volatile compounds, oxygenates, hydrocarbons, and non-condensable gases (De et al. 2018). Equation 1 displays the chemical reaction of heavier hydrocarbon molecules in biomass being broken down into smaller hydrocarbons (Basu 2013). Non-condensable gases are produced such as CO and CO_2 which are shown in the second to last product. Biochar is shown in the last product of the equation as solid carbon "C".

$$C_nH_mO_p + heat \rightarrow \sum_{Liquid} C_aH_bO_c + \sum_{Gas} C_aH_bO_z + \sum_{Solid} C \qquad \text{Eqn. 1}$$

where:

$C =$ Carbon element
$H =$ Hydrogen element
$O =$ Oxygen element

The pyrolysis reactor design used in this analysis consists of a Hearth-based biochar production system which produces biochar and volatile gases. The dryer and pyrolizer upon startup are heated using the combustion of natural gas. Once running, the pyrolizer utilizes the production of its volatile gasses to fuel the dryer and pyrolizer, replacing the fossil fuel.

Upon startup, the biomass consisting of pre-processed wood chips are fed onto a conveyor belt system which delivers them to the dryer (Figure 14). Here, the dryer brings the moisture content down from approximately 50% to a target level of 10%. From the dryer, the biomass is transported via conveyer to the various 43 hearth reactor units. Here, the feedstock moves downward through a series of chambers which progressively decrease in oxygen. These chambers are pressurized at near atmospheric conditions and range from 450 to 650 °C. During this time, the produced volatile vapors are taken from the reactor and combusted for heat to fuel the dryer and reactors (Figure 15). After a residence time ranging from 25 to 45 minutes, biochar is produced from the reactor units and immediately quenched in water to cool. Once cooled, the biochar is collected for sale.

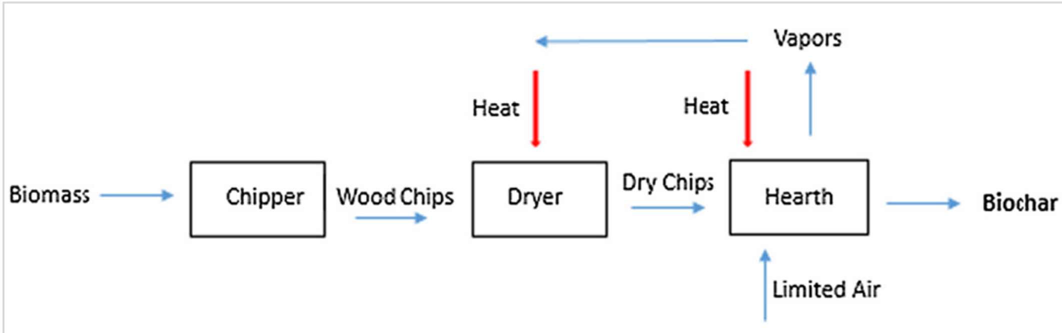

Figure 14. Flowchart of pyrolysis process showing the inputs and outputs (Campbell et al. 2018).

3.3.1 Cost Analysis

Within the United States, the potential market for biochar is predicted to exceed 3 billion tons. The biochar market has yet to be solidified and contains large variation in prices but is rapidly expanding (Grood et al. 2018, Campbell et al. 2018).

A biochar non-profit group named International Biochar Initiative (IBI) found that worldwide, biochar prices ranged from $80 to $13,480 per MT (Campbell et al. 2018). IBI also stated that the mean price of biochar in the U.S. during 2014 was $2,512/MT. For this analysis, a more conservative number derived in the study of 1,292/MT is used.

3.3.2 Pyrolysis Performance for Economic Criteria

The payback period for this alternative was calculated to be 2.8 years. This was found by incorporating capital costs, annual O&M, and annual revenue which are approximately $163.8, $29.0, $97.7 million, respectively. Capital costs incorporate fixed, working, and land costs. O&M costs incorporate fixed, variable, and labor costs. Within O&M, fixed costs include maintenance costs, insurance, and taxes, while variable costs include materials such as natural gas, electricity, diesel, water, and feedstock rates. O&M labor costs were calculated based on an average employee salary of $90,000 which incorporates 50% overhead to account for employee benefits. Annual revenue from biochar production was calculated using the mean price of $1,292/MT of biochar according to a study (Campbell et al. 2018). This biochar production was is expected to be sold locally to customers within county due to the abundance of farmland.

All capital and O&M costs except land and feedstock price were upscaled from a pilot plant system within a scientific report conducted by Robert Campbell in 2018. This report performed a techno-economic analysis of three different pyrolysis reactor plants to determine the most profitable system, which was concluded to be the hearth-based reactor system. Currently, subsidies and grants are not incorporated in this analysis but can be expected to increase and become available in the near future as biochar gains in popularity (Basu 2013). Operational flexibility is high for this hearth-based reactor system where production can be ramped down to accommodate any decreased input size. This is due to it the system consisting of 43 identical units in parallel which can be individually turned off without effecting the overall system performance.

3.3.3 Pyrolysis Performance for Environmental Criteria

Greenhouse gasses are low for this system resulting in 0.066 MT CO_2-eq/BDMT. This incorporates GHGs produced from the transportation of feedstock and the pyrolysis process which makes up approximately 24% and 76% of the total emissions, respectively. Particulate matter is also low for this system estimated to be 0.064 kg/BDMT which is produced from the pyrolysis reactor. NO_X, SO_X, and CO emission values were predicted to be 0.11, 0.22, 0.50 kg/BDMT, respectively.

One of the major benefits of pyrolysis with woody biomass is the sequestration of carbon in biochar. From the hearth-based reactor, approximately 55% of the carbon within the feedstock is sequestered into stable biochar. The location of this system is expected to be at the DG Fairhaven Plant site which would minimize the transportation distance for feedstock. Therefore, the decentralized utilization would be limited to under one mile. The overall land use is estimated to be 0.142 km^2. This land is sized to accommodate the pyrolysis plant, area for storing and drying feedstock, parking, and a buffer space for noise dissipation between the plant and the property line.

3.3.4 Pyrolysis Performance for Social Criteria

After construction of the pyrolysis system, the employment opportunities are estimated to be 106 direct jobs. This is calculated using the average worker's annual salary of $90,000. Public concern of this alternative is expected to be average. This is generated using RCEA's public poll from in Humboldt County which displayed a 48% support, 29% use as needed, and 24% against for bioenergy. Noise generation is expected to be below the minimum county standard of 60 decibels (CEQA 2016). At 15 meters from the plant the noise is predicted to be 54 decibels, which was accounted for in the land size use. is not expected to be a concern for this plant (Kipower and Station 2014). The main concerns associated with this system is the aesthetics and smell. Noise and smell are both expected to not be a problem with the hearth-based reactors. However, the aesthetics' approval is unable to be predicted within the community.

3.4 Alternative 2: Gasification for Power Generation

Gasification is a thermochemical process that converts carbonaceous inputs into a mixture of CO and H_2, known as syngas, and biochar (Dai et al. 2015). This process is done under high temperatures ranging from 500 – 1,300°C with an oxidant consisting of oxygen, air, subcritical steam, or a combination of these (Basu 2013). In the context of this project, the primary inputs for gasification include the woody biomass feedstock that would normally be combusted in the BAU case. Factors that influence the gasification process include particle size, temperature, inlet gas moisture content, gas, and solid mass flow rates (Dai et al. 2015).

Pretreatment measures are necessary to ensure a low moisture content and a reduction in particle size. The primary outputs of gasification include two main products: the primary being syngas which is 85% by weight, and secondary being biochar which is 10% by weight (Dai et al. 2018). The syngas that is produced can then be conditioned and used in a variety of applications including heat production, electricity generation via combustion, steam turbine, advanced transportation fuels, and biochemicals (CEC 2019b). Due to its highly porous composition, biochar can also be used for a variety of applications including agricultural amendments and filtration (CEC 2019b).

There are several different processes that must occur for the gasification of woody biomass. Figure 15 shows a simplified flow chart of the gasification process. Pretreatment is the first step of gasification and includes the processes of drying, densifying, and chipping or grinding (Sansaniwal et al. 2017). The typical moisture content of woody biomass feedstock should be anywhere from 5 – 35% for the gasification process (Dai et al. 2015). Having a low moisture content requires less energy in the drying process and increases the system efficiency. A common method for drying woody biomass is the process of Torrefaction. Torrefaction is a thermo-chemical process that reduces the moisture content of woody biomass through extended (about 1-hour) exposure to temperatures ranging from 200-300°C (Girones et al. 2017). Chipping or grinding woody biomass is preformed to reduce the size of the feedstock. The densifying process is necessary for certain biomass feedstocks but is not required for wood chips because they are easily fed into the gasifier (Adadullah 2013). Gas conditioning is a step that is necessary to reduce the concentration of any impurities after the gasification process and can be done either physically, thermally, or catalytically (Asadullah 2013). Electricity can be generated through combination using gas turbines, gas engines, and steam turbines (Sansaniwal et al. 2017).

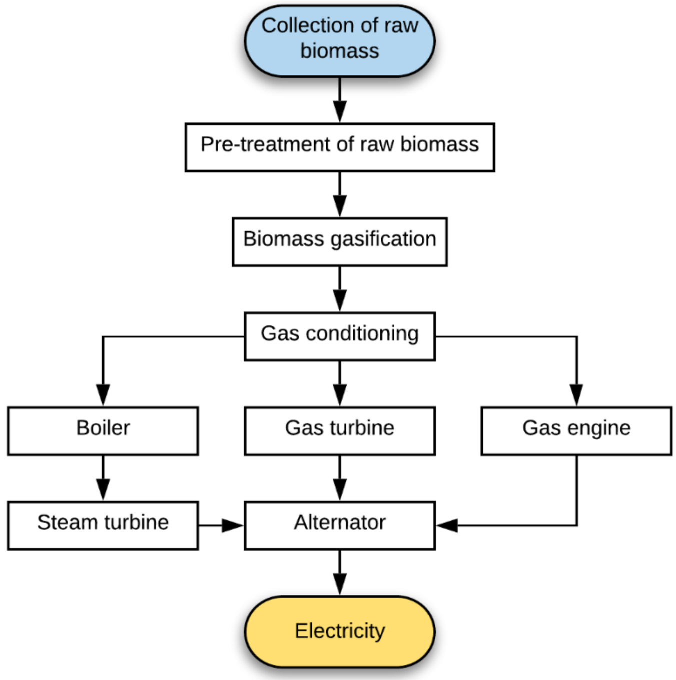

Figure 15. Flow chart of gasification-based power generation (Adapted from Sansaniwal et al. 2017).

Scalability is an important consideration when evaluating alternative designs. The gasification system must be able to accommodate the combined feedstock input of approximately 561,600 MT per year for the DG Fairhaven and Humboldt Sawmill Company power plants. The system should be able to supply the combined electricity generation of approximately 51 MW as a substitute for the electricity generated from both biomass power plants. Modular systems with power outputs ranging from 1 – 5 MW have been developed and are capable of being transported via a truck trailer (CEC 2019b). Multiple modular units could be constructed on-site, which would eliminate the costs and emissions associated with transportation. Gasification of woody biomass used for power generation has not been successfully implanted on a large scale due to logistical issues and the recommended size is 1 – 10 MW (Asadullah 2013).

3.4.1 Gasification Performance for Economic Criteria

The payback period for the gasification alternative was determined by using the costs associated with one – 3 MW gasification system and scaling to account for a total of sixteen gasification systems, which would satisfy the demand of 48 MW that is currently being generated by the existing biomass powerplants. The LCOE is the cost of electricity per MWh that is off set through the sale of biochar. Assuming 100% of the biochar is sold at $1.50/kg, the LCOE would be $-61/MWh (CEC 2019b). Assuming that electricity is sold at the current RCEA rate of $65/MWh, the estimated payback period is approximately 13.4 years. Since this alternative entails sixteen modular gasification systems, some of the systems could be taken offline to accommodate demand, giving it high operational flexibility.

3.4.2 Gasification Performance for Environmental Criteria

One of the main benefits of gasification of woody biomass over combustion is the reduction in greenhouse gas emissions, particularly CO_2. CO_2 emissions were calculated by using literature values for the mass of CO_2 produced per MJ of electricity produced (Dion et al. 2013). For this calculation, it was assumed that 62 g of CO_2 was produced per MJ of electricity generated, resulting in total annual emissions of 1.13 MT CO_2-eq/BDMT (Dion et al. 2013). Particulate matter was calculated by assuming an emission of 0.015 lb/MMBtu (Whitty et al. 2008). This was then scaled and converted for total PM emissions of 0.06 kg/BDMT. Carbon sequestration was calculated by comparing the mass of carbon sequestered annually to the input of annual feedstock, yielding a 37% carbon sequestration. Decentralized utilization was assumed to be less than one kilometer because modular gasification systems will be deployed on-site or near lumber mills. Ecological impact was calculated by accounting for the area of all the gasification system components as well as the area of feedstock. The total footprint of the project is estimated to be 0.02 km^2.

3.4.3 Gasification Performance for Social Criteria

The utilization of woody biomass gasification units would provide employment opportunities for Humboldt County residents. It was assumed that 4.9 jobs would be created per MW of electricity generated (CEC 2019b). This would yield a total of 235 employment opportunities within Humboldt County. Public concern of gasification in Humboldt County is unknown, although the results of public voting show the local biomass public opinion is split 50/50 (Furniss 2020). Some sources indicate that public concern is high due to transportation and total emissions (Upham & Shackley 2007). For this analysis, it was assumed that public concern was average.

3.5 Alternative 3: Tissue Paper Products (TPPs)

Pulping is a technology that transforms wood and recycled pre- and post-consumer paper goods into new paper products (EPA 2016). The recycled paper can come as direct waste from local industries or residential curbside collection and can consist of mixed office waste, magazines, and newsprint (Gemechu et al. 2013). The material is broken down so the fibers can disperse in liquid and be rearranged into a web (Biermann 1996). The type of wood chosen is dependent on the desired strength, stiffness, and absorbance of the end paper product (Abildgaard et al. 2003).

Other inputs needed to create the product are starch, additives, water for processing and cooling, and energy (Masternak-Janus & Rybaczewska-Błażejowska 2015). Dyes, bleaching agents and, wet and dry strength agents are the predominant chemicals retained after processing the paper (Abildgaard et al. 2003). Table 14 shows the common additive in paper making, the chemicals used in the process, and the concentrations added. Bleach and other whiteners are rinsed out after treatment and discharged in the manufacturer's wastewater treatment facility. The remaining bleach is inactive in the final product (Abildgaard et al. 2003).

Table 14. A list of common additives used in papermaking, their chemical compositions, and concentrations added in kg of additive per ton of paper produced (Abildgaard et al. 2003, Biermann 1996).

Additive/Agent	Chemical	Concentration in production (kg/ton)
Bleach/Brighteners	H_2O_2, ClO_2, ClO^-, NaClO, NaOH	30
Retention/Flocculation	Polyacrylamide	0.1 – 0.5
	Polyethylenamine	1 – 2
Wet Strength	Urea Formaldehyde (UF) or Melamine Formaldehyde (MF)	50
Dry Strength	Starch or Cationic Starch	10 – 50
Biocides/Slimicides	Myacide AS, Microbiocide B-6012, Intace B-100	0.05 - 1

Wet and dry strength agents are used to adapt the strength of the paper to its purpose. Dry strength additives are used to increase hydrogen bonding which results in better retention of fibers in pulping (Biermann 1996). Wet strength additives increase the tensile strength of wet paper from 0 – 5% to 15 – 50% of the dry strength of the same paper; this treatment is common in recycled paper goods (Abildgaard et al. 2003, Biermann 1996). Both additives are not used in the production of TPPs (Abildgaard et al. 2003).

Biocides, also known as slimicides (Abildgaard et al 2003), control slime made up of proteins and polysaccharides that bacteria feed on in paper making (Biermann 1996). The slime is a hinderance to production because it can break the fiber web and create holes in the paper. When bacteria feed on the slime they create odor problems with the introduction of methane, hydrogen sulfide, and/or hydrogen gas which can also result in dangerous explosions (Biermann 1996).

Paper product and sludge are the two major outputs for paper processing; for every ton of tissue produced, 1.3 tons of sludge is created (Gemechu et al. 2013). The sludge is comprised of wood fiber, starch, and chemical additives that are washed out during the production process (Biermann 1996). This byproduct can be screw pressed and spread on agricultural fields, landfilled, or burned. EPA now restricts the use of the sludge dependent if bleach was used in production (Biermann 1996). Bleach use in papermaking is shown to release dioxins into the rinsing water that is discharged as wastewater (Abildgaard et al. 2003).

There are four processing technologies that are used in pulping: mechanical, chemi-mechanical, chemical, and semi-chemical. A summary of the types, species of wood used, pulp properties and end uses are presented in Table 15, below, which has been adapted from the Handbook of Pulping and Papermaking by Christopher Biermann.

Table 15. The four main processes in pulping wood with the inputs and outputs. Tissue making uses chemical processes, which yield around 50% pulp for the inputted material (Biermann 1996).

Process	Chemicals	Wood species	Pulp Properties	Uses	Yield (%)
Mechanical	None; grindstones and disk refiners	Hardwoods or light-colored softwoods	High opacity, softness, and bulk. Low strength and brightness	Newsprint, books, and magazines	92 – 96
Chemi-Mechanical	CTMP; mild action; NaOH or $NaHSO_3$		Moderate strength		88 – 95
Chemical, pH 13 – 14 (Kraft)	NaOH + Na_2S in unlined digester, high recovery of chemicals, sulfur odor	All woods	High strength, brown pulp unless bleached	Brown paper bags and wrapping	65 – 70 if unbleached
Chemical, pH 1.5 – 5	H_2SO_3 + HSO_3^- with Ca_2^+, Mg^{2+}, Na^+, or NH_4^+ base with lined digesters	Hardwoods and non-resinous softwoods	Weaker than Kraft pulp, light brown	Fine paper, tissue, glassine	48 – 51 if unbleached
	Mg^{2+}	All species, spruce and firs preferred	Weaker than Kraft pulp, light brown	Newsprint or other fine paper	50 – 51
Semi-Chemical, pH 7 – 10	Na_2SO_3 + Na_2CO_3 with 50% chemical recovery as Na_2SO_4	Hardwoods preferred	High stiffness and moldability	Corrugated medium	70 – 80

Mechanical pulping results in the greatest percent yield of paper product to the input materials. This process results in a lower strength product because the fibers are reduced in size from the maceration of the wood. As chemicals are added, the more uncut the fibers are which produces a higher strength paper product (Biermann 1996). The highlighted row in Table 15 for chemical treatment is the determined process for creating TPPs like sanitary tissue, paper towels, and napkins. Tissue type paper is made from softwoods, like redwood and other conifers that area available in Humboldt county. Sawdust is also commonly used in tissue to create a soft and smooth texture to the tissue. When creating sanitary tissue Kraft and bleach sulfite processes contribute bulk, absorbency, and strength to the final product (Biermann 1996).

A general process flowchart for pulping is shown in Figure 16. For the purpose of rerouting mill residues from being combusted, they would be transported to the Samoa Pulp Mill near the DG Fairhaven powerplant; this results in a net zero carbon emission change from the BAU case for transportation. Recycled paper from the Recology Materials Recovery Facility (MRF) would also be transported less than a mile to the pulp mill site. The mill residues and recycled paper products would be cooked with chemicals, screened, and dried to create the pulp. Afterward, the pulp would be washed free of the chemicals used to break down the woody waste and whitened. The pulp would be remixed with processing water to be sprayed onto screens to dry and be pressed into paper product and wound around reels (EPA 2016).

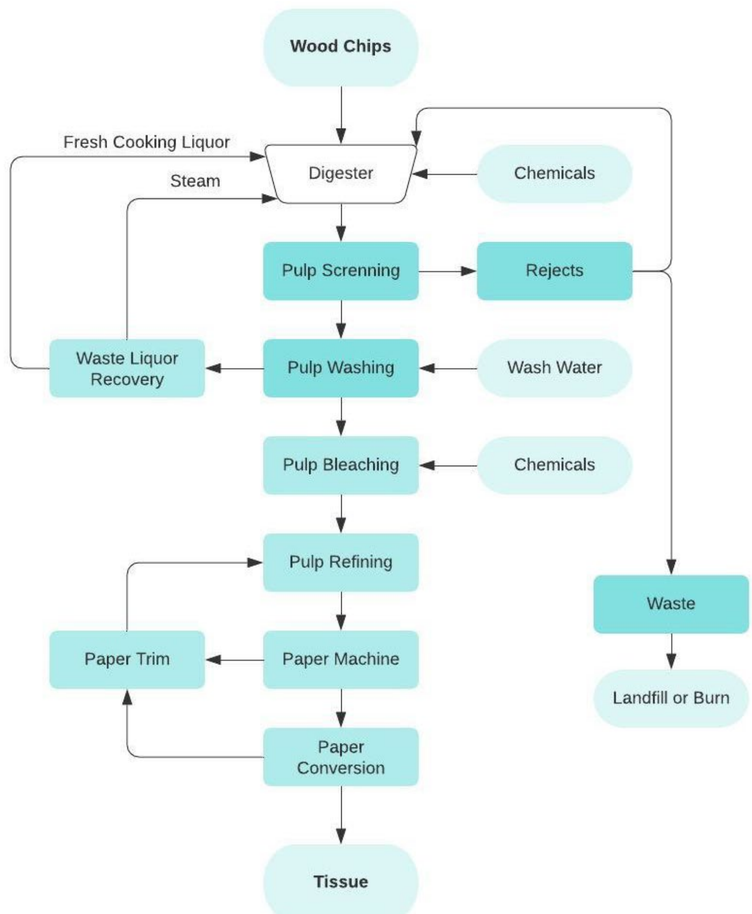

Figure 16. Flowchart of the papermaking process as adapted from "Handbook for Pulping and Papermaking." (Beirmann 1996).

3.5.1 Tissue Paper Performance for Economic Criteria

The old pulping mill was recently purchased by the Freshwater Tissue Company (FTC). Their vision was to transform the pulp mill and convert the forest residues into "eco-friendly" sanitary tissue (Sims 2010). FTC had hoped to upgrade with mill with a budget of $400 million dollars that would be financed by the DOE, but was rejected due to not being a solar, wind, or electric car production project. Without the necessary funding FTC abandoned the project and does not have any plans for the old pulp mill site (Sims 2010). In a similar pulp mill retrofit and upgrade project, the Wisconsin Tissue Company (WTC) purchased and renovated a mill is Flagstaff, Arizona. The total project cost was around $20 million dollars and the mill processes 40k tons of recycled paper per year to create 30k tons of industrial paper product (Fisher 1996).

To quantify the maximum projected capital cost of retrofitting the already existing pulping mill a factor was calculated based on production capacity of the mill and all the mills in the United States. In 1997 the US EPA published a study inventorying all the mills operating in the US and found the total capacity to be 15.5 MMT/year in 1995 (EPA 1997). The capacity of the old mill was reported to be 219,000 MT/year (Yolton & Patrick 2005) but was calculated to require the use of 225,000 MT/year. This value was based on a 50/50 mixture of virgin wood to recycled paper pulp and the 1.1 and 1.5 tons of material needed for every ton of tissue production (Gemechu et al 2013).

The 95,000 tons of woody waste processed at DG Fairhaven each year would need to be processed by the mill to divert any waste from landfills, when and if the power plant is shut down. The amount of mill waste utilized at the Humboldt Sawmill in Rio Dell because it is used to power the sawmill and diverting their waste would leave the mill without power for their operations. The resulting factor was calculated to be 0.014 by dividing the 225,000 tons by the 15.5 million tons and was used to scale the capital costs ($1.5 billion) and net annual profit ($490 million) for all operating US papermills (EPA 1997, Table 6-17). The resulting capital and profit were $22 million and $7 million, with a payback period of 3 years.

To maximize the profit of the paper mill, the operational flexibility would be low and would need to run at or near the maximum capacity and producing tissue at a constant rate over time. The machinery required to make tissue grade paper is specific to the paper type and could not be used to manufacture different products, should the demand for sanitary tissue decline (Bajpai 2018).

3.5.2 Tissue Paper Performance for Environmental Criteria

Worldwide, 40 to 42% of wood harvest is used for paper production (Gemechu et al. 2013). Using mill residues, dead trees, and recycled paper may reduce the overall GHG emissions associated with making lighter paper products like sanitary tissue. To make up for the loss in soil amendments (fly ash) being supplied to local farmers by DG Fairhaven, the papermill sludge can be anaerobically digested onsite to a Class B standard, which is allowable on agricultural lands that produce food for livestock. Class B biosolids can also be applied to forest lands.

Greenhouse gas emissions associated with making TPPs are 568- and 559-kg CO_2-eq per kg of tissue made with virgin pulp and recycled paper, respectively (Gemechu et al. 2013). Multiplying the these amounts by the 1.1 and 1.5 tons of wood and paper used to make the tissue resulted in a total CO_2-eq of 0.001 for production of the recycled tissue paper. This value was used in the alternatives analysis as the GHG potential to compare it to the other alternatives. The total amount of TPP was calculated to be 173,000 tons per year from the 50/50 mix of recycled materials and was multiplied by a factor of 1.1 tons of wood for every ton of tissue produced to determine the total mass of harvested wood needed to make the tissue. A carbon density (0.2027 g-C/cm^3) and density of woodchips (0.3193 g/cm^3) were used to calculate the amount of carbon content in the trees that wouldn't be harvested because of the use of recycled mill waste and paper (Jones & O'hara 2012). The tons of carbon sequestered per year was found to be 121,000 MT/year, which resulted in a 46% carbon sequestration

Emission values for PM, SO_X, NO_X, and CO were reported for the Port Townsend Paper Corporation (PTPC) for 2005 and were scaled to the size of the Samoa papermill. The capacity of PTPC is 687,000 tons per year, which is roughly three times the amount of the proposed mill. Each of the PTPC's reporting values was multiplied by a factor of 0.33 resulting in values of 0.90 ($PM_{2.5}$ and PM_{10}) and 0.60 (SO_X), 0.85 (NO_X), and 2.60 (CO) kg of pollutant per BDMT processed (WSDOH 2008).

Decentralized utilization was minimal because it factors in the changes of transportation factored into the use of the product. Values factored into value are the reduction in distance for the drop-off of the material, the distance from Recology's MRF to the paper mill, and the distance from the paper mill to Costco in Eureka for distribution of the tissue product. The change in distance was determined to be 10.5 km from the base case. All distances were measured using Google Earth Pro, which was also used to measure the area of the site used to characterize the relative ecological impact. The ecological impact of the site was measured to be 0.42 km^2.

3.5.3 Tissue Paper Performance for Social Criteria

When WTC purchased and renovated the 30-year old mill in Flagstaff, Arizona, they also bought land and build another mill 12-miles West of it. Between the two mills, 150 residents were employed, including 70% of the original mill staff (Fisher 1996). The last reported employment of the Samoa papermill was 171 employees (Yolton & Patrick 2005). With improvements to machinery and processes, it is hard to estimate an adjusted amount of people that would be employed by the proposed mill, so the value of 171 was used in the decision analysis against the other alternatives. Past exceedance of limitations on the water quality permit when under ownership of Evergreen Pulp, Inc. was a major factor in assigning a score to the criterion for public concern. A $463,000 fine was paid (CRWQCB 2008) by Evergreen Pulp for the damages and a webpage titled "People Against the Samoa Pulp Mill" was published in response to the community's disapproval of the mill's pollution. The site lists all the effluent emissions violations and cites a liabilities order issued by the California Resources Board (No. R1-2008-0097). It is unclear how many people are against the Samoa pulp mill, since there is not a published list of members, so a conservative scoring of "High" was given to the criterion of Public Concern.

3.6 Alternative 4: Organic Mulch

Woody biomass can be transformed into an organic mulch which is often used to stabilize soil, slow evaporation rates, prevent weed growth, and create a more attractive landscape (Davis 2020). The incorporation of organic mulch into moisture deprived soils reduces the rate of evaporation, mitigates exposure to solar radiation, and prevents erosion through slope stabilization. A study performed that compared the effectiveness of different mulches found forest mulch (organic mulch) maintained higher moisture levels in soil as opposed to hydro mulch and granite in the event of a drought. The study also found the nutrient content in the forest mulch incorporated soil was significantly higher than the other two mulches (Hosseini 2014).

Woody residues are introduced to the soil as sawdust or woodchips for soil enhancement. Prior to incorporation, woody biomass is reduced into smaller particles through a mill. The sawdust must be properly mixed and evenly spread near the surface rather than buried to promote plant growth (Davis 2020). The incorporation of woody biomass into soil can cause nitrogen deficiency's if not prepared and mixed properly. Decomposition of woody material is essential for nitrogen retention within the soil prior to mixing. Once organic mulches are decomposed, they become useless to organisms that would have otherwise depleted nitrogen from plants during the decomposition process. Mulch is typically introduced to the soil surface as a thin top layer (Davis 2020). Organic mulch can be incorporated in soil as soft or hardwood which are most often by-products of paper and lumber industries. Hardwood bark is often incorporated in the soils of shrubs and perennial beds whereas softwood bark, typically made of pine bark, is used to enhance larger trees and shrubs (Chicago Botanic Garden 2020). Hydro seeders can be used to apply bark fines more efficiently to a site however the mulch applied must be screened to the allowable diameter (Emanual 1976).

The inputs required for mulch production are logging residuals which are then stored in piles to later be transported to a chipping mill. Once the woody biomass is transformed into mulch it is stock piled and distributed to companies in need (Figure 17).

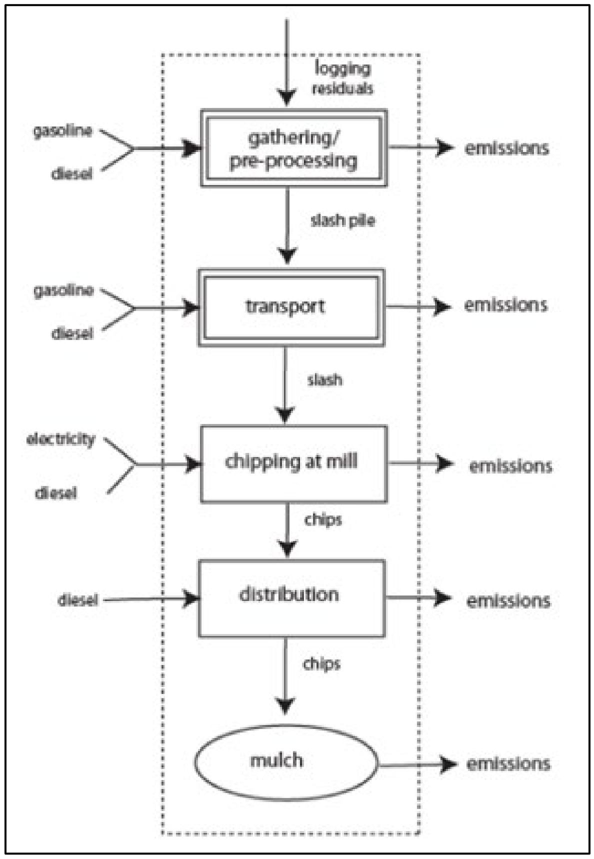

Figure 17. Flowchart of mulch production alternative (Lee et al. 2010).

3.6.1 Organic Mulch Performance for Economic Criteria

Both the Scotia and Fairhaven biomass power plants receive a supply of woody biomass of approximately 255,000 BDMT/year or 818,916 yards^3/year, all of which needs to be utilized as mulch and/or be disposed of. The demand for mulch as a product in the northern region of California is approximately 20,320 yards^3/year (CalRecycle 2010). Given Humboldt County is mostly a rural area, most of the mulch is assumed to be utilized for agricultural purposes. Agricultural uses for mulch include prevention of soil compaction or drying, prevention of weed growth, stabilization, and increased produce quality (CalRecycle 2020). California Transportation (CALTRANS) also utilizes organic mulch as a slope stabilization control product (CALTRANS 2020). The remaining supply of mulch, 798,596 yards^3/year will be utilized as alternative daily cover (ADC) and non-ADC at the Humboldt Waste Management Authority (HWMA). According to "Homeguide" the minimum range for labor and installation fees in Eureka, California is $50/cubic yard (Liaison Ventures Inc. 2020). To ensure mulch buyers will purchase enough mulch to utilize the supply available in this analysis, prices remain competitive. With installation and labor fees being the only source of revenue for the mulching facility, the total income is $1,016,000/year. This alternative assumes one mulch facility in operation with 22 employees who process, distribute, and install the mulch as a product all over Humboldt County and deliver excess to the HWMA. The total cost to run the mulching facility, assuming one installation per year, is $8,640,070 which includes the salary for each employee as well as gas compensation for distributors, cost of equipment and land use. Green waste disposal is not part of the cost analysis assuming HWMA receives excess mulch as a donation for ADC and non-ADC. The payback period for this mulching facility is 9 years based on the ratio of cost to revenue.

The operation flexibility of this alternative is determined by the allowable range of mass treated. The equipment on site at the mulching facility can process the mulch as needed for a more refined product, as requested by the customer. Otherwise most of the supply is utilized as woodchips. Most or all the material in the green waste can be used as mulch.

3.6.2 Organic Mulch Performance for Environmental Criteria

GHGs are associated with mulch chipping as opposed to the on-site decomposition case due to distribution and pre-processing. The total GHGs generated with this alternative is 2.0 MT CO_2-eq/BDMT accounting for distribution, use, and disposal. CO emissions are emitted throughout the distribution and pre-processing stage of mulch however net CO emissions amount to zero or negative depending on the mulches ability to sequester carbon. Nitrogen and sulfur oxides are not produced in the processing of organic mulch (EPA 2010). Organic mulch was estimated to sequester 20% of carbon based on the high range of composting carbon sequestration percentages to remain conservative (Furniss 2020). PM2.5 emissions are not generated in the production of mulch however preprocessing and distribution of the mulch contributes 0.018 kg/BDMT of PM2.5. Below, Table 16 provides a qualitative analysis for net emissions associated with mulch chipping. These values assume a 100-mile distribution distance (Lee et al. 2010).

Table 16. Life cycle emissions for composting (Lee et al. 2010).

	CO_2	N_2O	CH_4	CO	$PM_{2.5}$
	(MT CO_2-eq/BDMT)			(lb/BDMT)	
System					
Woody biomass preprocessing	0.03	~0	~0	0.29	0.03
Distribution (100 mi)	0.01	~0	~0	0.15	0.01
Use	1.74	---	---	---	---
System emissions	1.78	~0	~0	0.44	0.04
Displaced: wood mulch					
Alternate use: wood bulking agent	-0.14	---	---	---	---
Net wood mulch emissions	1.64	~0	~0	0.44	0.04
Displaced: other organic material (OM)					
Alternate use: other organic bulking agent	-0.15	---	---	---	---
Net OM emissions	1.63	~0	~0	0.44	0.04

The mulching facility will distribute mulch as a product to customers within a 100-mile radius or 161 km, making service available to all of Humboldt County. The ecological impact of organic mulch as an alternative is determined by the volume of the supply distributed over 10 ft stockpiles of mulch resulting in an ecological impact of 0.061 km^2.

3.6.3 Organic Mulch Performance for Social Criteria

Mulch installments will introduce job opportunities for distributors, processors, and landscapers. The mulching facility will require 11 composters and 11 processors resulting in 22 people employed. This range of employees was documented from a survey of composting facilities (CalRecycle 2010). Assuming public concern was high for the BAU case based on emissions due to combustion, public concern was rated "average" for this alternative. Concern was not rated low due to the ability for mulch stockpiles to ignite when disposed of in a landfill, affecting safety of the public (Furniss 2020).

4 Decision Analysis

The four proposed alternatives were compared and evaluated based upon their ability to satisfy the design constraints and criteria. The Delphi and Pugh methods were used independently to score each alternative for the given design criteria. The results of these methods were then compared for consistency. For the Delphi method, scores ranging from 1 – 5 were assigned to each alternative based upon how it satisfied each of the design criteria. Weighting factors were assigned to each criterion based upon its relative importance to the project. Normalized weighting factors were then created so the economic, environmental, and social criteria classes were evenly weighted. All weighting factors were adjusted to reflect the needs of the client. Below, Table 17 displays the scoring criteria used in the Delphi decision matrix.

Table 17. Possible scores and associated qualitative criteria used in Delphi Matrix decision analysis.

Score	**1**	**2**	**3**	**4**	**5**
Qualitative Criteria	Poor	Less than Average	Average	Greater than Average	Excellent
Economic					
Payback Period (years)	>75	75 – 50	49 – 25	24 - 10	<10
Operational Flexibility (range of mass treated)	Little to none	Low	Average	High	Very High
Environmental					
GHG Emissions (MT CO_2-eq/BDMT)	>2.0	1.99 – 1.5	1.49 – 1	0.99 – 0.5	<0.49
Particulate Matter (kg/BDMT)	>0.10	0.10 – 0.08	0.07 – 0.50	0.04 – 0.02	<0.02
NO_X (kg/BDMT)	>0.50	0.49-0.35	0.34-0.20	0.19-0.05	<0.05
SO_X (kg/BDMT)	>1.00	0.99-0.75	0.74-0.50	0.49-0.25	<0.24
CO (kg/BDMT)	>2.00	1.99-1.50	1.49-1.00	0.99-0.50	<0.50
Carbon Sequestration (%)	<25	25 – 49	50 – 74	75 – 99	100
Decentralized Utilization (km)	>30	21 – 30	11 – 20	1 – 10	0
Ecological Impact (km^2)	>0.3	0.3 – 0.21	0.2 – 0.11	0.1 – 0.01	<0.01
Social					
Employment Opportunities (#)	0	1-100	101-200	201-400	>400
Public Concerns	Very High	High	Average	Low	Little to none

Below, Table 18 displays the results of the Delphi decision analysis performed on the four proposed alternatives. After normalizing the weight of each criteria for the economic, environmental, and social classes, the scores assigned to each alternative were multiplied by the normalized weight of the criteria. These scores were then totaled to determine the highest score, which would indicate the preferred alternative. The gasification alternative resulted with the highest score of 11.4, making it the preferred alternative. The pyrolysis, tissue products, and mulch alternatives resulted in final scores of 11.2, 8.9, and 8.4, respectively. The results of the Pugh method are consistent with the Delphi method and are available in the Appendix B.

Table 18. Results of Delphi Matrix decision analysis.

Criteria	Normalized Weight	Score			
		Pyrolysis	Gasification	Tissue	Mulch
Payback Period (years)	5	25	20	25	25
Operational Flexibility (range treated)	5	25	25	10	20
GHG Emissions (MT CO_2-eq/BDMT)	2	10	6	10	2
Particulate Matter (kg/BDMT	2	6	8	2	8
NO_X (kg/BDMT)	1.3	5	5	1	7
SO_X (kg/BDMT)	1.3	7	5	5	7
CO (kg/BDMT)	1.3	5	7	1	7
Carbon Sequestration (%)	0.5	2	1	1	1
Decentralized Utilization (km)	1	4	5	4	1
Ecological Impact (km^2)	0.5	2	3	1	1
Employment Opportunities (#)	6	18	24	18	6
Public Concerns	4	12	12	8	12
Weighted Score		**120**	**121**	**87**	**95**

5 Preferred Alternative

The following section describes the preferred alternative design proposed as an alternative use for woody biomass feedstock in Humboldt County. A description of the preferred alternative is outlined and includes important information such as the system configuration, location, and inputs. Additionally, the preferred alternative is further evaluated with respect to the economic, environmental, and social criteria classes. The preferred alternative of gasification ranked number one in weighted social criteria and number two in economic and environmental criteria (Figure 18). This combined ranking gave it the highest score of 121 out of all four alternatives. The compared alternatives of pyrolysis, mulch, and tissue products scored combined scores of 120, 95, 87, respectively.

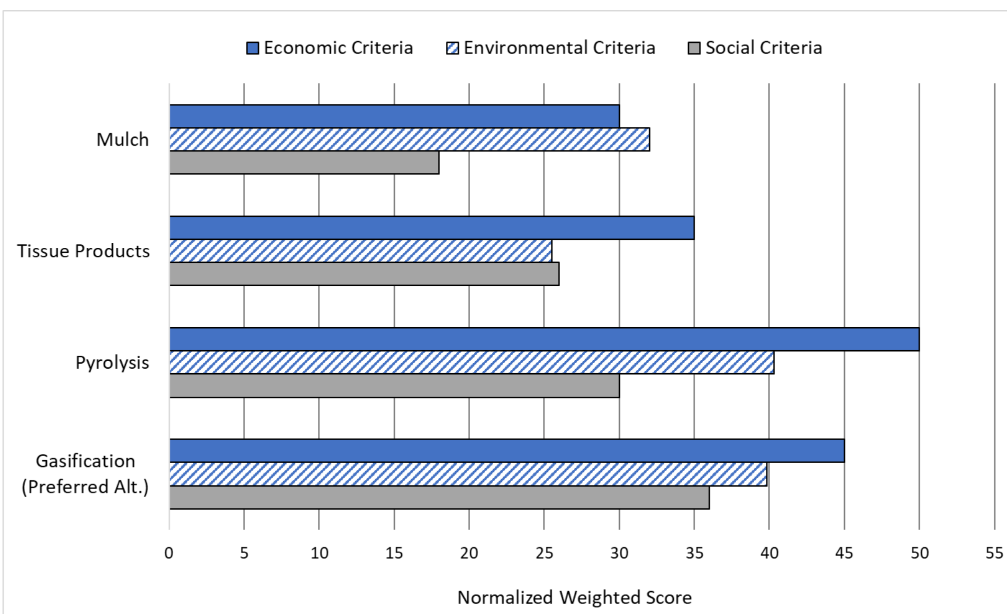

Figure 18. Comparison of normalized weighted scores of criteria for each alternative.

5.1 Project Description

The DG Fairhaven site will be retrofitted to create available space for gasification of woody biomass (Figure 19). Approximately 1,540 MT/day of woody biomass will be delivered to the site where it will be stored in stockpiles until pretreatment. The daily feedstock volume assumes a wet weight of 562,000 MT/year and a density of 247 kg/m^3. Stockpile volume will be modeled as trapezoid with a height of 20 meters and a total area of 0.004 km^2, assuming enough space for a week's worth of feedstock supply.

Figure 19. Proposed location of preferred alternative (Google Earth Pro 2020).

Gasification will require the following components seen in Figure 20. Pretreatment measures include chipping, metering, and drying. Chipping reduces to feedstock size and ensures a relatively homogenous particle diameter. A metering bin feeds the woody biomass at a constant rate to a dryer to reduce the moisture content to achieve a moisture content of 5 – 35 % (Dai et al. 2015). Once dried, the feedstock is directed to a rotary gasifier where the feedstock is converted to syngas (85%) and biochar (15%) (CEC 2019b). At maximum capacity, the gasification systems would collectively produce 48 MW of electricity and 42,000 MT of biochar annually.

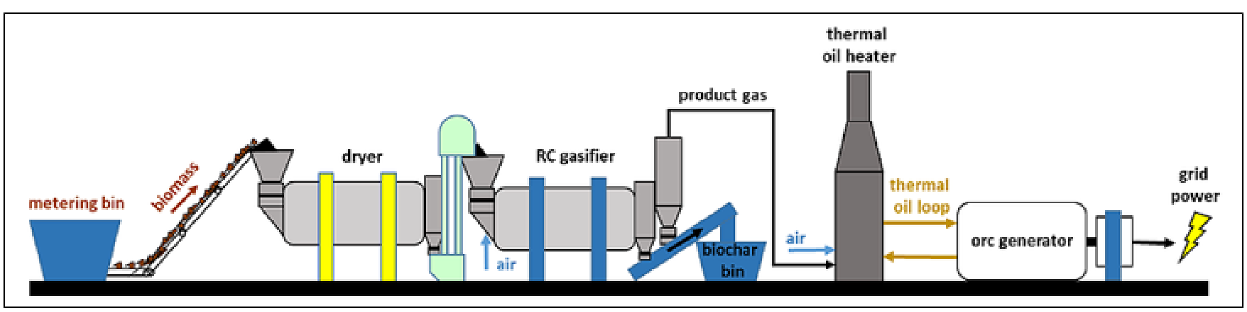

Figure 20. Configuration of gasification system (CEC 2019-b).

The syngas is routed to a thermal oil heater looped with an ORC generator to create electricity as the final product (Figure 21). A hydrocarbon fluid is recirculated between the thermal oil heater and ORC generator in a closed-loop thermodynamic cycle to produce electricity and thermal power (Turboden 2020). A total of 16 gasification systems are be used in parallel to process the supply of woody biomass resulting in an area of 0.2 km^2 for the gasification systems. To leave room for office space, parking, and supportive equipment 50% of the site area will be designated, resulting in an area of 0.102 km^2.

Figure 21. Commercial 3 MW Organic Rankine Cycle (ORC) Generator (CEC 2019-b).

5.2 Analysis of Economic Criteria

A total capital cost of $270,216,000 was estimated for the preferred alternative. This estimate includes all capital costs associated with 16 – 3 MW modular gasification systems and were sourced from the CEC 2019 modular gasification study (CEC 2019b). The estimates provided in this study were scaled to account for a total of 16 modular gasification units. The capital costs associated with each gasification system include truck unloading/fuel yard equipment, feedstock sizing equipment, metering and conveyance, feedstock dryer, rotary gasifier, TO heater, ORC generator, interconnection gear, and site improvement costs. The total system costs were estimated to be $180,144,000. It was assumed that construction/installation costs were 30% of the total system costs, which is approximately $54,043,000 (CEC 2019b). To account for any unforeseeable costs, a 20% contingency cost of $36,029,000 was added to the capital costs (CEC 2019b). Table 19 summarizes the capital costs associated with each component for the preferred alternative.

Table 19. Summary of capital costs (CEC 2019b)

Item	Quantity	Total Costs (thousand $)
Truck unloading/fuel yard equipment	16	3,200
Feedstock sizing equipment	16	5,600
Metering and conveyance	16	3,200
Feedstock dryer	16	9,600
Rotary gasifier	16	40,000
Thermal oil heater	16	41,600
3 MWe ORC generator	16	64,000
Grid interconnectivity cost	16	4,800
Site improvement costs	16	8,000
Land costs[1]	1	144
Total System:		**180,144**
Construction/installation costs, 30%:		54,043
Contingency, 20%		36,029
Grand Total Capital Cost:		**270,216**

[1]Based on cost per acre of $13,836 using property assessment of former Samoa Pump Mill

A total system annual O&M cost of $32,832,000 was estimated for the preferred alternative. Operational components include manager-level staff, labor-level staff, insurance, property taxes, utilities, and administration. Operational costs were estimated to be $14,800,000/year. Maintenance components include feedstock handling, conversion system, ORC generator, and other. Maintenance costs were estimated to be $7,088,000/year. After construction/installation (30%) and contingency (20%) costs, the total system O&M is estimated at $32,832,000/year. Table 20 summarizes the annual O&M costs associated with each component of the preferred alternative based upon study performed by the California Energy Commission (CEC 2019b).

Table 20. Summary of annual O&M costs (CEC 2019b)

Item	Quantity	Total Costs (thousand $/year)
Manager-Level Staff	32	4,480
Labor-Level Staff	96	6,720
Insurance	16	1,200
Property Taxes	16	800
Utilities	16	960
Administration	16	640
Feedstock Handling	16	1,088
Conversion System	16	4,088
Organic Rankine Cycle Generator	16	1,280
Other	16	640
	System O&M:	**21,888**
	Construction/installation costs, 30%:	6,566
	Contingency, 20%	4,378
	Total System O&M:	**32,832**

The payback period for the preferred alternative was estimated at 24.1 years using Equation 2 (DOC 1984). A discounted payback period was calculated using an interest rate of 8%, which is common for gasification plant projects (OSTI 2003). The discounted payback period calculation assumes that the electricity generated is sold at the current rate of $78/MWh, which is a 20% increase from the current rate of $65/MWh.

$$\sum_{t=1}^{Y} \left[\frac{B_t - C_t}{(1+i)^t}\right] - C_o = 0 \qquad \text{Equation 2}$$

where,

B_t = dollar value of benefits in year (t)

C_t = dollar value of costs in year (t)

C_o = initial project investment costs

i = interest rate (%)

Y = number of years required for cash flows to offset initial investment

A sensitivity analysis was performed to determine the individual effects of the interest rate, LCOE, and cost of electricity on the payback period (Figure 22). The cost at which electricity is sold has the highest effect on the payback period, while the LCOE and interest rate also play important roles in the payback period.

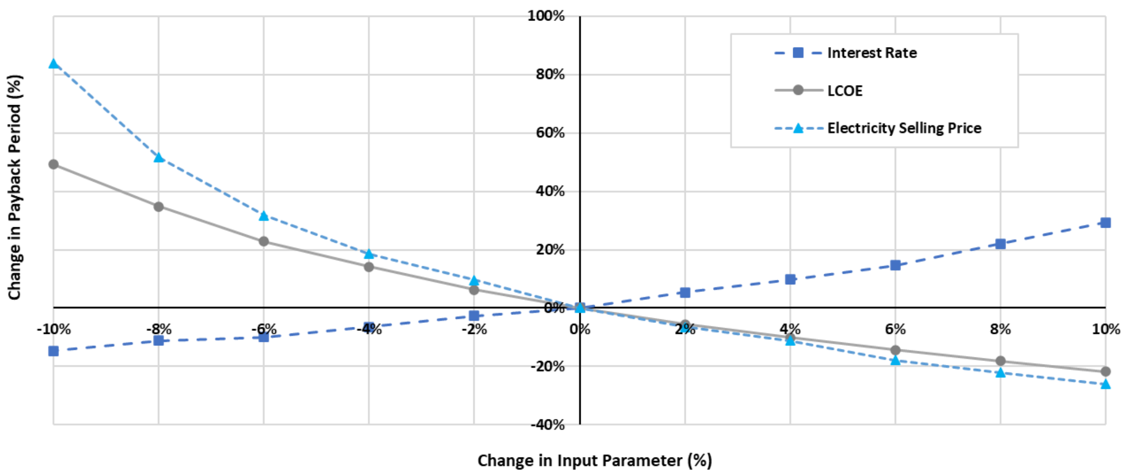

Figure 22. Results of sensitivity analysis performed on interest rate, LCOE, and electricity cost.

The payback period is dependent upon the biochar market price, which influences the levelized cost of electricity (LCOE) (Figure 23). The LCOE is a common measure used in the comparison of renewable energy technologies, as it measures the lifetime cost divided by the total energy production (DOE 2009). The LCOE is essentially the cost of producing electricity for the given technology. In this instance, the cost of electricity is off set through the sale of biochar. Assuming that biochar is sold at $1.50/kg, the LCOE would be -$61 (CEC 2019b). Biochar prices below $1.45/kg result in a payback period that is infeasible, assuming an interest rate of 8% and electricity selling rate of $78/MWh. The 24.1-year calculation is a conservative estimate that does not account for grants and tax incentives available to biorefineries. More information regarding loans, grants, and tax incentives can be found in Appendix A, 8.2.

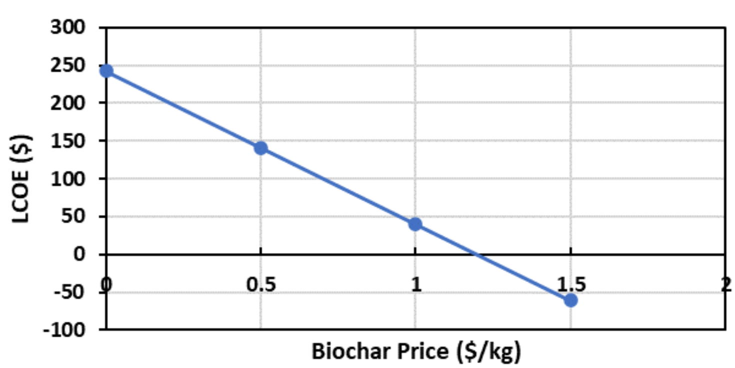

Figure 23. Impacts of biochar price on the LCEO (CEC 2019b)

Operational flexibility was the other criterion within the economic criteria class. The operational flexibility for the preferred alternative was estimated as extremely high. This qualitative criterion accounts for the possible range of mass that can be processed on an annual basis. Each 3 MW modular gasification unit can process approximately 31,600 BDMT/year (CEC 2019b). It was assumed that some units could be taken offline to account for annual variation in the mass of woody biomass feedstock.

5.3 Analysis of Environmental Criteria

GHG emissions for the preferred alternative were estimated at 317,000 MT CO_2-eq/year. The combined CO_2-eq emissions of the DG Fairhaven and Humboldt Sawmill Company biomass power plants is estimated at 435,000 MT CO_2-eq/year (CARB 2020c). This represents a 27% reduction in CO_2-eq emissions compared to the BAU case. The preferred alternative also had a decrease in the combined emissions of VOC, CO, SOx, NOx, and PM compared to the BAU case (Figure 24). For these constituents, the preferred alternative had combined emissions of approximately 253 MT/year, while the BAU case had combined emissions of 2,304 MT/year, representing an 89% reduction (CARB 2020c).

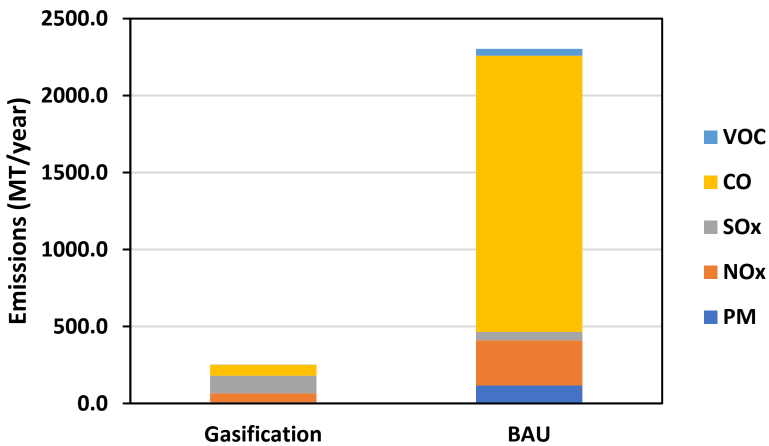

Figure 24. Comparison of emissions for gasification and BAU case.

The preferred alternative has an ecological impact of 10.4 acres, which is equivalent to the existing footprint of the DG Fairhaven biomass powerplant. The DG Fairhaven facility was selected as the project site because of its proximity to the PG&E transmission grid. While distributed gasification systems were initially proposed to reduce transportation costs and emissions, they are technically infeasible due to their relatively small size and costs associated with required transformers and transmission lines (CEC 2019b). Additionally, retrofitting the DG Fairhaven facility may present opportunities for funding through retrofitting-based grants.

Decentralized utilization was defined as the import radius to transport the biomass to the treatment facility compared to the BAU case. Decentralized utilization for the preferred alternative was estimated as less than 1 km. This calculation assumes that the preferred alternative will be located at the existing DG Fairhaven facility, resulting in no changes in transportation compared to the BAU case.

5.4 Analysis of Social Criteria

Employment Opportunities were evaluated from direct and indirect jobs created from the implementation of the gasification alternative. Direct jobs were calculated based on jobs per MW value within a gasification system. Based on this 48 MW gasification plant, 144 direct jobs were created. Indirect jobs were calculated from a report on gasification employment which stated a 1.65 indirect to direct job ratio (US Department of Energy 2006). When incorporating this factor, 238 indirect jobs are estimated to be created from the implementation of this gasification system. In total, 382 jobs are created from the gasification system. The employment opportunities calculated do not include labor associated with construction of the facility.

Public Concern for gasification is estimated from polls conducted in the Humboldt County community as well as predictable annoyance associated with noise, smell, and visual aspects. Results from a public poll conducted by RCEA show a 48% support and 24% against local biomass. With a reduction in gasification emissions at 27% of the BAU system, public opinion can be estimated to raise (Figure 25). The gasification plant is located in a remote location away from residents. Therefore, noise and aesthetics is not expected to be a problem to the surrounding community. Within the gasification plant, slight odors are common, but do not create a problem to the surrounding community. When accounting for all concerns affecting the public, public acceptance is expected to sit at an estimated 70% approval.

5.5 Summary of Preferred Alternative

The preferred alternative has a total capital cost of $270,000,000 with annual O&M costs of approximately $32,800,000. This initial capital investment and annual O&M include a 30% construction/installation cost as well as a 20% contingency buffer. The annual revenue generated is highly dependent upon the market price of electricity and biochar. It was assumed that the electricity generated will be sold at a rate of $78/MWh and 100% of the biochar will be sold at $1.50/kg. Using these assumptions, a discounted payback period for the preferred alternative would be approximately 24.1 years, using an interest rate of 8%.

The preferred alternative includes a total of 16 – 3MW modular gasification systems in parallel. Each system will include a metering bin, rotary drier, rotary gasifier, TO heater, and ORC generator. Each unit will produce syngas (85%) and biochar (15%). The outputs of the system operating at full capacity would be 48 MW of electricity and 42,000 MT of biochar annually. Retrofitting the existing infrastructure of the DG Fairhaven facility will allow for grid interconnectivity. Additionally, grants, loans, and tax incentives may be available by retrofitting an existing biorefinery. Biochar that is produced will be available for pickup.

Advantages

- Reduction in emissions compared to BAU case
- Replaces electricity generated from DG Fairhaven and Humboldt Sawmill Company
- 144 direct and 238 indirect employment opportunities
- Can be implemented at DG Fairhaven site for grid interconnectivity
- Retrofitting existing biorefinery may qualify project for loans, grants, and tax incentives

Disadvantages

- High capital investment cost of $270,216,000
- Highly dependent upon cost of electricity ($78/MWh) and biochar market price ($1.50/kg)
- Relatively new technology
- Multiple systems required. Large-scale gasification still infeasible for this specific feedstock type

6 Recommendations

While there are many aspects of the preferred alternative that are attractive, the success of this project is highly dependent upon several factors. Addressing the following recommendations would help to solidify modular gasification as an alternative to the incineration of woody biomass within Humboldt County. Recommendations for future work include:

- Further investigation into optimizing the location of multiple modular gasification systems to reduce the costs and emissions associated with transportation of woody biomass
- Establishing a biochar market within Humboldt County or a method of exporting biochar
- Identifying possible loans, financing, or incentives that could reduce the capital costs associated with this project.

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8 Appendix A: Continued Background Information

8.1 Additional Figures

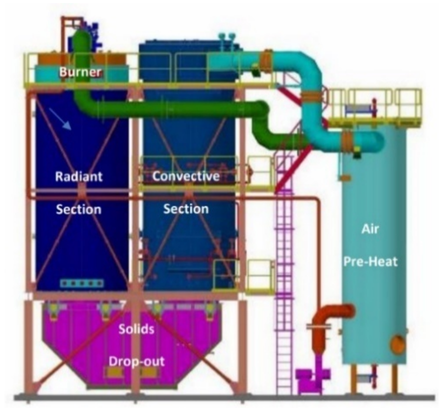

Figure 25. Thermal Oil (TO) heater (CEC 2019-b).

8.2 Financing, Loans, and Incentives

There are multiple sources of funding for renewable energy projects from the U.S. DOE, CEC, and the US Department of Agriculture (USDA). In 2015, Phoenix Energy and North Fork Community Power were awarded a $4.9 million grant through CEC. The grant aided in the construction of a biomass gasification plant in the Sierra Foothills that utilizes forest biomass from fuel reduction in surrounding forests (Phoenix Energy 2015). Currently CEC's availability for grants in the renewable energy sector are for research and development projects that are precommercial (CEC 2019). Low interest loan availability, at 1%, is available through the CEC for the maximum amount of $3 million (CEC 2020).

Federal grants provide the opportunity for larger grant awards and loan maximums, which is required for the preferred alternative. The DOE has allocated $4.5 billion for renewable energy and efficiencies projects through the Energy Policy Act of 2005 that are innovative and will result in a reduction of anthropogenic emissions of GHGs (LPO 2020). The application process is two parts, with part 1 requiring a fee of $50,00 for the project to be evaluated for basic eligibility. Part 2 costs an additional minimum of $100,000 and the project criteria is further evaluated for the following: "risk allocation, credit worthiness, technological relevance and merit, technological approach, work plan, construction plan, and legal, environmental, and regulatory factors." (LPO 2020)

Other loans are available through the USDA and the Agricultural Improvement Act of 2018, which has $428 billion of funding available from 2018 to 2023, most of which is allocated for nutrition programs like the Supplemental Nutrition Assistance Program (SNAP) (USDA 2019b). The programs have been expanded beyond nutrition and crop insurance with research (Title VII) and energy (Title IX) projects. The Biorefinery Assistance Program was expanded under Title IX to guarantee loans for the development, construction, and retrofitting of commercial scale biorefineries, regardless of the feedstock (USDA 2019b).

The last source of financial assistance found was a corporate tax credit in the amount of $0.023/kWh created from renewable energy biorefineries (IRS 2020). The IRS Federal Renewable Production Tax Credit (PTC) is given for the first 10 years that the project is running and unused credits can be used for up to 20 years after they are generated (Dsire 2018). A credit reported and generated in the year 2020 is available for use in any tax year until 2040. The price per kWh credit is also adjusted to account for inflation (Dsire 2019). The 2019 tax form outlines that qualified biorefineries would have to be in the construction phase before January 1, 2021 (IRS 2020). Since incentives change annually, it is probable that an adjusted cut-off date would be applied to future tax forms.

9 Appendix B – Analysis of Alternatives

Calculations for each alternative were documented and can be found in the attached Excel spreadsheet titled *Capstone Calculations*.